Strategy Research Project

Increasing Capabilities and Improving Army Readiness through Additive Manufacturing Technologies

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Abstract

In today's environment of budgetary restraints and an eroding technological edge over its enemies and near peer competitors, the Army is in need of capabilities that spawn innovation and gain efficiencies to improve Soldier and unit readiness. Additive manufacturing is an emerging technology that the Army can leverage to enable innovation and address readiness concerns. Due to the wide-range of applications, from strategic-level research and development to tactical level unit-sustainment functions, additive manufacturing stands as a promising technology to produce the greatest overall impact for the Army. This paper will provide a brief introduction of various additive manufacturing technologies, including types, capabilities and resources; examine how additives manufacturing can assist with maintaining a technological dominance through improvements in the acquisition process; provide possible applications for improving Soldier and unit readiness; and finally identify challenges that the Army must address in order to fully implement additive manufacturing technologies and distribute the capabilities throughout the force.

Increasing Capabilities and Improving Army Readiness through Additive Manufacturing Technologies

> With 3D printing, the factories of the future could become community-run micro-operations. Products could be made on-demand and closer to their point of purchase.
>
> —Bram de Zwart[1]

As the Deputy Secretary of Defense, Bob Work, highlighted in January 2015, the United States (U.S.) military has relied on a "comfortable technological edge" since World War II, but that edge is eroding over time.[2] In response, the Department of Defense (DOD) is implementing a third offset strategy to "identify and invest in innovative ways to sustain and advance America's military dominance for the 21st century."[3] Although the third offset strategy is not purely technology driven, there are emerging technologies that the DOD, and more precisely the Army, should invest as innovative methods to sustain and advance the military. In today's environment of pursuing innovation and maintaining readiness in the face of budgetary restraints, the Army needs to better leverage additive manufacturing technology to maintain its technological advantage over its enemies and improve unit readiness.

Additive manufacturing is but one of the many possible emerging technologies that the Army must better leverage to address eroding technological edge and unit readiness concerns. Due to the wide-range of applications, from strategic level research and development to tactical-level unit sustainment functions, it stands as a promising technology to produce the greatest overall impact. This paper will provide a brief introduction of additive manufacturing technology to include types, capabilities and resources; examine how additives manufacturing can assist with maintaining a technological dominance; provide possible applications for improving unit readiness;

and finally, identify the challenges that the Army must address to fully implement additive manufacturing technologies and distribute the capabilities throughout the force.

Additive Manufacturing Background

To understand how additive manufacturing can assist with maintaining America's military technological dominance and improve unit readiness, one must first comprehend the basic principles of additive manufacturing, its capabilities, and the resources required for additive manufacturing operations. According to the American Society for Testing and Materials (ASTM), additive manufacturing is the "process of joining materials to make objects from three-dimensional (3D) model data, usually layer by layer, as opposed to subtractive manufacturing methodologies."[4] Although sometimes called 3D printing, 3D printing is actually one of the seven recognized forms of additive manufacturing.[5] The seven forms and their basic process are:

1. Binder jetting (3D printing) – liquid bonding agent is selectively deposited to join powder materials;

2. Direct energy deposition – thermal energy is used to fuse materials by melting as they are deposited;

3. Material extrusion – material is selectively dispensed through a nozzle or orifice;

4. Material jetting – droplets of build material are selectively deposited;

5. Powder bed fusion – thermal energy selectively fuses regions of a powder bed;

6. Sheet lamination – sheets of material are bond to form an object;

7. Vat photopolymerization – liquid photopolymer in a vat is selectively cured by light-activated polymerization.[6]

Each of these processes have distinct advantages depending on the requirements of the final product. A technical discussion of the advantages and disadvantages of each form of additive manufacturing is outside the scope of this paper. However, what is of relevance is the variety of different materials that are available for use due to the various additive manufacturing processes.

Anyone who has walked through a home improvement or craft store recently is likely to have seen a commercial “3D printer” on the shelf designed for home use. These machines, technically material extrusion versus the “3D printer” (binder jetting) as described, typically use thermoplastic filament to produce a plastic finished product.[7] Plastic is the most commonly known, but it is only one of the many additive manufacturing raw materials. The additive manufacturing process can use thermoplastics, waxes, ultraviolet curable resins, ceramics, composites, polymers, paper, metals, and even biological materials.[8] The combination of the nine different raw materials and seven different forms of additive manufacturing produce almost limitless possibilities for this technology.

