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SPECIAL ISSUE Additive Manufacturing (3D Printing)

**When and When Not
to Accelerate
Acquisitions**

by the Under Secretary
of Defense for Acquisition,
Technology, and Logistics

**An Overview of
Additive
Manufacturing**

**Ensuring a Safe
Technological
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**The Digital Thread
as the Key Enabler**

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SPECIAL ISSUE: ADDITIVE MANUFACTURING (3D Printing)



An Overview of Additive Manufacturing

Mark Vitale, Mark Cotteleer and John Holdowsky

Various technologies, processes and end-market applications are involved in additive manufacturing (AM). Flexibility can be increased and capital requirements reduced by AM to achieve greater scope and economies of scale.



Ensuring a Safe Technological Revolution

William E. Frazier, Ph.D.; Elizabeth L. McMichael; Jennifer Wolk, Ph.D.; and Caroline Scheck

AM could radically change how the Department of Defense (DoD) and the Navy and their partners and allies develop, manufacture and support their platforms and systems.



The Digital Thread as the Key Enabler

Col. Keith Bearden, USAF

Digital engineering can help the Air Force refine engineering roles, improve technical information management and standardization and make possible decisions of high quality with seamless communication.

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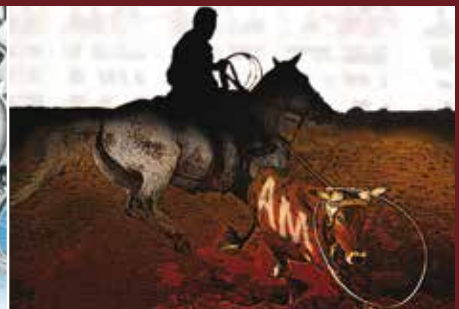
Raymond Langlais Jr., Nick Avdellas, Colin Finfrock, Russ Salley and Madelyn Newcomb
AM is evolving rapidly from its past use in prototyping into a computer-enhanced method of end-use production with great potential for DoD use.



Additive Manufacturing as a Sustainment Enabler An Industry Perspective

Marilyn Gaska, Ph.D., and Teresa Clement, Ph.D.

Recently sharpened awareness of AM's potential as a sustainment and maintenance enabler has resulted in public-private partnerships.



Harnessing the Potential of Additive Manufacturing and Competition

Bill Decker

AM can enable the manufacturing of parts and components closer to the point of need for U.S. military forces.

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When and When Not to Accelerate Acquisitions

Frank Kendall

Why don't we do all our acquisition programs faster? What keeps us from having all acquisition programs be "rapid" acquisitions? The short answer is that, if we choose to, we can trade quality for time.

Sometimes that is smart, and sometimes it isn't.



Often, and for good reasons, we demand high quality, and that takes more time. What I mean by "quality" in this case is the suite of features we want in the equipment intended for a large fraction of the force and that we keep in our inventory for a long time—30 or 40 years, in many cases. Quality includes high reliability, maintainability, operation in a range of climates and terrains, modularity and upgradability, well-designed user interfaces, cybersecurity, robustness against responsive threats, and effective training and logistics systems. None of these things is free, and they all take time to design for and test.

For most so-called Programs of Record, we do take the time to design and build products of the quality desired by the customers, our operational communities. If you want something quick, it is generally going to be of lower quality—but that may be perfectly fine, depending on what you want. This is the operator's call; the acquisition system responds to operator

requirements. As acquisition professionals, we do want a two-way continuing discussion about requirements throughout the design and development process—and beyond. That conversation is necessary because design and development always involve a voyage of discovery. And because many desired design features have to be traded off against each other and against cost, those trade-offs should be operator/customer decisions, but should still be decisions informed by acquisition professionals.

To do anything, we need money and a contract. There are vehicles that let us spend some money quickly, particularly for early stage prototypes, and there are some contract types that allow us to move out quickly, but they have limitations on scope, purpose, and amount we can spend. Lead time can be close to zero, or up to 2 years if we have to wait for a budget to be prepared, submitted and funded by Congress. We can work contracting activities (preparation of the request for proposal or even source selection) and milestone review processes (Defense Acquisition Board document preparation, as required) in parallel with the process of getting money—and usually we do so. If we already have the money, then some time is needed to have a contract. Again, for some limited

purposes, this can be fast—but for major competitive awards this now takes about 18 months, close to the time it takes us to get funding from Congress. That’s twice the time it used to take a couple of decades ago, and one of the actions we are working is to reduce this lead time.

If we just want a small number of prototypes for experimental purposes, and we only care about some key features and not the overall quality of the product, we can deliver in a matter of months or a few years, depending on how much new design work has to be done and the lead time for building small numbers of items or acquiring any needed subsystems from the manufacturers in the supply chain. If we want to try out a new kind of capability, to experiment, and don’t care about long-term ownership quality quality-related features, then rapid prototyping is the way to go. We can do this sort of thing fast, and the technical community loves to work on projects like this. However, some quality aspects such as safety must be dealt with when we work with energetics such as munitions and rocket propellants. We can do experimental prototyping without having a program of record, so no acquisition system bureaucracy overhead need be involved in an experimental prototype program. The product you will get from an experimental prototyping program is unlikely to be one you can just replicate and field in large numbers—it wasn’t designed for that. Sometimes we have liked the key features of experimental prototypes and just bought more of them. Because of their poor quality for long-term ownership and use, this has often been a disaster (see Global Hawk and the Exoatmospheric Kill Vehicle, as examples).

Next up on the quality hierarchy are assembled items that focus on one or two key performance parameters that we do want in larger quantities, but where we are willing to sacrifice some aspects of quality in order to have an important operational capability fast, usually for operational reasons or maybe because we’ve been surprised by a threat. Think Mine-Resistant Ambush Protected MRAP (vehicles), which were pulled together from existing automotive components. The goal was to get more protection to the field and to get it fast. MRAPs were a big success. We saved a lot of lives. MRAPs are relatively simple designs assembled from existing components and designed for low-end threats. They lack a lot of the features needed or desired by the Army, however,

and almost all of the 30,000 or so we built are going out of the inventory now that the major counterinsurgency campaigns are over.

Next on the quality scale are new designs that take into account all the things the customer wants. These are high-quality products, and they take longer, but that’s because we ask for more of them and have to do more work designing, building and testing. We want integrated designs that have many features desired by the customer (again requirements). Think of the Joint Light Tactical Vehicle (JLTV). The JLTV is a much higher-quality product than any of the MRAPs. It will be in the Army inventory for decades, and most of the cost will be in maintenance and sustainment. The Army wants a highly reliable, maintainable design that will operate in a wide variety of terrain and in any climate. This is very different from what we did with MRAPs. JLTV is still a relatively simple design, but it has taken several years to mature the designs and pick a winner. For most of these systems, we do use the standard acquisition system milestones associated with decisions to start risk reduction (if needed), design for production and production itself. When the acquisition system’s set of milestone decisions is needed, we do this in parallel with the actual work so we don’t slow programs down. The decision process adds overhead, but it generally does not add time.

Highest of all in terms of quality are systems like the F-35 fighter jet. These are designs that integrate the newest tech-

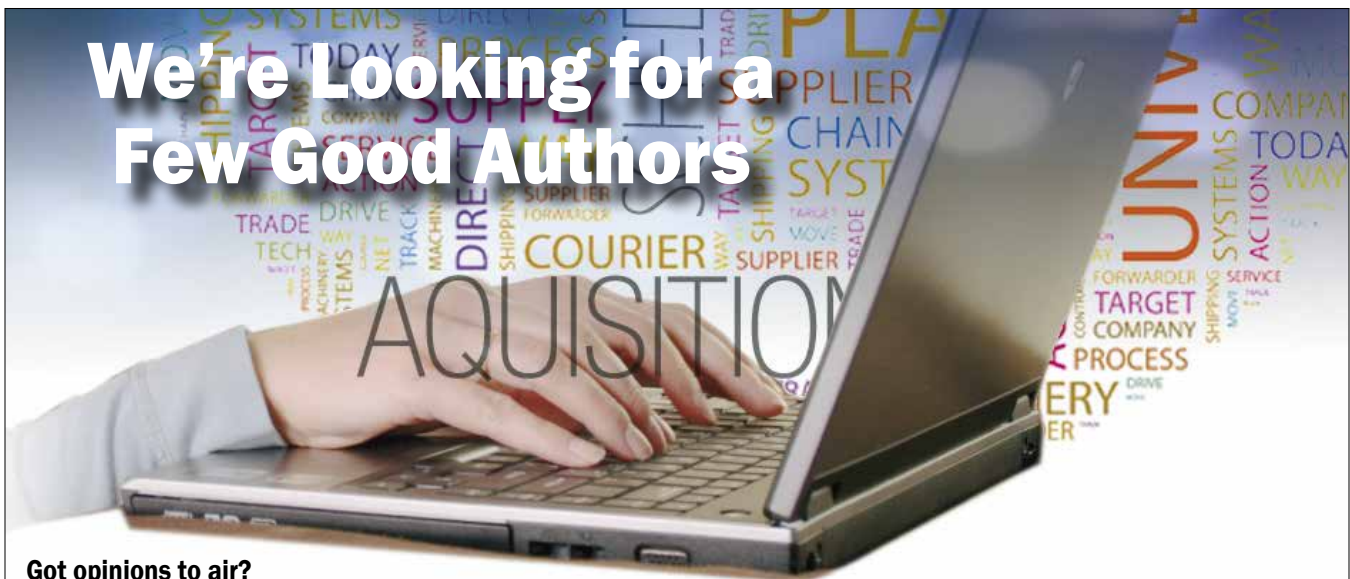


**Sometimes we have liked
the key features of
experimental prototypes
and just bought more of them.
Because of their poor quality
for long-term ownership and
use, this has often been a
disaster.**

nology, have the highest possible performance, and that we count on for a significant, decades-long military advantage. We want quality features like high reliability, maintainability, upgradability for tech insertion, well-designed user interfaces, cybersecurity, anti-tamper, resilience against jamming and responsive threats, and a host of other things our operators understandably desire. These systems are the Formula 1 race cars that are going to win against the best there is and do so for years, not just for one racing season. They are not Chevies. These are our highest quality and most difficult products, but these are also the ones that often make the most difference in terms of technological superiority and operational dominance. They take several years in development, and often we need to do a risk-reduction technology maturation phase before we start designing for production. That adds 3 years or more if we build risk reduction prototypes before we start designing for production. For these systems, you do have to wait about 10 years, but they are what populates most of our force. Think F-18 combat jet, Aegis missile defense, DDG-51 destroyer, the Virginia SSN

submarine, F-15 and F-22 fighter jets, C-17 military transport aircraft, AMRAAM air-to-air missile, Abrams tank, Bradley fighting vehicle, Patriot missile, and Apache helicopter. Notably, every one of these high-quality systems struggled to get through development and into production. Most were close to cancellation at some time in their development cycles.