Additive manufacturing initially began with the limited scope of producing prototypes and models for traditional processes but evolved its capabilities with the addition of new materials and process into four major end uses: rapid prototyping, rapid tooling, direct digital manufacturing, and maintenance and repair.[9] Subsequent sections of this paper will discuss these capabilities in more detail and relate how they can benefit the Army with regards to innovation and enhancing unit readiness. Even with understanding the major end uses, materials, and processes involved with additive manufacturing, there are still additional resources required to implement this initiative throughout the Army.

Although material and processes are essential resources in additive manufacturing, there are still three additional requirements for implementation that warrant discussion: software, equipment, and integration with conventional manufacturing technologies.[10] Computer-aided design (CAD) software is a critical component of additive manufacturing procedures.[11] This software must be capable of producing complex designs, dealing with intricate geometry and accounting for the unique attributes of the various types of raw materials available for use in additive manufacturing.[12] Likewise, the best materials, CAD software and processes are useless without the manufacturing equipment itself. In 2012, over 7,500 industrial and 35,500 personal 3D printers were sold world-wide.[13] The typical machine is capable of only one form of additive manufacturing, and the most state-of-the-art machines are available in multi-material configurations with the capability of embedding electronic and/or mechanical functions into the final product.[14]

The final requirement for implementing additive manufacturing technology is the ability to integrate it with traditional production methods. It is unlikely that additive manufacturing will replace traditional processes at any time in the near future, so it is essential that the two integrate to improve the overall process.[15] Industry is already producing complex machines that combine additive manufacturing processes with computer numerical control machining into a hybrid equipment that takes advantage of both additive and subtractive processes.[16] The complex machines use the best elements of additive and subtractive manufacturing processes to produce precise final products. Now that you have a basic understanding of additive manufacturing principle, its capabilities, and the resources required for operations, this paper will discuss how additive manufacturing can assist with maintaining America's military technological dominance and improve Army unit readiness.

Maintaining Technological Advantage

As noted above, additive manufacturing has four primary end uses: rapid prototyping, rapid tooling, direct digital manufacturing, and maintenance and repair.[17] Of these, rapid prototyping and rapid tooling can play a significant role in assisting the Army's ability to maintain its technological dominance over its near peer competitors. Additive manufacturing stimulates innovation because the design process is no longer hampered by the limitations of traditional manufacturing processes.[18] Rapid prototyping provides a significant improvement over conventional research and development processes used in traditional manufacturing processes.

Rapid prototyping is the "additive manufacturing of a design, often iterative, for form, fit, or functional testing or a combination thereof."[19] With traditional manufacturing processes, producing a prototype represented a significant investment in time and cost due to the retooling of manufacturing equipment for small runs of prototype parts.[20] Since form, fit, and functional testing are typically iterative processes, the time and money associated with each change can limit the experimentation that is necessary to maintaining technological dominance.[21]

Additive manufacturing allows engineers to quickly redesign components without having to wait months for traditional methods to produce a prototype for testing.[22] This reduced product development cycle is a key component in spawning innovation and maintaining technological dominance. From a defense acquisition standpoint, additive manufacturing would speed up Milestone A approvals as industry teams produce competitive prototypes during the technology maturation and risk reduction phase.[23]

Faster development cycle and quicker acquisition processes enable the Army to stay ahead of competitors. The Army can continue working on next generation capabilities while competitors are still reverse engineering current capabilities and designing initial responses. Rapid prototyping is a key capability of additive manufacturing, but rapid tooling is equally important for the Army to maintain a technological dominance over its enemies.

Although additive manufacturing has a number of advantages over traditional manufacturing processes, it does have limitations when it comes to production speed. Additive manufacturing processes may take hours or even days to produce a product where, once tooled, traditional manufacturing process can do it much quicker.[24] That being said, studies have shown that additive manufacturing does provide a cost benefit for small batch production.[25] Once again, additive manufacturing processes could improve the speed of the defense acquisition system during Milestone B, where low numbers of models are produce for testing, and even full production during Milestone C depending on the total quantity needed.[26] Through increasing the speed of the acquisition process, additive manufacturing is again ensuring American Soldiers are training with and employing the newest technology well ahead of their enemies.