The acquisition system can produce experimental prototypes quickly, but if our customers want a high-quality product that we will have in the inventory in large numbers for a lot of years, that takes longer. Many of the demonstrations we have funded in the budget are experimental early prototypes. We are effectively buying options to do lower risk follow-on Engineering and Manufacturing Development phases leading to production. The ability to afford those follow-on programs, or even a subset of the concepts we will have demonstrated in the next few years, will be problematic. Unfortunately, the threats we are most worried about are not low-end threats—we are going to need high-quality robust designs. &



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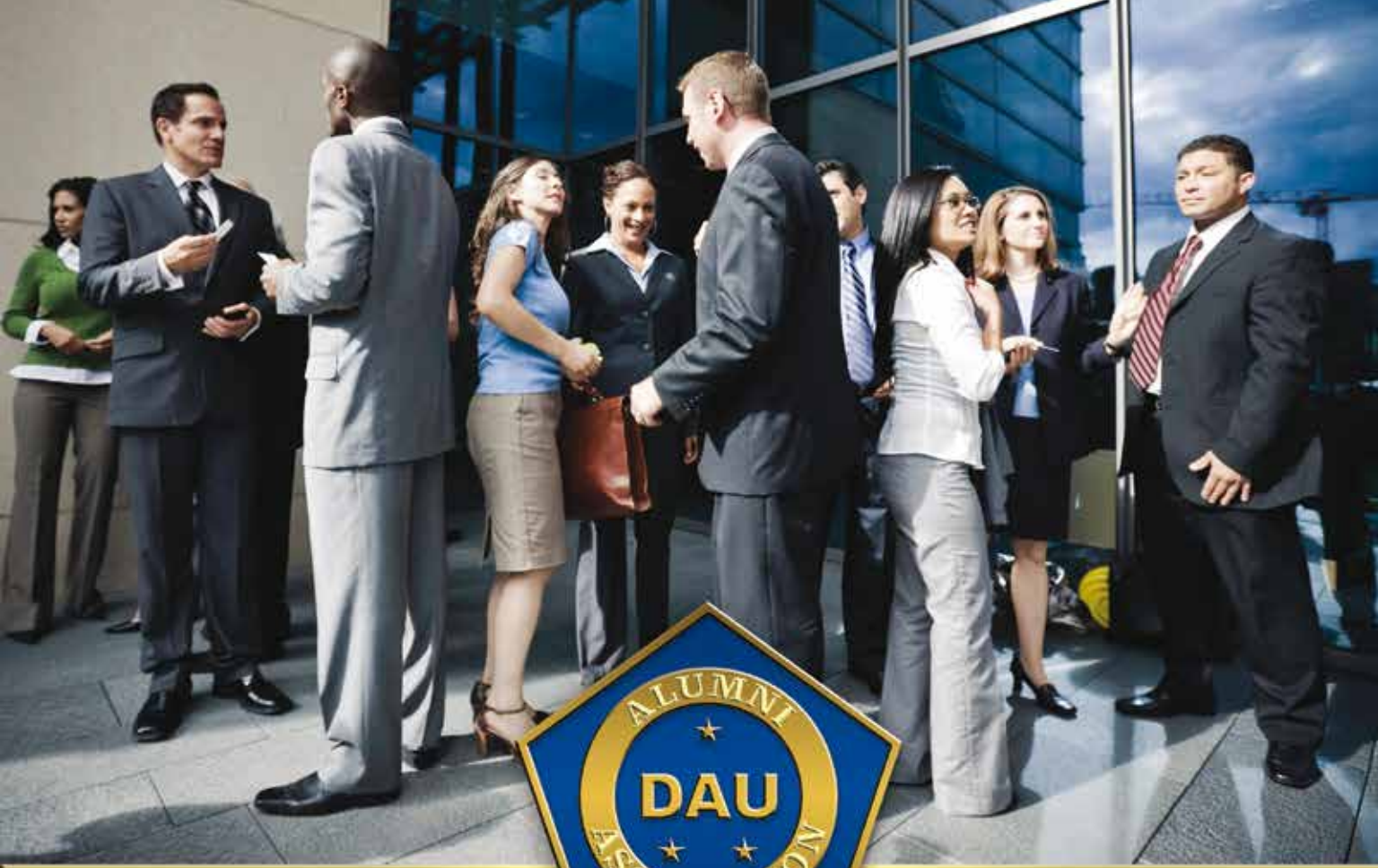
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An **Overview** of Additive Manufacturing

Mark Vitale ■ Mark Cotteleer ■ Jonathan Holdowsky

Additive manufacturing (AM)—known also as “3D printing”—has exploded into public consciousness over the past several years. Stories and perspectives seem to appear in the popular press and technology blogs on a near daily basis.

Enthusiasts tout the prospect for AM to revolutionize manufacturing industries and the markets they serve, while skeptics point to the relatively limited number of applications and materials in current use. While the reality of AM likely rests somewhere between these two views, there can be little doubt that the technology is enjoying an increasing deployment across sectors—both within manufacturing and beyond—and throughout all phases of the value chain.

This article provides an overview of AM—its technologies, processes and end-market applications. In addition, we touch upon a number of strategic challenges that companies should consider as they integrate AM into their value propositions. We also offer a strategic framework that may help companies understand how this set of technologies and processes increases flexibility and reduces the capital required to achieve greater scope and economies of scale.

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What Is AM?

AM refers to a set of technologies and processes developed over more than 30 years. ASTM International, a global body recognized for the development and delivery of consensus standards within the manufacturing industry, defines AM as: "A process of joining materials to make objects from 3D [three-dimensional] model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies." In common practice, the terms "AM" and "3D printing" are used interchangeably.

Layer by Layer Additive Process

The AM process traditionally begins with the creation of a 3D model through the use of computer-aided design (CAD) software. The CAD-based 3D model typically is saved as a standard tessellation language (.STL) file, which is a triangulated representation of the model. Software then slices the data file into individual layers, which are sent as instructions to the AM device. The AM device creates the object by adding layers of material, one on top of the other, until the physical object is created.

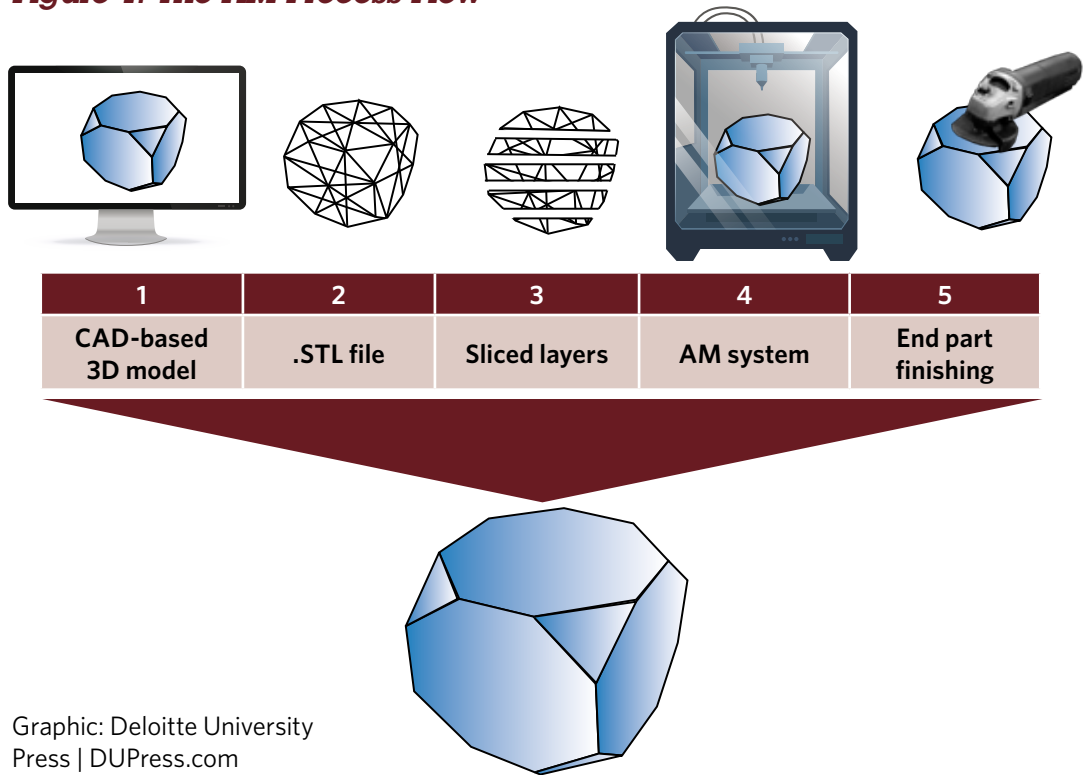
Once the object is created, a variety of finishing activities may be required. Depending on the material used and the complexity of the product, some parts may need secondary processing, which can include sanding, filing, polishing, curing, material fill or painting. Figure 1 depicts the overall AM process.

Sophisticated 3D scanning and imaging tools are emerging as alternatives for traditional CAD programs. In addition, stylus-based and other design technologies that allow consumers to modify digital models themselves—without the need for extensive CAD experience—are expected to contribute to growth in the personal AM systems space. New formats, such as AM file format (AMF), are also being developed to address .STL's limitations and allow for more flexible file structures.

Trade-offs Versus Traditional Manufacturing

AM creates 3D structures by adding materials layer upon layer. In contrast, traditional manufacturing practices (such as drilling or machining) are often "subtractive," as they remove material from areas where it is not desired. AM and

Figure 1. The AM Process Flow



Graphic: Deloitte University Press | DUPress.com

Table 1. Comparative Advantages of AM and Traditional Manufacturing

Advantages of AM	Advantages of Traditional Manufacturing
Design complexity: AM enables the creation of intricate designs to precise dimensions that are difficult or near impossible to create using traditional methods.	Mass production: Traditional manufacturing is well-suited for high-volume production where fixed tooling and setup costs can be amortized over a larger number of units. AM is generally more competitive for low-to-medium volume production runs.
Speed to market: AM systems can manufacture products with little or no tooling, saving time during product design and development—and enabling on-demand manufacturing.	Choice of materials: Traditional manufacturing techniques can be deployed to a wider range of materials.
Waste reduction: AM typically uses less extraneous material when manufacturing components, significantly reducing or eliminating scrap and waste during production. This makes AM a more efficient process.	Manufacturing large parts: Despite advancements in "big area" printing, AM systems are still largely constrained by limited envelope sizes. By comparison, traditional machining is better suited to manufacturing large parts.

Source: Deloitte analysis

traditional manufacturing face different trade-offs, with each process likely to play a role in the deployment of manufacturing capabilities. Table 1 lists some of the respective advantages of AM and traditional manufacturing.

Overall, AM offers companies an array of time efficiencies and cost reductions throughout the product life cycle and supply chain, as well as greater flexibility in design and product customization than traditional manufacturing. These benefits will likely drive increasing levels of AM adoption going forward.

Processes, Technologies and Applications

Functional prototypes and end-use parts built through AM technologies have wide applications in industries such as industrial and consumer products, automotive, medical and commercial aerospace and defense. AM technologies deploy multiple different processes to address issues such as design complexity, surface finish, unit cost, speed of operations, and others. To meet diverse requirements, industrial-grade AM systems are available in the market ranging in cost from less than \$10,000 to \$1 million—and more.

AM technologies typically are based on one of the seven primary manufacturing processes described below in Table 2. The major AM processes and technologies can be characterized by the materials they use and the advantages and disadvantages they offer (see Table 3).

Although AM material availability is less varied when compared to traditional manufacturing approaches, AM technologies still use a range of materials, including plastics, metals, ceramics and composites, as Table 3 shows. At the present time, plastics (polymers) and metals are most commonly used in AM systems. To a lesser extent, ceramics and composites also support AM processes. Increasing use of varied materials in AM is an area of focus for future research and development.

Inherent Benefits to Increasing Penetration in the Next Decade

Overall, since its beginnings some 30 years ago, AM systems have become markedly faster, more versatile in complexity of design and variety of materials used, and less expensive. At the same time, the global AM products and services industry has seen remarkable growth—from virtually nothing in 1985 to more than \$20 billion projected in 2020 according to Wohlers Associates.

Application of AM technologies is expected to grow across industries as increasing numbers of companies use the processes not just for producing prototypes, but to manufacture parts and full-scale products. Such applications will act as a particularly strong catalyst for substantive research developments in the health care and manufacturing industries. Table 4 summarizes some current applications of and potential future developments in AM in select industries. The breadth of

Table 2. AM Major Manufacturing Processes

Vat photopolymerization

A liquid photopolymer (i.e., plastic) in a vat is selectively cured by light-activated polymerization. The process is also referred to as light polymerization.

Related AM technologies: Stereolithography (SLA), digital light processing (DLP)

Material jetting

A print head selectively deposits material on the build area. These droplets most often are comprised of photopolymers with secondary materials (e.g., wax) used to create support structures during the build process. An ultraviolet light solidifies the photopolymer material to form cured parts.

Support material is removed during post-build processing.
Related AM technologies: Multi-jet modeling (MJM)

Material extrusion

Thermoplastic material is fed through a heated nozzle and deposited on a build platform. The nozzle melts the material and extrudes it to form each object layer. This process continues until the part is completed.

Related AM technologies: Fused deposition modeling (FDM)

Powder bed fusion

Particles of material (e.g., plastic or metal) are selectively fused together using a thermal energy source such as a laser. Once a layer is fused, a new one is created by spreading powder over the top of the object and repeating the process. Unfused material is used to support the object being produced, thus reducing the need for support systems.

Related AM technologies: Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)

Binder jetting

Particles of material are selectively joined together using a liquid binding agent (e.g., glue). Inks also may be deposited to impart color. Once a layer is formed, a new one is created by spreading powder over the top of the object and repeating the process until the object is formed. Unbound material is used to support the object being produced, thus reducing the need for support systems.

Related AM technologies: Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)

Sheet lamination

Thin sheets of material (e.g., plastic or metal) are bonded together using a variety of methods (e.g., glue, ultrasonic welding) to form an object. Each new sheet of material is placed over previous layers. A laser or knife is used to cut a border around the desired part and unneeded material is removed. This process is repeated until the part is completed.

Related AM technologies: Laminated object manufacturing (LOM), ultrasonic consolidation (UC)

Directed energy deposition

Focused thermal energy is used to fuse (typically metal) material as it is being deposited. Directed energy deposition systems may employ either wire-based or powder-based approaches.

Related AM technologies: Laser metal deposition (LMD)

Sources: Deloitte analysis; ASTM International, Standard terminology for additive manufacturing technologies, designation F2792 – 12a, 2013, p. 2

Table 3. AM Technologies—Their Base Materials, Advantages and Disadvantages

Technology	AM process	Typical materials	Advantages	Disadvantages
Stereolithography	Vat polymerization	Liquid photopolymer, composites	Complex geometries; detailed parts; smooth finish	Post-curing required; requires support structures
Digital light processing	Vat polymerization	Liquid photopolymer	Allows concurrent production; complex shapes and sizes; high precision	Limited product thickness; limited range of materials
Multi-jet modeling	Material jetting	Photopolymers, wax	Good accuracy and surface finish; may use multiple materials (also with color); hands-free removal of support material	Range of wax-like materials is limited; relatively slow build process
Fused deposition modeling	Material extrusion	Thermoplastics	Strong parts; complex geometries	Poorer surface finish and slower build times than SLA
Electron beam melting	Powder bed fusion	Titanium powder, cobalt chrome	Speed; less distortion of parts; less material waste	Needs finishing; difficult to clean the machine; caution required when dealing with X-rays
Selective laser sintering	Powder bed fusion	Paper, plastic, metal, glass, ceramic, composites	Requires no support structures; high heat and chemical resistant; high speed	Accuracy limited to powder particle size; rough surface finish
Selective heat sintering	Powder bed fusion	Thermoplastic powder	Lower cost than SLS; complex geometries; no support structures required; quick turnaround	New technology with limited track record
Direct metal laser sintering	Powder bed fusion	Stainless steel, cobalt chrome, nickel alloy	Dense components; intricate geometries	Needs finishing; not suitable for large parts
Powder bed and inkjet head printing	Binder jetting	Ceramic powders, metal laminates, acrylic, sand, composites	Full-color models; inexpensive; fast to build	Limited accuracy; poor surface finish
Plaster-based 3D printing	Binder jetting	Bonded plaster, plaster composites	Lower price; enables color printing; high speed; excess powder can be reused	Limited choice of materials; fragile parts
Laminated object manufacturing	Sheet lamination	Paper, plastic, metal laminates, ceramics, composites	Relatively less expensive; no toxic materials; quick to make big parts	Less accurate; non-homogenous parts
Ultrasonic consolidation	Sheet lamination	Metal and metal alloys	Quick to make big parts; faster build speed of newer ultrasonic consolidation systems; generally nontoxic materials	Parts with relatively less accuracy and inconsistent quality compared to other AM processes; need for post-processing
Laser metal deposition	Directed energy deposition	Metals and metal alloys	Multi-material printing capability; ability to build large parts; production flexibility	Relatively high cost of systems; support structures are required; need for post-processing activities to obtain smooth finish

Sources: Deloitte analysis; Wohlers Associates, Additive manufacturing and 3D Printing state of the industry, 2012; Troy Jensen and Pipar Jaffray, 3D printing: A model of the future, March 2013; Justin Scott, IDA Science and Technology Policy Institute, Additive manufacturing: status and opportunities, March 2012.

current and likely future applications suggests that there is strong growth potential for AM going forward.

Strategic Considerations Going Forward

Some experts have heralded AM as the next great disruptive technology, similar to personal computing, giving everyone on the planet the ability to imagine, design and create custom and personalized products. As powerful and transformational as AM will likely be across an array of industries and applications for years to come, organizations should address a number of strategic challenges as they integrate AM into their value

chain. We identify four such strategic challenges as especially worthy of further consideration.

AM Workforce Development

This projected growth for AM, while positive, also brings with it a significant challenge: heightened competition for a finite talent pool with the skills to use this technology. This challenge is expected to affect organizations of all sizes, from start-up to enterprise-level. The constricted supply of skilled AM labor is the result of several factors, which can be broadly categorized into the three key talent areas: recruitment and hiring, train-

Table 4. AM Applications by Select End Markets

Industries	Current applications	Potential future applications
Commercial aerospace and defense	<ul style="list-style-type: none"> • Concept modeling and prototyping • Structural and nonstructural production parts • Low-volume replacement parts • Complex engine parts 	<ul style="list-style-type: none"> • Embedding additively manufactured electronics directly on parts • Aircraft wing components • Other structural aircraft components
Space	<ul style="list-style-type: none"> • Specialized parts for space exploration • Structures using lightweight, high-strength materials 	<ul style="list-style-type: none"> • On-demand parts/spares in space • Large structures directly created in space, circumventing launch vehicle size limitations
Automotive	<ul style="list-style-type: none"> • Rapid prototyping and manufacturing of end-use auto parts • Parts and assemblies for antique cars and race cars • Quick production of parts or entire vehicles for the entertainment industry 	<ul style="list-style-type: none"> • Sophisticated auto components • Auto components designed through crowdsourcing
Health care	<ul style="list-style-type: none"> • Prostheses and implants • Medical instruments and models • Hearing aids and dental implants 	<ul style="list-style-type: none"> • Developing organs for transplants • Large-scale pharmaceutical production • Developing human tissues for regenerative therapies
Consumer products/retail	<ul style="list-style-type: none"> • Rapid prototyping • Creating and testing design iterations • Customized jewelry and watches • Limited product customization • Co-designing and creating with customers 	<ul style="list-style-type: none"> • Customized living spaces • Growing mass customization of consumer products

Sources: Deloitte analysis; CSC, 3D printing and the future of manufacturing, 2012.; “US NAVAIR tests 3D printed, safety-critical parts on MV-22B Osprey aircraft”, Naval-technology.com, <http://www.naval-technology.com/news/newsus-navair-tests-3-d-printed-safety-critical-parts-on-mv-22b-osprey-aircraft-4965373>, accessed Aug. 12, 2016.

ing and retention. Recruitment and hiring challenges primarily include accelerated retirement of skilled workers, a generally negative view of manufacturing among members of the Millennial Generation born from the early 1980s until the early 2000s, and an overall lack of science, technology, engineering and mathematics skills in the manufacturing market. For its part, training challenges include the relatively limited number of AM-specific educational programs offered in post-secondary and vocational institutions—no matter how much programs focused on AM are growing in number. Finally, retention of skilled AM professionals presents a challenge precisely because demand is so high for their talents given the limited number of training programs for aspiring AM workers. While many challenges face AM workforce development, organizations can use strategic workforce planning approaches to shape a robust AM workforce and build an AM talent pipeline.

AM Digital Thread

The AM process draws upon a digital design file to deposit material, layer upon layer, to construct 3D-printed parts composed of often complex geometries. Despite their promise and potential, digital designs dictating the production of end-use, 3D-printed objects have not yet moved fully into the mainstream. While AM has become a crucial part of the design process through rapid prototyping and other low-volume applications, it has not reached critical mass for applications in end-use parts and products at the enterprise level. For AM processes to scale at the industrial level, a series of complex,

connected and data-driven events is needed. This series of data-driven events is commonly referred to as the digital thread: a single, seamless strand of data that stretches from the initial design concept to the finished part, constituting the information that enables the design, modeling, production, use and monitoring of an individual manufactured part.

This thread enables the flow of data throughout the manufacturing process, including design concept, modeling, build plan monitoring, quality assurance, the build process itself, and post-production monitoring and inspection. The ability to dissect, understand and apply the potentially massive amounts of data and intense computing demands within the digital thread allows users to enhance and scale their AM capabilities and manage the complexities of AM production. Yet, for all its importance, the digital thread is only as useful as it is integrated. Gaps in connectivity or stages within the design and manufacturing process where information remains siloed or isolated in separate parts of the organization prevent the manufacturer from gaining full visibility across the process. Thus, the right digital infrastructure—one that can store, access and analyze vast amounts of data and interoperate across multiple different machines and processes—is crucial to building and operating a successful digital thread.