As discussed above, additive manufacturing clearly has applications in model and even full production in unique situations. However, where additive manufacturing provides its greatest benefit in full production in through rapid tooling. Rapid tooling is "the use of additive manufacturing to make tools or tooling quickly, either directly, by making parts that serve as the actual tools or tooling components, such as mold inserts, or indirectly, by producing patterns that are, in turn, used in a secondary process to produce the actual tools."[27] In other words, using additive manufacturing will more quickly produce the tools used in traditional manufacturing processes.

Similar to rapid prototyping, rapid tooling can "dramatically shorten the development cycle time for new components by circumventing the fabrication of new tooling."[28] Manufactures no longer need to wait for traditional subtractive processes to produce the tools. It also provides a more cost effective means to produce tooling for low-run, customizable products. Rapid retooling not only reduces the development cycle and the defense acquisition process, it can also speed the traditional production timeline, getting new and improved equipment into the hands of Soldiers more quickly. Therefore, rapid retooling is another means that will enable the Army to maintain its technological dominance over its enemies.

The final advantage that additive manufacturing offers the Army towards maintaining a technological advantage over its near peer competitors is in the ability to use advanced materials. Additive manufacturing processes allow the use of purpose designed materials, e.g. new alloys with specific chemical and physical characteristics, high performance magnets, or materials with smart technology (sensors) built into the material structure.[29] Additionally, the availability of biological materials offers unique additive manufacturing opportunities in the biomedical field for producing tissue scaffolds, living tissue, and biological chips.[30] A more detailed discussion of the biomedical possibilities will follow in the improving readiness section of this paper. The ability of additive manufacturing to use advanced materials encourages innovation because researchers are no longer held back by the properties of traditional raw materials. Instead, they can start from the ground up and build the required properties directly into the raw material.

As a result of the significant opportunities additive manufacturing presents with regards to rapid prototyping, rapid tooling, and the use of advanced materials, additive manufacturing is clearly an emerging technology that the Army should leverage to address the eroding technological edge. With additive manufacturing, the defense acquisition process is no longer limited by traditional manufacturing process and raw materials. Instead, there is a reduced product development cycle and more advanced materials facilitating innovative and state of the art capabilities to ensure the Army maintains a technological advantage over its competitors. If this advantage alone is not enough of a reason to invest in additive manufacturing, it also has the potential to improve unit readiness throughout the Army.

Improving Unit Readiness through Additive Manufacturing

In addition to the potential benefits additive manufacturing provides with respect to addressing the Army's eroding technological edge over its enemies, additive manufacturing also has the potential to improve readiness. Additive manufacturing has the capability to deliver critical equipment and repair parts, directly at the point of need, through its direct digital manufacturing and maintenance and repair end uses. Additionally, additive manufacturing offers unique medical applications that can improve individual Soldier readiness. The combination of these capabilities can directly affect unit readiness across the Army.

Direct digital manufacturing is simply using additive manufacturing to create "a final component or a final product for direct use" rather than being a step in the overall manufacturing process.[31] The ability to produce products on demand, when and where they are needed, would have an enormous impact on operational readiness and could totally revolutionize the supply system.[32] Take for example any warehouse on an Army installation that stocks durable hand tools or personal clothing and equipment. With traditional supply chain procedures, warehouses stock multiple items in various sizes in an attempt to ensure that adequate equipment is on-hand when a Soldier or unit needs the item. These warehouses are limited both physically and fiscally on types and quantities of equipment they can keep on-hand. If the equipment is not on-hand, the warehouse must order the equipment and the unit waits for delivery. During that time, the Soldier or unit is not operational ready because they do not have the equipment they require to do the mission. Imagine instead, a warehouse with a 3D printer and the raw materials that can "print" the needed equipment. In that scenario, Soldiers and units will are ready for operations in hours versus days or weeks waiting for equipment to arrive at the warehouse.