AM Quality Assurance

While companies have widely explored AM’s potential to shrink the scale and scope necessary for manufacturing,

What AM Means for Your Organization: Four Tactical Paths

AM is an important technology innovation with roots going back nearly 3 decades. Its importance derives from its ability to break existing performance trade-offs in two fundamental ways. First, AM reduces the investment required to achieve economies of scale. Second, it can increase flexibility and reduces the funding required to achieve scope.

Investment versus scale: Considerations of minimum efficient scale shape the supply chain. AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the barriers to entry to manufacturing for a given location.

Investment versus scope:

Economies of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of equipment can produce, reducing the costs associated with production changeovers and customization and/or the overall amount of equipment and funding required. Changing the investment-versus-scale relationship has the potential to impact how supply chains are configured, while changing the

investment-versus-scope relationship has the potential to impact product designs. These impacts present companies with choices on how to deploy AM across their businesses.

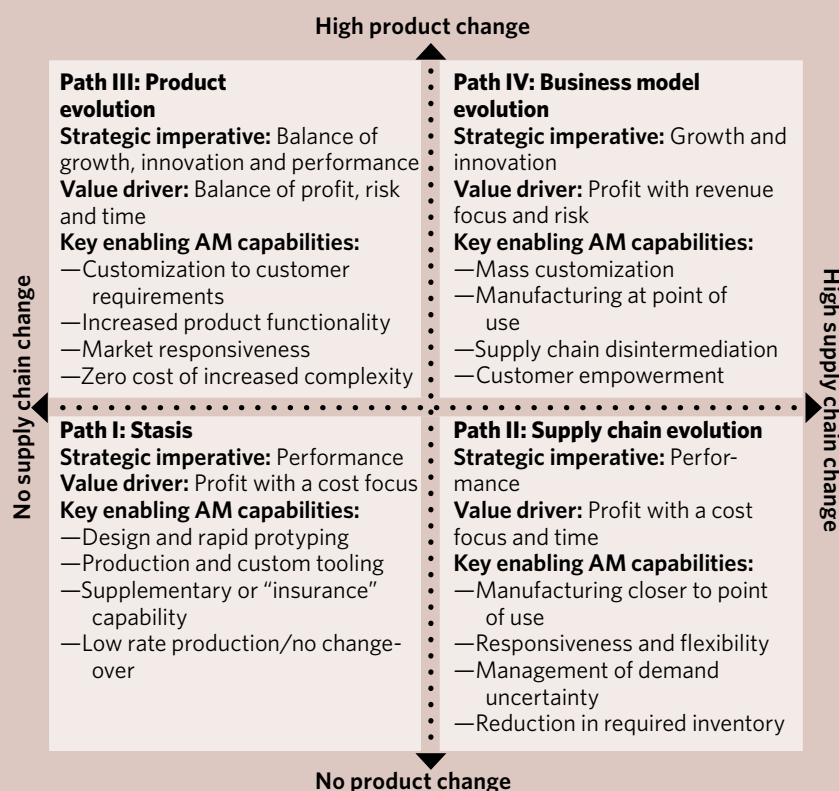
The four tactical paths that companies can take are outlined in the framework below:

Path I: Organizations do not seek radical alterations in either supply chains or products, but may explore AM technologies to improve value delivery for current products within existing supply chains.

Path II: Organizations take advantage of scale economics offered by AM as a potential enabler of supply chain transformation for the products they offer.

Path III: Organizations take advantage of the scope economics offered by AM technologies to achieve new levels of performance or innovation in the products they offer.

Path IV: Organizations alter both supply chains and products in the pursuit of new business models.



Graphic: Deloitte University Press | DUPress.com

produce items based on previously impossible designs, and alter the makeup of organizational supply chains, several significant hurdles prevent its wider adoption. One of the most important barriers is the qualification of AM-produced parts. So crucial is this issue, in fact, that many characterize quality assurance (QA) as the single biggest hurdle to widespread adoption of AM technology, particularly for metals. Put simply, many manufacturers and end users have difficulty stating with certainty that parts or products produced via 3D printing—whether all on the same printer or across geographies—will be of consistent quality, strength

and reliability. Without this guarantee, many manufacturers will remain leery of AM technology, judging the risks of uncertain quality as too costly a trade-off for any gains they might realize.

QA presents a multifaceted challenge, encompassing both the scale and scope of production. Indeed, quality doesn't just exist on one dimension; it exists on several from ensuring repeatable quality to guaranteeing quality under any environmental conditions and operational constraints to recognizing circumstances in which quality cannot be guaranteed. Each

dimension should be addressed in order for parts qualification—and AM’s potential—to be more fully realized.


AM Business Model Considerations

At its core, the AM process is a technical process based on data; without data, nothing gets printed. Yet the very central role that data play in the process of AM value creation inspires consideration of an array of issues that go to the core of the AM business transaction—issues that range from data ownership to data quality to protection of intellectual property rights.

In May 2016, America Makes sponsored a strategic simulation of a procurement action with 80 participants from the Department of Defense and industry. This event highlighted the many varied business model challenges that must be addressed for data to be exchanged enabling AM. For example, these challenges include: product liability, information security

and suitable cost and profitability. A chartered working group is addressing these issues, with additional events planned to further explore solutions.

Closing Thoughts

There can be little doubt that the last 30 years have witnessed an unceasing advancement in AM system functionality, ease of use, cost and adoption across multiple industrial sectors. Indeed, there is an unmistakable shift in the AM landscape—from relatively common prototyping and modeling applications toward emerging applications aimed at manufacturing direct parts and end products. If the past is prologue, the role of AM technology in the manufacturing value chain will only grow in scope, scale and complexity. While there is still some time before AM realizes its full potential, companies should assess how AM can help advance their performance, growth and innovation goals. 

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MDAP/MAIS Program Manager Changes

With the assistance of the Office of the Secretary of Defense, *Defense AT&L* magazine publishes the names of incoming and outgoing program managers for major defense acquisition programs (MDAPs) and major automated information system (MAIS) programs. This announcement lists recent changes of leadership this year, for both civilian and military program managers, including two for the Air Force that were not reported earlier.

Army

Col. David Warnick relieved **Col. James Romero** as the program manager for the Joint Attack Munition Systems program on July 6.

Col. Troy Crosby relieved **Col. Michael Thurston Mission** as the program manager for the Mission Command program on July 13.

Col. Jonathan Slater relieved **Col. Richard Hornstein** as program manager for the Close Combat Systems program on July 21.

Col. Charles Woshim relieved **Col. Terrence Howard** as the program manager for the Cruise Missile Defense Systems program on July 22.

Navy/Marine Corps

CAPT Casey Moton relieved **CAPT Mark Vandroff** as program manager for the Arleigh Burke Class Guided Missile Destroyer (DDG-51) (PMS 400D) on Aug. 10.

Yeling Wang Bird relieved **CAPT Chris Meyer** as program manager for the Gerald R. Ford Class Nuclear Aircraft Carrier (PMS 378) on Aug. 26.

COL Donald Gordon relieved **COL Rey Masinsin** as program manager for the Command Aviation Command and Control System (CAC2S)(AC2SN) on Aug. 16.

Air Force

Col. John Newberry relieved **Col Christopher Coombs** as program manager for the KC-46A program on Feb. 8.

Col. Brian Henson relieved **Col. Jeffrey Sobel** as the program manager for the Advanced Medium Range Air to Air Missile program on May 27.

Col. Scott Wallace relieved **Col. Douglas Roth** as program manager for the CV-22 program on July 11.

Col. Luke Cropsey relieved **Col. Darren Cochran** as program manager for the GBU-57 Massive Ordinance Penetrator program on July 14.

Col. Paul Rounsavall relieved **John Mistretta** as program manager for the B61-12 Life Extension Program Tailkit Assembly on July 27.

Col. Riley Pyles relieved **Col. Norman Leonard** as program manager for the National Air Space program on Aug. 2.



Ensuring a Safe Technological Revolution

William E. Frazier, Ph.D. ■ Elizabeth L. McMichael ■ Jennifer Wolk, Ph.D. ■ Caroline Scheck

In an era of increasing global hostilities, the Department of Defense (DoD) faces increasing fiscal constraints. Maritime security challenges continue while the defense industrial base shrinks, platforms and systems age and readiness declines. To help confront these challenges and meet the needs of defense missions, new enabling technologies must be identified and integrated into the DoD.

Additive manufacturing (AM), commonly referred to as 3D printing, is an identified enabling technology with the potential to radically change how the DoD, the Department of the Navy, and their partners and allies develop, manufacture and support their platforms and systems. In the last decade, AM technology has moved beyond

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simple plastic prototypes to printing metal, integrated circuits, biomaterials and compound materials. Reports of AM's technology advancement can seem to approach the realm of science fiction, with demonstrations of 3D printing of various body parts such as customized bone and joint implants.

The naval community has successfully used AM technology in its facilities since the early 1990s. Polymer AM systems have become commonplace in enabling unique production tooling, rapid prototyping, training aids and customized repair part development. The flexibility and digital aspects of AM, which enable parts to rapidly move through design iterations, have opened additional options in production tooling that would be costly and time-consuming to set up through traditional manufacturing. The types of parts producible by AM increase every day. AM systems that "print" metals are maturing to the point where direct manufacture of certain safety critical parts is on the horizon.

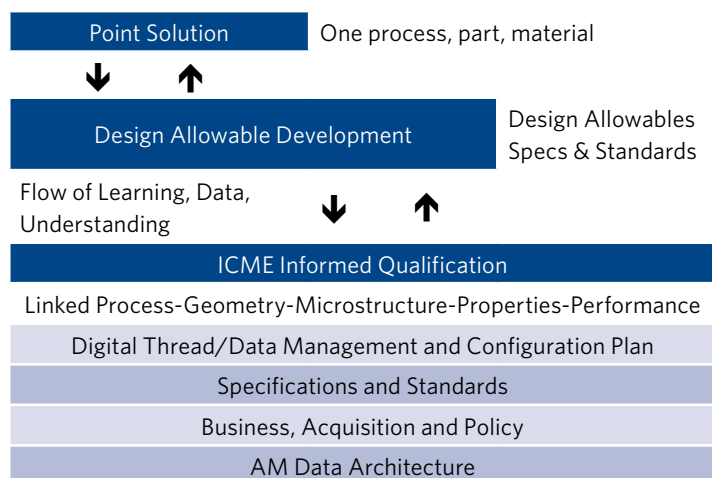
AM creates opportunities that range from designing parts for increased capabilities and reliability to re-imagining naval logistics and supply chains. A digital supply chain can enable "stock[ing] the data, not the part" and fabricating parts when and where they are needed. This supply chain resiliency, coupled with manufacturing agility for increased innovation and performance capabilities, is the cusp of the AM technology revolution.

AM provides the opportunity to truly reduce costs, minimize obsolescence issues and improve both capability and readiness across the entire life cycle of naval systems—including both the new developments and systems of today. But it will require a common vision across the DoD and industry to address not only AM's technical challenges but include the policy, business and acquisition changes necessary to realize its potential.

Barriers to AM Implementation

Qualification/Certification: The ability to qualify and certify AM parts, including safety-critical metallic parts is a fundamental barrier to its more extensive use in Navy platforms. Safety-critical parts are "head hurters"—difficult to produce, made only of well understood and characterized materials, with very specific manufacturing processes and rigorous testing requirements. A "qualified" process is capable of consistently turning out a product that has acceptable properties. A "certified" part can perform properly in its operating environment. The conventional qualification/certification building block approach used today requires that a single process be standardized and characterized and that statistically substantiated data be generated. Significant cost and time are associated with this conventional process. Given the large number of AM processes, vendors, equipment models and potential material options, the Navy is examining methods to enable rapid qualification over the long term as the traditional

Figure 1. Navy Approach to Qualification/Certification



qualification certification process will make it impossible to achieve the flexibility that AM offers. To enable the innovative designs, customization and improved performance promised by AM, qualification and certification process must be accelerated by an order of magnitude.

The naval community has adopted a three-pronged approach to overcoming the Barriers to Qualification/Certification (see Figure 1). Because of the complexity of the AM processes, the long-term strategic approach is to use Integrated Computational Material Engineering (ICME) to inform qualification and certification. ICME links the AM process, part geometry, material microstructure and properties together to understand these relationships for end use. In the near term, the traditional approach to qualification and certification is being utilized on a case-by-case basis. These point solutions are parts demonstrations that help accelerate AM qualification by generating sufficient engineering confidence to field critical demonstration parts. The understanding and knowledge gained through multiple demonstrations and case-by-case certifications allow us to design parts that are optimized for AM production and begin to define the necessary naval requirements for AM specifications and standards.

The data gathered from demonstrations support our goal of an "ICME informed" approach to qualification. When implemented, ICME-informed qualification will reduce the required testing and facilitate the building of parts using different AM processes, manufacturers and equipment. The naval plan's final step links the ICME models that allow selection of the right AM process, materials and component design to a suite of sensors and controls for monitoring the AM manufacturing process. This provides real-time understanding of any manufacturing issues that will affect quality and inspection and that can significantly reduce testing requirements—depending on the part's criticality and operating environment.

Another critical aspect of qualification and certification is nondestructive inspection (NDI). Basic work is still needed on identifying anomalies in AM processes and materials, the relationship of these anomalies to processing parameters and their effects on part performance. The material variability that is observed and must be understood through modeling and simulation also poses challenges to NDI. Specific issues include variable microstructures, complex geometries and adaptation of existing and new inspection methods for AM.

Polymer and composite AM materials for use in naval applications also require qualification and certification. A current hurdle to usage of polymeric materials aboard ship is the inability of currently tested AM polymer materials to comply with standards regarding flammability, smoke or emissions and toxicity. Polymeric AM materials have been used in non-structural aviation applications.

The vision of parts on demand, made available when and where they are needed, will be achieved by lowering the cost and enhancing the operational availability of naval weapon systems. The Navy is actively engaging its various communities to align needs and ensure that AM can be safely accelerated and used to meet critical needs.

The Data Problem: AM is a digital process, from design through printing. The digital process depends on a significant quantity of data. The amount, type and methodology for managing the data associated with an AM part are readily amenable to existing government methods for managing technical data. While the DoD as a whole is beginning to move toward digital 3D data for new systems, addressing obsolescence and repair issues for legacy platforms and systems that use standard two-dimensional drawings requires significant analysis and reverse engineering to enable adaptation for AM. This data migration has occurred in defense prime contractors and major suppliers that have gone digital in their design and production infrastructures. These suppliers have migrated to a 3D model based environment that uses product life-cycle management software to ensure every element of a product is managed—from design work done in computer-aided design, to analysis, qualification/certification, computer-aided manufacturing, configuration management and supply. The infrastructure and tools needed to support the digital technical data required for AM are the standard in defense industry and commercial manufacturing companies. The Navy will need to implement the same infrastructure and standards to make AM achievable.

Business, Acquisition and Policy: It is difficult to develop an AM use cost model that captures the associated savings and cost avoidance. This is particularly true in defense, where most cost models are based on actual cost history for similar programs.

Because it is a technology in which shorter production runs for complex parts can actually prove more cost-effective than

long production runs, AM presents a unique costing challenge. While material and design costs are higher for AM parts production, the specialized tooling costs and “touch labor” costs are much lower, and the performance gained can dramatically reduce life-cycle costs. Validated cost data are scarce, and accurate AM cost models need to be assigned a high priority.

Contracting with AM in mind (buying adequate data rights, enabling a wider supply base, and moving toward shorter acquisition cycles) will require a different approach to acquisition planning. While only a limited number of suppliers can produce an airplane, the entrance cost to AM is significantly lower, and over the next decade there will be many suppliers that can make safety-critical parts. In that future, defense policy may be the biggest impediment to broad adoption of AM. Specialty metals restrictions for defense contracts may limit options in expanding our industrial base for complex parts, and impact the level of cost sharing we achieve with our NATO partners.


Accelerating AM for Defense

How do we leverage the huge AM investments by commercial industry, while ensuring that AM can safely be used for carrier aviation and on our nuclear submarines? If we want AM to mature for defense applications, and if we ever want to use it in the future, we need to start now.

Every platform or system in the naval inventory includes parts that are hard to get. These parts are difficult to produce and are made with materials that require long lead times. They have limited supply bases and suboptimal designs; the DoD has hundreds of thousands of “problem children” parts. The ability to produce a subset of these parts through AM will dramatically increase readiness and reduce costs. And—if we commit to making them through AM—we can mature AM qualification and certification, AM data management and AM business processes much more quickly.

There are other steps that we need to take in order to accelerate AM use:

- Increase collaboration opportunities across the AM community.
- Develop an AM data architecture that will allow us to tie all the AM data together across the defense enterprise.
- Work with our suppliers, the Defense Logistics Agency, and the Naval Supply Systems Command to source AM parts.
- Validate DoD cost models and manage the data rights for maximum reuse.

If we want to use AM, we need to start using AM. And there’s no time like the present. 

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The **Digital Thread** as the Key Enabler

Col. Keith Bearden, USAF



You are down in the trenches trying to deliver agile war-winning capabilities every day, regardless of your Service or affiliation. Your time is valuable and you constantly find yourself

facing more and more requirements on your time.

The engineering community is seeking ways to reduce your workload while at the same time enabling you to do your job better, faster and cheaper. There is one initiative, the key enabler, to accomplish this goal—the digital thread. But let's set the stage first.

The 2013 *Global Horizons* report was the forcing function that kicked off a massive change in the U.S. Air Force. *Global Horizons* specifically challenged the Air Force and our science and engineering workforce to:

Bearden is the deputy director of engineering and technical management for the Air Force Materiel Command at Wright-Patterson Air Force Base in Ohio.

- Investigate and institutionalize digital engineering to reduce development cycle time.
- Develop and institutionalize a re-engineered prototyping and experimentation process that would allow for rapid cross-domain analysis and technology transition prior to bending metal.
- Re-establish a culture of “hands-on” engineering that allows the Air Force to restore technical prominence and recruit and retain the best and brightest from our academic institutions.
- Implement advanced manufacturing techniques, including additive manufacturing (AM) for enabling part optimization unburdened by the restraints of traditional manufacturing techniques and ensuring just-in-time parts availability.

we will need to rapidly flex between multiple options overwhelming our adversary’s ability to counter. This ultimately will provide a dynamic form of resilience. It will be the responsibility of the research and acquisition communities to provide solutions that have this inherent flexibility and interoperability. We need to deliver the ability to assess capabilities across multi-domain operations, ensure superior decision speed unencumbered by classification barriers through our technical solutions, and provide a method to investigate a balanced capabilities mix and performance-optimized teams.



The *Future Operating Concept* provides high-level descriptions of these agility concepts

All this will require process qualification and certification as opposed to part qualification and certification.

This visionary work detailed what the Air Force must do to recapture organic engineering excellence and continued technological superiority. Of course, this vision will require a change in culture in order to

succeed. Fortunately, this work was not simply put on the shelf to collect dust. The Air Force acted on it.

The Department of Defense (DoD) and the Air Force issued game-changing strategic guidance in 2014 and 2015 following *Global Horizons 13*. Have you read the guidance from the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) on Better Buying 3.0? Have you read *America’s Air Force—A Call to the Future*, our 30-year vision, or the *USAF Strategic Master Plan*, our 20-year plan to achieve the vision or the recently published *Air Force Future Operating Concept*? For the first time in memory, these revolutionary documents specifically impose requirements on the research and acquisition communities as well as the operational community.

Let’s begin with the central idea of operational agility, “the ability to rapidly generate—and shift among—multiple solutions for a given challenge.” In the past, our systems were conceived and designed as “exquisite platforms.” In the future,



but the bottom line is that our scientists and engineers will have to determine how to bring this vision to fruition. The good news is that our leadership understands this will require a change in the institutional culture. “An acquisition and logistics enterprise that is capable of rapidly identifying, acquiring, and fielding solutions through organic

additive manufacturing or commercial off-the-shelf sources ... and technology development using live, virtual and constructive (LVC) venues to enable the conservation of resources, improve the realism of training for combat and multi-domain challenges, and facilitate the development of innovative and collaborative solutions.”

The *USAF Strategic Master Plan* takes these overarching goals one step further, demanding the research and acquisition communities embrace a capability development process that is agile, adaptable and responsive in delivering affordable and mission-effective capabilities. It challenges the research and acquisition communities to:

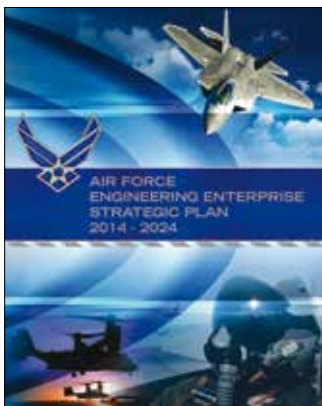
- Pursue modular, adaptable and reconfigurable solutions.
- Have the Air Force perform as the integrator at both the platform and enterprise level.
- Empower the Air Force to demand an agile acquisition enterprise that can balance cost, capability and schedule and can incentivize innovation in competitive solutions.

- Inject pivot points into acquisition allowing for programs to change direction based upon advances in technology, changes in threat environment, and the ever-present budget issues.
- Increase experimentation, both virtual and live, to allow for multidisciplinary teams to evolve concepts prior to committing to a development program. This is what our senior leaders expect. When they demand this type of engineering rigor, the culture change throughout our enterprise will take hold.