In addition to improving readiness by providing needed equipment more quickly than the traditional supply chain, additive manufacturing can also save money. A 2014 case study of a 3rd Party Logistics warehouse cost of operations found that implement additive manufacturing into warehouse operations could save between 70 and 85 percent of the traditional supply chain costs.[33] The greatest cost saving was due to reduced transportation costs but there was also significant savings (17 percent) attributed to the cost of carrying inventory.[34] Clearly it would be unreasonable to suggest the Army could replace all warehouses with additive manufacturing; however, additive manufacturing capabilities in select warehouse could be cost effective.

Additive manufacturing capabilities are not limited to garrison operations. Units can also use the technology to produce operational equipment when away from home station for training or while deployed. The U.S. Navy already has 3D printers aboard ships and has used them to produce customized drones aboard the United States Ship (USS) Essex while underway.[35] The availability of the 3D printer allowed the USS Essex crew to save space by only carrying the electronic components and then "print" highly customizable, mission specific components of the drone as needed.[36] With new, advanced technology it is now possible for 3D printers to actually "print" the electronics and seamlessly integrate them into the finished product.[37] This capability can further reduce the requirement to carry critical electronic components since the printers can now produce them as well. Although there are numerous potential applications to improve unit readiness through direct manufacturing of individual and organizational equipment, the most promising applications will be in the maintenance and repair end use.

The maintenance and repair end use is exactly as it sounds, using additive manufacturing technologies to repair broken parts or manufacturing repair parts at the point of need.[38] Additive manufacturing processes have the ability to repair metal parts when a portion of the part is damaged instead of purchasing or producing a new part.[39] Likewise, by introducing additive manufacturing technology into the supply chain, the Army could "produce parts in the field to reduce the need to store parts, to produce discontinued parts or temporary parts until a permanent part can be obtained, and to quickly build parts to meet mission requirements."[40] Thru smaller and distributed production locations, additive manufacturing can reduce or even eliminate the need to carry inventories of certain types of repair parts.[41] In addition to speeding up the supply chain, a recent automotive repair part industry case study calculated a 33 percent cost savings by adopting additive manufacturing where possible.[42]

It is not difficult to imagine the positive impacts additive manufacturing can have on unit readiness. Units can free up operating funds rather than having them tied up in repair parts sitting on the shelf in case they are needed. Maintenance companies can "print" a part in hours instead of waiting months for a traditional factory to retool a production line to create a part of a legacy piece of equipment. Supply Support Activities can replace multiple lines of parts and equipment with a 3D printer and raw materials instead to produce the items closer to the point of need. Additive manufacturing could potentially revolutionize the way the way the Army approaches field level maintenance. By significantly reducing non-mission capable time while waiting on the supply system to deliver parts, the Army could see dramatic improvements in operational readiness.

The third area where additive manufacturing could improve unit readiness is at the individual Soldier level. As previously mentioned in this paper, additive manufacturing's biomedical applications have grown significantly in the recent years. These biomedical applications fall into three broad categories: bioprinting of tissues and organs, customized implants and prostheses, and production of anatomical models for surgical preparation.[43]

Although still in its infancy, the bioprinting of tissues and organs does represent a potential to noticeably affect a Soldier's health and ability to continually contribute to the unit's readiness. The printing of organs and tissue scaffolds for stem cell seeding developing into functioning tissue may sound like science fiction, but studies already exist verifying the proofs of concept.[44] This level of bioprinting may be beyond the Army's requirements but researchers have also printed knee meniscus, spinal disk, other bones and cartilage, skin for burn victim, and an artificial ear.[45] This level of capability could have numerous applications for treating Soldiers with musculoskeletal injuries and even combat wounds. The ability to repair a Soldier's knee or back and return them to their unit fully medical ready directly affects the operational readiness of the unit and the Army.