Flowing from this strategic guidance are many initiatives. Digital engineering is driven by the Deputy Assistant Secretary of Defense for Science and Engineering, defining the requirements to institutionalize digital engineering across the DoD—including data, tools and required training. In BBP 3.0, USD(AT&L) Frank Kendall challenged the Services to “strengthen organic engineering capability.” In order to manage risk associated with the execution of our programs and maintain our technical superiority, Kendall said that the technical workforce requires the right training, data, physics-based tools and facilities. Owning the technical baseline is one of the five priorities of the Assistant Secretary of the Air Force (Acquisition) challenging the acquisition enterprise and engineers to technically understand their system and ensure we are better informed decision makers and can go toe-to-toe with our industry counterparts.

Cost Capability Analysis (CCA) is a direct result of our senior leadership realizing that they were not demanding technical

Advanced manufacturing, including AM, is outpacing our ability to incorporate the new capabilities. These game-changing technologies have the potential to allow the reclamation of parts that previously were considered irreparable; drastically reduce part lead time from years to just hours or days; and allow the production of repair parts at deployed locations. These technologies present us with several challenges, ranging from policy to processes.



Condition Based Maintenance plus Prognostication (CBM+P) will significantly reduce operations and support costs by allowing a continuous understanding of the condition of our systems and bringing them in when they are needed. Finally, the *Air Force Engineering Enterprise Strategic Plan 2014-2024* is the strategic vision for transforming Air Force engineering. The Air Force Engineering Enterprise Executive Council (EEEC) is the body executing the *Air Force Engineering Enterprise Strategic Plan*. The EEEEC is the framework for how Air Force engineering will bring all these initiatives together in a cogent manner, reduce duplication of effort and seek and exploit synergies.

The EEEEC has four priorities:

- Refine engineering roles, responsibilities and policy.
- Enable high-quality decisions and seamless communication.
- Improve technical information management and standardization.
- Improve technical workforce and address competency gaps.

In order to achieve our senior leaders' vision, the acquisition community must institutionalize the digital thread throughout the enterprise. This requires access to the right data, the right tools and the right training.

rigor in order to ensure that our systems deliver the needed capability at a sustainable cost. CCA is a methodology to fully investigate the systems trade space, evaluate the performance requirements for mission effectiveness and determine the cost for each solution. This allows the decision maker to see the “knee in the curve” and determine the best solution for the Air Force and prevent the “exquisite solution.”

Below those four priorities are 10 goals and 57 objectives. Over the last 2 years, the EEEEC has closed 16 of those 57 objectives. This 10-year plan and governing body is producing results.

The digital thread is the key enabler for achieving all these initiatives and is defined as an extensible, configurable and component enterprise-level analytical framework that seam-

lessly expedites the controlled interplay of authoritative technical data, software, information and knowledge in the enterprise data-information-knowledge systems, based on the digital system model template. This is done to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information. The digital thread is the method to manage the Digital System Model throughout the life cycle;

The right technical data are just parts of the digital thread. The right technical data must be managed throughout the life cycle. The Air Force engineering and logistics communities are developing the Product Life-cycle Management (PLM) Capability Initiative (CI) as the backbone of the digital thread. PLM-CI provides the Air Force with a single comprehensive enterprise capability to manage all program data and business processes from gap identification through disposal.

Our senior leaders have provided a future vision. The engineering community has defined our minimum requirements of access to the right data, right tools and right training, and is in the process of providing an infrastructure and capability to manage our program data.

from conceptual design, to "as designed," "as built" and "as maintained." The digital thread provides you the information necessary to:


- **BBP 3.0—Strengthen Organic Engineering Capability:** There is no reason to do this if there is no digital thread to organically evaluate.
- **Own the Technical Baseline:** We will not become better-informed buyers or be able to go toe-to-toe with our industry counterparts if there is no digital thread to organically evaluate.
- **Take advantage of AM:** All advanced manufacturing techniques and especially AM require the digital thread for implementation.
- **Implement Live-Virtual-Constructive Modeling and Simulation:** This requires verified and validated models that can be generated only by applying the right physics-based engineering tools to the digital thread.
- **Reap the benefits of CBM+P:** It is not possible to predict system condition without a digital thread to organically evaluate.
- **Accomplish CCA:** We cannot organically perform system of systems cost capability trades without a digital thread.
- **Acquisition Pivot Points:** We cannot deliver high-quality decision support and cost-effective experimentation to senior Air Force leaders without the digital thread.

The bottom line: In order to achieve our senior leaders' vision, the acquisition community must institutionalize the digital thread throughout the enterprise. This requires access to the right data, the right tools and the right training.

Our senior leaders have provided a future vision. The engineering community has defined our minimum requirements of access to the right data, right tools and right training, and is in the process of providing an infrastructure and capability to manage our program data. These are great steps in the right direction. We now are embarking on the next phase.

- What are the right data and how do we specify that in a contract?
- How do we incentivize collaboration and protect intellectual property?
- What are the right engineering tools and how are they accessed?
- What tools are needed on the desktop and in an engineering lab with high-powered work stations?
- What competency gaps exist and how will we grow our workforce to fill those gaps?

These critical questions are now being addressed in the Air Force Engineering Enterprise with our first spiral due by September 2016.

This is the perfect time to embrace a fundamental culture change and recapture organic engineering excellence. All Air Force strategic guidance fully supports this technical vision enabled by the digital thread. The Engineering Enterprise is producing actionable results, but we can't do this alone. We need your help in our efforts to define the right data, the right tools and the right training. 

The author can be contacted at keith.bearden@us.af.mil.

Separating **Hype** from **Reality**

Raymond Langlais Jr. ■ Nick Avdellas ■ Colin Finrock
Russ Salley ■ Madelyn Newcomb

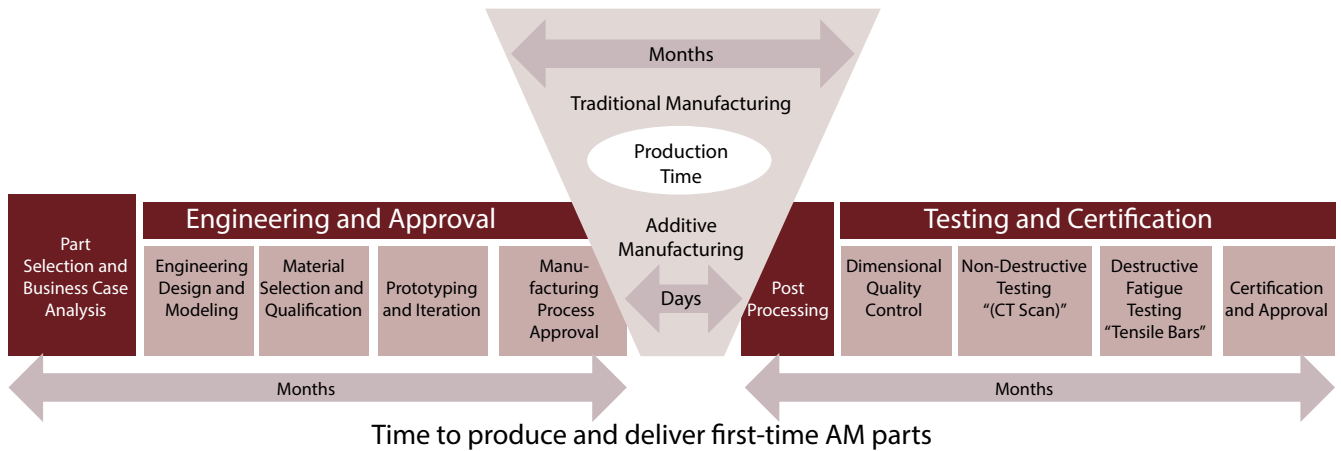


Additive manufacturing (AM) technology is changing and improving rapidly. For years, AM has been used for rapid prototyping, but as computing power and software, input materials, machine speed and performance have improved, AM has morphed into a method for end-use production with great potential for Department of Defense (DoD) use. Imagine a future battlefield where U.S. forces fully leverage AM capabilities to support their materiel needs—producing critical, but otherwise unavailable, parts on demand in the optimum location in the DoD supply chain. You can see why AM has captured the imagination of military planners.

By prepositioning three-dimensional (3D) printing machines, feedstock, and post-processing equipment at choice locations, only the technical data, or “recipe,” would need to be sent forward, instead of the part itself. Oner-

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Figure 1. A Realistic View of Additive Manufacturing



ous supply wait times, large inventory levels, and dangerous transportation requirements could all decrease, resulting in higher materiel availability and equipment readiness rates, and a streamlined, less costly supply chain. If the DoD develops, fields and monitors AM capabilities thoughtfully and deliberately, this scenario could become reality.

Although a fully leveraged AM future for the DoD is appealing to contemplate, we should not let the “hype” of this vision blind us to the real requirements to achieve implementation. AM is complicated, and the DoD must acknowledge and understand the key challenges to integrating it into the DoD maintenance and supply chain overall:

- Current limitations of the AM process
- AM technical data requirements
- Intellectual property (IP) rights
- Liability and warranties
- AM workforce development

For each of these, we examine the associated issues unique to AM, separating the hype from the reality. We then offer insight into how the DoD and industry can address these challenges and conclude by discussing both the promise and the hard work required to realize AM’s full potential to support DoD sustainment.

DoD’s AM Challenges

Current Process Limitations: AM often is discussed as if it were push-button technology. The reality is much more complex. The extensive work that occurs before and after the printing process is not always visible.

In Figure 1, the central triangle illustrates the current “hype” of AM—the notion that production through AM is significantly faster than production using traditional manufacturing methods. The actual printing of a part can be accomplished in hours or days, but that is only a small piece of a larger process. For

example, identifying the parts that can and should be manufactured with AM, along with prior engineering and approval, can take months. On the back end, post-processing and testing and certification can take a similar amount of time. The reality of using AM for end-use part production is complicated and involves significant analysis, planning, testing and specialized skill sets.

In addition, AM is a maturing and rapidly changing technology, and so does not have recognized certifications to standardize output. The machines vary enough that each is in effect its own “foundry,” producing slight variations in its end products. The “hype” is that all parts can be made to the same standard as conventional manufacturing; the reality is that they will vary slightly from machine to machine without extensive calibration.

AM Technical Data Requirements: Every AM part requires a 3D model, but for decades most DoD engineering efforts have relied on blueprints—that is, two-dimensional (2D) schematics. Transitioning from 2D to 3D is neither simple nor inexpensive.

Table 1 shows key roadblocks facing the DoD. Many new weapon systems are being designed in 3D. But to utilize AM for production of legacy weapon system parts, the vast majority of parts in the DoD inventory will have to be converted to a 3D format. In addition, many of the 3D data packages available are in a proprietary format that requires expensive software even to read. The DoD could buy, license or re-engineer the technical data packages (TDPs) needed to produce parts using AM, but none of these options is easy, quick or cheap. Finally, the DoD lacks central direction on standards for 3D model content and metadata to guide further development among the several military Services.

TDPs contain many elements other than 3D model data (Table 2). Standard TDPs are needed to move AM forward.

Table 1. Roadblocks: The Hype Vs. the DoD's AM Reality

Hype	Reality
DoD has access to Technical Data Packages (TDPs) in a consistent and complete format	→ Approximately 75% of parts the Defense Logistics Agency manages do not have TDPs; of the remaining 23%, most are in 2D format not optimized for AM
The current acquisition system allows the DoD to purchase TDPs in an efficient and cost-effective manner	→ The DoD acquisition system makes procuring government purpose rights to TDPs challenging and prohibitively expensive
3D model formats are universal	→ There are over 50 different 3D file formats, many of which are proprietary

Graphics courtesy of LMI

Table 2. Elements in the Technical Data Package

- 3D Model Data
- Engineering Drawings
- Specifications
- Standards
- Performance Requirements
- Quality Assurance
- Reliability Data
- Packing Details

LMI has led efforts to standardize model formats DoD-wide. For example, LMI has designed a test procurement for the Defense Logistics Agency (DLA) that will use legacy procurement systems. DLA is testing the use of neutral file formats for procuring weapon system parts. The agency is engaging with the military Service engineering activities to provide validated 3D Portable Data File (PDF) and Standard for the Exchange of Product Model Data (STEP) files that meet all of the procurement legal requirements for fair and open competition.

In addition, in partnership with DLA, LMI is leading the next step: testing a real world government commercial acquisition to validate the feasibility of using these model formats in open competition. Currently, DLA is seeking bids to manufacture selected legacy parts using a TDP containing only 3D PDF and STEP files. (No 2D drawing data are included in the bid packages.) After the parts are delivered, DLA and the military Services will validate that the parts were made correctly and of the expected quality through using only the provided 3D data. By early 2017, the project will have results and lessons learned it can share. This type of project will lay the groundwork for a standardized process to acquire, rent access, or create and approve TDPs. This may involve a royalty system to distribute the upfront costs associated with procuring government purpose data rights.

Intellectual Property (IP) Rights: The original equipment manufacturer (OEM) owns the IP rights to the TDP. At initial acquisition or later, the government can acquire those rights, but it does not purchase the IP rights to the vast majority of parts. Because the TDP is needed to produce a part with AM, a streamlined process is required for the DoD to rapidly gain access to the TDP.

The "hype" is that DoD can just purchase the IP rights from the OEM and start producing the parts with organic AM assets.

The LMI Research Institute studied the feasibility of creating a rapidly executable protocol for the temporary exchange of IP/technical data between the OEM and the DoD to produce urgently needed nonstocked parts with 3D printers. LMI's objective was to help DoD and the OEMs resolve questions concerning limited use and assured disposition of technical data once they have been used to additively manufacture a needed part temporarily in a "remote" location. The focus is on a specific legal exchange of IP from OEM to DoD (Figure 2).

LMI's goal is to create a rapidly executable protocol for the DoD and the OEMs to follow when exchanging technical data for unavailable AM-producible parts. In an emergency, the DoD needs to be able to additively manufacture an unavailable component or part without having to work out IP issues with the OEMs. This effort proactively addressed the issue of IP access, security and storage; certification and qualification repeatability; and legal agreements between the DoD and the OEMs.

In a May 2016 AM business process wargame sponsored by America Makes, IP access and security were cited as the top issues among industry participants during a simulation of a scenario involving IP/TDP exchange between the OEM and the DoD. The "reality" is that allowing DoD access to IP creates serious industry concerns in the areas of security, quality, reliability and liability. For example, security of the data as well as access to the machines will need to be tightly controlled.

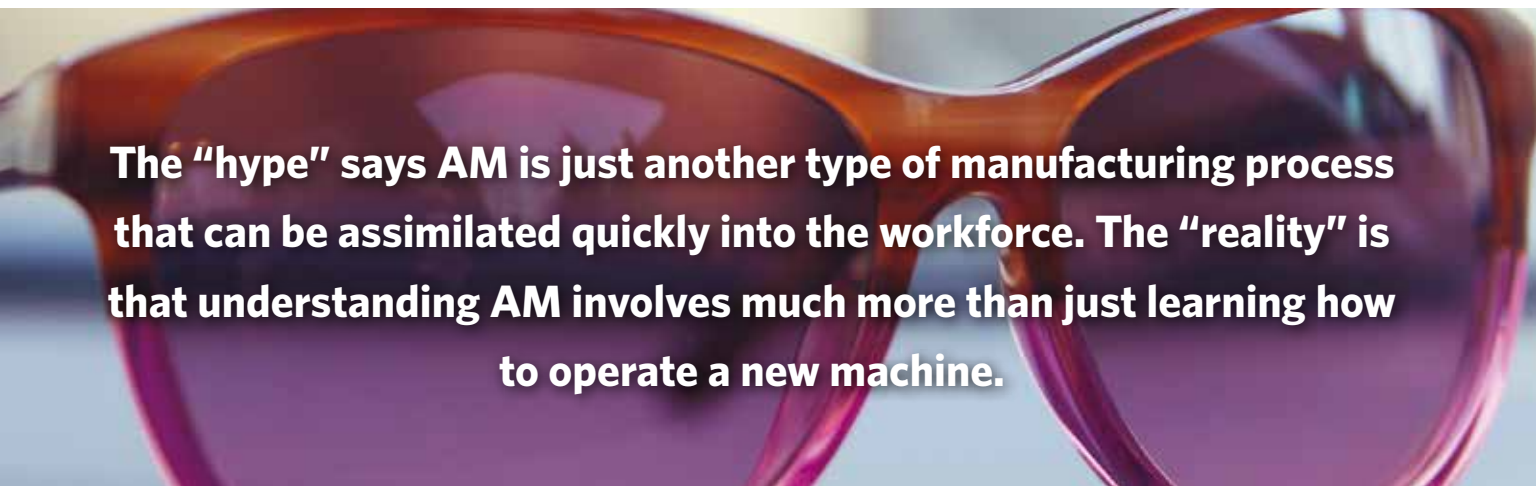
Figure 2. The Legal Exchange of Intellectual Property



This includes user identification and proper safeguarding and storage of the data across wireless networks. Any transfer of IP to the government, even temporarily, will require negotiating terms covering these concerns, as well as compensation.

Liability and Warranties: In the wargame scenario, two questions arose. Who is liable if the part fails? Does the OEM's warranty still apply? Normally, the manufacturer is liable, but in this case, the customer is the manufacturer, using OEM-provided build instructions. Does liability shift to the DoD? A strict certification and qualification process, possibly using a field Service representative, may ensure the manufactured part complies, but the OEM's brand reputation also is an issue. Once these questions and IP issues are resolved, they must be incorporated into the Federal Acquisition Regulation (FAR).

and a partial solution. Many of the OEMs have long since gone out of business, so obtaining parts from traditional sources can prove problematic. The DoD is working to find ways to identify parts amenable to AM and prototyping the process to get them approved for use after manufacturing. LMI has helped the DoD develop a method to evaluate millions of DLA legacy parts to determine those that can be supported by AM. This method looks at not only whether AM production is possible but whether it makes fiscal and operational sense to manufacture with AM. Once the part is identified, it must be made and certified ready for use, an area in which the Navy is taking the lead. Naval Air Systems Command spent the last 18 months developing and testing the first flight-critical part, a link and fitting assembly for the MV-22 Osprey.



The “hype” says AM is just another type of manufacturing process that can be assimilated quickly into the workforce. The “reality” is that understanding AM involves much more than just learning how to operate a new machine.

AM Workforce Development: The “hype” says AM is just another type of manufacturing process that can be assimilated quickly into the workforce. The “reality” is that understanding AM involves much more than just learning how to operate a new machine. To fully understand AM, the workforce must think differently about design. Also, the AM workforce needs multiple skills, including knowledge of AM design, manufacture and material properties. Due to the variations in AM feedstock, material types, part orientation during manufacture, post-processing, and even the output of the machines themselves, AM requires more of an “artisan” skill set—featuring extended hands-on experience—than traditional manufacturing. The difficulty of training the workforce in AM is exacerbated by the lack of standards in the field. The DoD needs better defined, improved standards to properly develop the workforce.

Answering the Challenges

The challenges facing the DoD and AM integration appear daunting, but numerous efforts are aimed at establishing a solid foundation to enable integration into the acquisition and maintenance processes. Here are a few:

Defining AM's role in DoD: AM cannot solve all of the DoD's legacy part acquisition problems, but it can be a useful tool

America Makes—the National Additive Manufacturing Innovation Institute—is the nation's leading collaborator in AM technology research, discovery, creation and innovation. It has established working groups to examine AM challenges, including the following:

- The Additive Manufacturing Sustainment Business Model Working Group, (AMMO WG) addresses the business model aspects of AM sustainment, focusing on the use of AM for maintenance and sustainment of commercial and defense equipment. The group provides a forum for addressing issues discovered during the May 2016 AM Business Model Wargame.
- The AM Legal Working Group focuses on the legal issues associated with adopting AM technologies. Its goal is foster a collaborative effort between government and industry to identify, examine and propose solutions for these legal issues.

AMMO WG seeks an integrated DoD strategic vision and facilitates collaborative implementation of AM technology in support of DoD maintenance. The AMMO WG promotes the development and adoption of AM capabilities through collaborative efforts between the DoD, other government agencies and industry.

Future AM Wargames: The May 2016 wargame brought together sustainment executives and managers from the DoD and industry to simulate a specific scenario and identify issues, form potential courses of action and propose solutions. America Makes plans to continue with future collaborative AM wargames to expand the areas of interest and better understand the issues and solutions available to government and industry.

Conclusion

Compared with other manufacturing capabilities, AM holds incredible promise to dramatically reduce warfighter wait times for materiel. Progress must be deliberate, however, and the sustainment community must now work hard to deliver on this promise by contemplating a different and likely smaller supply chain that can be responsive and reliable to serve this dynamic AM environment.


The DoD sustainment community must balance the excitement about the novelty and expediency of current and emerging AM capabilities with appropriate consideration of accountability and predictability.

If the DoD approaches business rule development through partnerships with industry, it can ensure it “walks before it runs.” For example, the DoD can begin to imagine echelons or levels of AM capability akin to its organizational, intermediate,

and depot maintenance levels—all operating in a supportive and lean business framework. This kind of progress will contribute directly to delivering required availability at best cost.

As DoD sustainment and maintenance professionals move forward and integrate AM into operations, leaders and policymakers need to do the following:

- Take the lead in creating standards, updating policy and the FAR, and simplifying certification processes to take advantage of the full potential of this technology.
- Continue the DoD-wide education on AM, emphasizing that the full scope of the business processes involved in implementing AM need to be understood before deployment.
- Realize that achieving AM benefits will take time and investment in developing essential business processes as well as the AM technology itself.
- Focus on where AM can add value now and build on successes to further advance business process maturity.

In the DoD’s emerging AM environment, our key task is to continue to foster innovation and experimentation while forming an emerging policy framework that progresses with AM business rules. 