Another promising application with the potential to improve a Soldier's health and unit readiness is the use of additive manufacturing technology to produce custom implants and prostheses. The health care industry is already using 3D printers to produce "standard and complex customized prosthetic limbs and surgical implants."[46] Additionally, Walter Reed National Military Medical Center already has a 3D medical application center that uses additive manufacturing to produce custom Poly methyl methacrylate and Titanium cranial reconstruction plates.[47] Although the Walter Reed initiative is a great start, there are several opportunities for expansion. Capabilities like customized orthopedic braces and thermoplastic braces to replace plaster casts are just a few possibilities. If fact, the 2013 "A'Design Award for 3D-printed forms and products" was for a 3D printed cast with integrated low-intensity pulsed ultrasound capability that has shown to reduce healing time by 38 percent and increasing healing rate by up to 80 percent.[48] Like bioprinting, using additive manufacturing technology applications that can help Soldiers heal and return to units more quickly will have a direct effect on individual health and unit readiness.

The final additive manufacturing application for improving Soldier readiness is the creation of anatomical models for surgical preparation. A realistic 3D model allows a surgeon to see the individual's specific anatomy and is "ideal for surgical preparation."[49] Again, Walter Reed National Military Medical Center is already using this capability to provide surgeons with 3D models to study and plan complex surgeries.[50] The Army should export this capability to other medical centers to take advantage of this cutting-edge technology and provide better medical treatment for Soldiers. Like the two previous applications, better medical care translates to improved individual and unit readiness.

As demonstrated thus far, additive manufacturing has a wide-range of applications that makes it a promising technology that the Army could leverage to address the eroding technological edge and improve operational readiness of individuals and units. By fully embracing additive manufacturing and distributing the technology throughout, the Army can drive innovation while simultaneously improving readiness. With that in mind, additive manufacturing is not without its challenges and the Army must carefully plan how it implements additive manufacturing and ultimately authorizes its use.

Challenges with Army-wide Introduction of Additive Manufacturing

As with any new change, expanding additive manufacturing initiatives within Army research and development and introducing it into Army supply and maintenance operations will not be without challenges or risk. Army leadership must determine the best way or ways to introduce additive manufacturing technology and then establish policy to govern its use. Key elements that the Army additive manufacturing policy should address are establishing a lead agency for additive manufacturing technology, expanding current and developing new personnel requirements, and establishing quality and certification standards. The Army policy must also establish comprehensive knowledge management procedures to protect intellectual property that simultaneously makes the data readily available to the Army's new additive manufacturing community at large. Addressing these challenges will ensure additive manufacturing technology is fully integrated into initiatives to maintain a technological advantage and improving operational readiness.

The first challenge that the Army must address is establishing a lead agency to track and coordinate additive manufacturing initiatives across the Army. Currently, at least five separate organizations are exploring or using additive manufacturing technologies: the U.S. Army Medical Materiel Development Activity; U.S. Army Research Laboratory; Tobyhanna Army Depot; Army Rapid Equipping Force; and the Combined Arms Support Command.[51] Increasing this organizational complexity, these units are split between three of the Army's major subordinate command, U.S. Army Medical Department, U.S. Army Materiel Command and U.S. Army Training Doctrine Command. In an attempt to coordinate efforts and share information, individual specialists have voluntary joined in an Army community of practice. The group meets regularly to discuss additive manufacturing initiatives, but there is no indication of a designated governing body or published guidance to lead additive manufacturing technology initiatives.[52]

In September 2016, the U.S. Marine Corps designated the Deputy Commandant for Installations and Logistics, Logistics Policy, Logistics Vision and Strategy branch as the Marine Corps lead for all additive manufacturing technology initiatives.[53] As the lead, he/she ensures that “initiatives are aligned and deconflicted to support utilization and advancement of AM [additive manufacturing] technologies.”[54] The Army Research Lab officials acknowledge the need to improve cross-communication “to avoid having to reinvent advances while they continue to expand the implementation of these technologies and capabilities.”[55] The Army should follow the Marine Corps example and appoint a lead agency for additive manufacturing technologies to achieve unity of effort and “leverage resources and lessons learned” to facilitate efforts Army-wide and prevent wasting precious resource due to duplication of effort.[56] Without a lead agent, the Army will be unable to effectively regulate additive manufacturing or prioritize efforts as required.

The second challenge the Army must address is identifying personnel requirements for expanding and implementing additive manufacturing initiatives. This creates two separate and distinct issues for two of the major subordinate commands with additive manufacturing initiatives. The Army Materiel Command initiatives are primarily focused on materials research, developing manufacturing techniques, prototyping and full rate production.[57] These activities take place in research laboratories and depots that are primarily based in the continental U.S. and staffed by a civilian workforce with scientific and engineering backgrounds.[58] These activities can simply hire additional personnel for their already highly qualified staff. Unfortunately, this approach will not work as easily for initiatives within the Training and Doctrine Command.

The Rapid Equipping Force and Combined Arms Support Command initiatives within Training and Doctrine Command are both designed to go forward on the battlefield.[59] The Rapid Equipping Force's Expeditionary Lab has already deployed to Afghanistan and uses a combination of military personnel for liaison and civilian engineers for the technical aspects.[60] Since these labs are already operational, the Rapid Equipping can continue its current manning process. The largest portion of this challenge is how to man additive manufacturing initiatives in operational units.

The Combined Arms Support Command initiative is still in development, but the concept calls for a remote parts manufacturing system in operational units.[61] The recent emphasis on reducing the Army's reliance on contractors and civilians performing maintenance and for units to conduct their own maintenance dictates something other than a civilian solution.[62] This requires the Army to either create a new military occupational specialty or add additive manufacturing operations as a critical task to an existing specialty. The most logical approach would be to add it to the allied trade specialist (91E) whose job duties already include "fabricate, repair, and modify metallic and nonmetallic parts."[63] Use of additive manufacturing equipment and 3D design requirements are complimentary to the subtractive manufacturing techniques that allied trades specialist already perform. Adding additive manufacturing tasks would require a modification to the initial entry training program of instruction and possibly lengthening their advance individual training. This approach would not be without its challenges, but it would be less resource intensive than adding a new military occupational specialty, resourcing the personnel, and developing an entire program of instruction for "additive manufacturing specialist."

The third challenge the Army must address with implementing additive manufacturing technology is establishing quality standards and certification procedures.

When additive manufacturing products are limited to plastic prototypes for fit or simple 3D models, quality standards are not that important. Once used to produce equipment or parts where structural failure could result in serious injury or even loss of life, quality standards and certification procedures are essential for safety. The Army must develop quality standards for the approved additive manufacturing processes, approved equipment, materials, and for the personnel operating the equipment. Similarly, it must develop certification procedures to ensure finished products meet quality standards.

Presently, ASTM standards do exist for specific metal alloys and processes.[64] However, these standards are not nearly expansive enough to cover all the possible military applications of additive manufacturing process. The Army's lead agency will need to first define the allowable additive manufacturing processes and then identify the approved equipment for each process. In doing so, the lead agency will have initially scoped the challenge into a manageable situation rather than trying to set standards for all combinations of processes and equipment that are commercially available. Once complete, they can develop quality standards for raw materials, equipment, and procedures to improve the overall quality of the end products.[65] The next step will be to systematically approve "production recipes" that include equipment, raw materials, and 3D designs for products that have passed quality control standards.

Concurrently, the lead agency will need to establish certification procedures for the personnel operating the equipment to ensure they are properly trained and qualified to conduct additive manufacturing operations. General knowledge can be part of a Soldier's advanced individual training or a civilian's hiring qualification, but organizations should be responsible for training and certifying their personnel. Establishing quality standards and certification procedures will “ensure the safety, reliability, and quality of processes and products.”[66] Once the quality standards and certification procedures are established, the lead agency can begin broad implementation of additive manufacturing.

The final, and arguably the most difficult, challenge with broad implementation of additive manufacturing technology will be the knowledge management of associated information. Additive manufacturing produces enormous amounts of data and a simple internet search will illustrate what is readily available in open source forums. To ensure organizations only use approved sources and organizations do not waste efforts developing designs that are already approved, the Army must develop a knowledge management process that serves as the system of record for additive manufacturing operations. This challenge is divided into two separate but interdependent aspects – protection of intellectual and protected property, and sharing of production information across the force.

The emerging use of additive manufacturing creates unique issues with regards to patent, trademark, copyright, product liability, and intellectual property laws.[67] As of 2014, “No specific law in the U.S. addresses intellectual property infringement based solely on the fact that the tool used to ‘infringe’ is a 3D printer.”[68] However, existing patent, copyright, and trademark laws are all arguably applicable with regards to products produce locally through additive manufacturing processes.[69] As the Army fully implements additive manufacturing technologies and distributes the capabilities, special care must to taken to ensure organizations are not producing products that create liability issues. Just because an Army organization has the capability to technically produce an item does not always mean they have the authorization to produce it. The

Army will need to implement regulatory guidance early in the process to specifically address this area.

Closely related to the intellectual property discussion above is the Army's requirement to protect and share its own intellectual property. Websites and companies are already showing up to share and sell 3D models for home and commercial use.[70] The Army must ensure its 3D models are not shared on these open sources sites for both security and liability reasons. Whether it is a 3D model that an Army organization developed internally or one reproduced under license from the original manufacturer, the Army has a responsibility to protect its intellectual property. An enemy could use a 3D model to reverse engineer a capability or someone could be injured by an "Army approved" 3D model. Either scenario creates undo risk for the Army as a whole.

Equally as important as protecting the Army's intellectual property is developing a capability to share intellectual property and 3D models with authorized organizations. Developing a knowledge management system that allows all Army organizations involved in additive manufacturing initiatives to share information is critical to reducing costs and literally avoiding "reinventing the wheel."[71] Once an organization has developed a 3D model, there must be a system of record that the lead agency uses for certification and approval of the "production recipe" and then makes it available to the Army's additive manufacturing community at large. Not only does this prevent duplication of effort, but it also distributes the intellectual knowledge across the entire community, continuing to reinforce what is in the realm of possible.

There are a number of challenges associated with expanding additive manufacturing initiatives within research and development and introducing it into supply and maintenance operations, but these challenges should not deter the Army leadership. By establishing clear policies and guidelines early in the process, the Army can address these challenges and move forward with fully implementing additive manufacturing into daily operations. The first step is identifying a lead agency that has the authority to govern the process instead of the current coordination through the community of practice that currently exists. Once the lead agency is established, the Army can begin to address the remaining challenges of: personnel requirements, establishing quality and certification standards, and establishing comprehensive knowledge management procedures to protect intellectual property and make it readily available to the greater Army additive manufacturing community. Addressing these challenges will ensure additive manufacturing technology is fully integrated into initiatives to maintain a technological advantage and improving unit readiness.

Conclusion

By analyzing the various additive manufacturing technologies available today, including the types capabilities and required resources, it is evident that it is a technology that enables innovation. The ability to rapidly prototype new products or tool traditional production lines to bring new capabilities to the force are essential to the Army regaining its technological edge over its enemies and near peer competitors. Likewise, the vast array of traditional and advanced materials available through additive manufacturing makes what was once thought impossible, through traditional manufacturing means, not only possible but achievable.

In addition to spawning innovation, additive manufacturing has enormous implications for unit readiness. Direct digital manufacturing of individual and organizational equipment, combined with production at the point of need for repair parts, has the potential to revolutionize the current supply system. Those applications, along with the advanced biomedical applications to improve individual Soldiers' health, will directly improve unit readiness across the Army.

Granted, additive manufacturing is no silver bullet, and it is not without its implementation challenges. First and foremost, the Army must act now and establish a lead agent to coordinate and oversee the various additive manufacturing initiatives that are already underway. Once identified, the lead agency needs to establish the policies and guidelines to govern additive manufacturing actions. The early establishment of policies is critical for identifying the personnel requirements, setting quality and certification standards, and protecting against infringement of intellectual property while simultaneously sharing approved information throughout the Army's additive manufacturing community at large.

In today's environment of budgetary restraints and an eroding technological edge over enemies and competitors, the Army is in need of capabilities that spawn innovation and gain efficiencies to improve unit readiness. Additive manufacturing is an emerging technology that the Army can leverage to produce innovation and address readiness concerns. Due to the wide-range of applications, from strategic-level research and development to tactical-level unit sustainment functions, it stands as a promising technology to produce the greatest overall impact.

Endnotes

[1] Bram de Zwart, CEO and Cofounder of 3D Hubs, "3D Hubs Crowdsources 3D Printing," quoted by Jennifer Hicks, *Forbes Online*, August 27, 2013, http://www.forbes.com/sites/jenniferhicks/2013/08/27/3d-hubs-crowdsources-3d-printing/#59d09f47759d (accessed October 20, 2016).

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