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Holguin Receives Contracting Excellence Award



This year’s recipient of the Elmer B. Staats Contracting Professional Award is Luis Albert Holguin, certified federal contracts manager (CFCM) of the U.S. Air Force at Hanscom Air Force Base in Massachusetts. Holguin leads a five-member team in the contract execution of a \$2.8 billion development portfolio that is directly

sponsored by the Under Secretary of Defense for Acquisition, Technology, and Logistics.

Runners up included Raymond McCollum, a certified professional contracts manager (CPCM) with the General Services Administration (GSA) Information Technology Schedule 70 Program; Kristina Parmenter, a CFCM with

the Missile Defense Agency; Jennifer Mattessino, a CFCM with the Army Contracting Command; and Brittney Davis, a CFCM with the Naval Air Systems Command.

The award is issued by the Procurement Round Table (PRT) to recognize a federal acquisition professional with extraordinary business leadership or team participation in the design, development or execution of an acquisition program or project that furthers an agency’s mission.

The PRT is a nonprofit organization chartered in 1984 by former federal acquisition officials concerned about the economy, efficiency and effectiveness of the federal acquisition system. Its directors and officers are private citizens who serve pro bono with the objective of advising and assisting the government in making improvements in federal acquisition.

Additive Manufacturing as a Sustainment Enabler

An Industry Perspective

Marilyn Gaska, Ph.D. ■ Teresa Clement, Ph.D.



From an industry perspective, additive manufacturing (AM) has been a focus for more than 10 years, though rapid prototyping has actually been in practice for over 30 years with early emphasis and continued usage primarily during design and manufacturing of new systems.

However, AM recently received increased public focus in the Department of Defense (DoD) and the media, as well as in discussions within the Aerospace Industry Association (AIA) Product Support Committee. Over the last 2 years, increased awareness around the opportunity for AM as an enabler for sustainment has led industry to actively support the vision and begin to realize the benefits for the warfighter by aligning with new public-private partnership constructs, such as those enabled by the National Network for Manufacturing Innovation (NNMI). In support of this vision, America Makes, as the National Additive Manufacturing Innovation Institute, also expanded focus in 2015 to include application to maintenance and sustainment.

Gaska is chief engineer/fellow of logistics and sustainment at Lockheed Martin Corporation in Fairfax, Virginia. She has a doctorate in Systems Science and Industrial Engineering from Binghamton University. **Clement** is a materials expert and manager of strategic technology planning for missiles systems at Raytheon Company in Tucson, Arizona. She holds a Ph.D. in Materials Science Engineering from Arizona State University. Both authors are members of the Aerospace Industries Association and of America Makes, the National Additive Manufacturing Innovation Institute.



The opportunities for AM in sustainment apply not only to replacement parts production and repair but also to tools and fixtures for repairs. As such, opportunities can apply to both industry- and government-operated repair depots in the United States and abroad. The application of AM in the deployed environment also provides a unique opportunity to seek industry digital data or thread in order to secure an AM-enabled distributed supply chain solution and rapid field-delivery of components. As part of the approach for obsolescence, many industry and government depots are evaluating capabilities for scanning, redesign for AM, and fabrication in the field of parts no longer available on long-lifetime fielded systems.

Incorporation of newly designed AM-produced components into planned modifications and upgrades is an additional post-production opportunity funded by sustainment budgets. Defining and implementing the

business model and infrastructure for reimbursing the participants in the value chain for intellectual property, data as a service and actual AM of components is a current focus. There are opportunities for original equipment manufacturers and suppliers, including small business. This focus complements AIA's ongoing leadership in technical data management, industry standards and data rights as well as government and industry collaboration in Sustainment Business Model Wargames.

Current Applications/Capabilities

A look at current applications in industry of AM and supporting capabilities needs to go beyond the focus on parts. While AM with both polymers and metals provides a path from computer-aided design to finished part with minimum touch labor and time, today AM offers the capability to rapidly and affordably produce custom tooling and shop aids to improve maintenance efficiency. The photos provide examples of AM small tools citing



Left: A future leading-edge tool for a C-5 cargo plane. Right: Examples of 16 aircraft additive manufacturing tools that are up to 9-feet long when assembled.

Source: William Flite, "Large Scale Additive Manufacturing at Lockheed Martin," from briefing at the 2015 conference of Additive Manufacturing in Defense and Aerospace (AMDA), June 23, 2015. Used by permission of Lockheed Martin. These images © 2014, Lockheed Martin Corp., All Rights Reserved.

\$225,000 cost savings over conventional methods and of large tools used in sustainment. As metal AM technologies mature and become more widespread, they likely will be used to produce replacement parts for legacy aircraft even when drawings and tooling no longer exist. AM integrates seamlessly with the "Digital Thread."

Success requires a team sport. Methods require not just the actual printing of the part by one of a number of technologies. Material science is key, as well as secondary processing operations to include heat treatment and surface finishing. Non-destructive inspection (NDI) approaches are also needed to support certification and accreditation of the parts. Design practices also need to change to have maximum leverage of the technology. In sustainment, additive repair processes provide options for addition to materials to parts that may have previously been considered "consumables" as opposed to "reparables." Culture also is important across the team, including design engineering, quality and airworthiness roles. A communication challenge is presented by the fact that the term "certification" means different things to each of these organizations.

When we look for specific successes in industry, the following is a short list of examples:

- Lockheed Martin parts obsolescence solutions for legacy platforms in depot operations
- Sikorsky cold spray repair applications

- Printing of specialty tools on demand rather than storing for years or deploying more support equipment, including indirect part tooling and castings
- Raytheon field grip refit for human factors considerations and personal customization
- Elevate Systems small business design service for reverse engineering and legacy part replacement (Source: Scott Gray, "Utilizing Additive Manufacturing For the B-52 Radar Blower Assembly," National Center for Manufacturing Sciences Technology Showcase, George Mason University, Nov. 3, 2015)

One additional benefit has been the reduction in number of mechanical parts to perform a function, resulting in less time in assembly and fewer connectors.

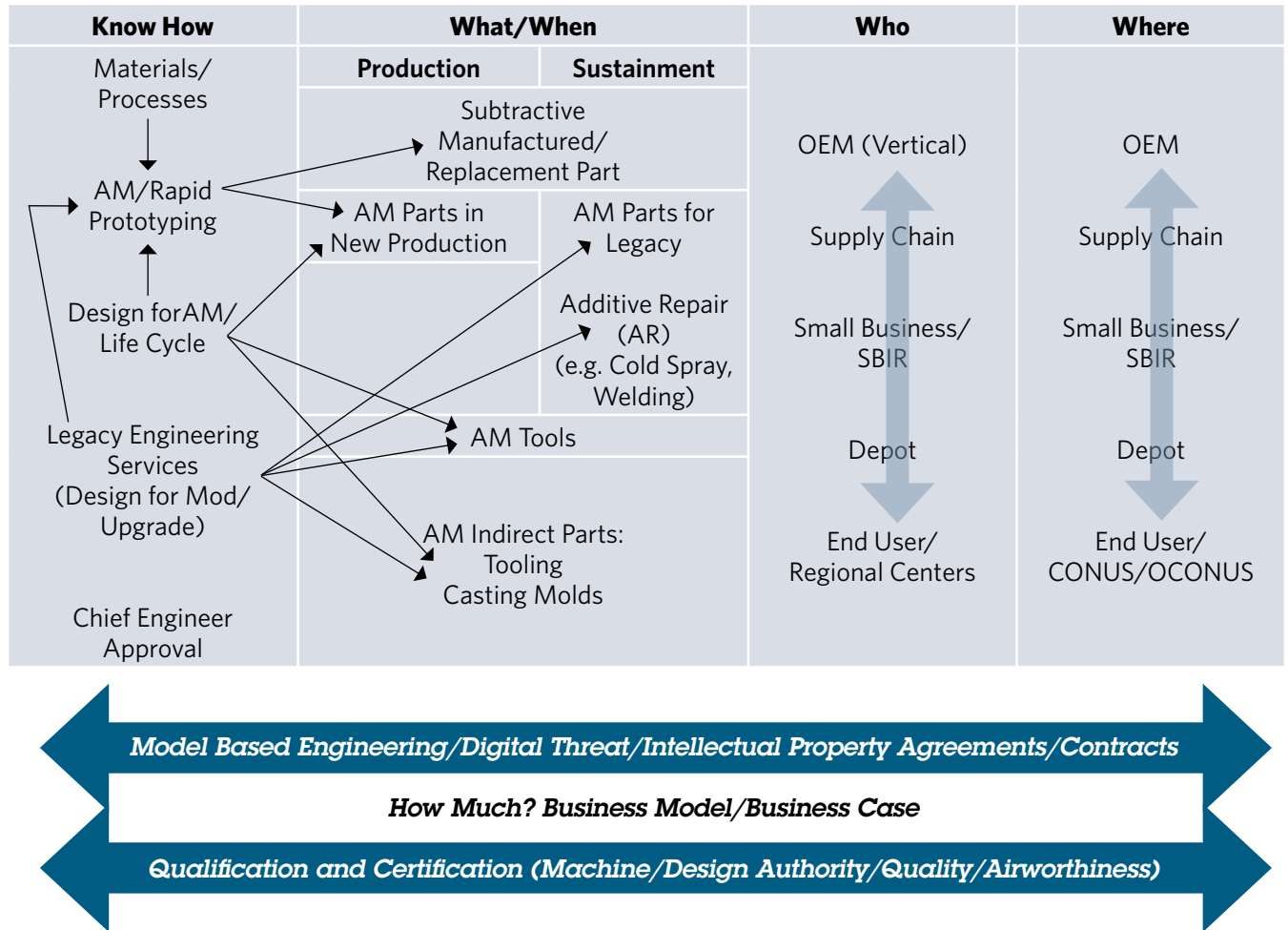
Challenges/Hurdles

Successful application of AM to sustainment requires partnership across an organization from manufacturing technology applications to the post-production stage. Putting together the solution relies on technical data management, application of industry standards for interoperability, and data rights considerations. In addition, cybersecurity risks for a distributed AM environment must be managed to safeguard the integrity of the three dimensional (3D) data inputs and the industrial control systems in the manufacturing/depot environment.

The large scale of aerospace and defense parts also provides challenges for the printing technology applied to initial structure production, as well as modifications and upgrades.

Figure 1. Additive Manufacturing for Sustainment Industry Use and Value Chain

Why? Faster, Lower Cost, Improved Readiness, Lower Inventory/Warehousing



Source: Diagram by author. Note: OEM=original equipment manufacturer; SBIR=Small Business Innovation Research; CONUS=continental United States; OCONUS=outside the continental United States.

Specific challenges surrounding adoption of AM technologies for rapid repair and rapid AM inspection continue to be a focus of America Makes projects. With three projects around rapid repair and AM inspection technologies now under way, additional work toward digital thread integration is a major focus for upcoming technology development investments. These three critical technology elements largely hinge upon the need for approved standards, schemas and protocols when creating parts through AM, with variants of these standards needed for original builds and for sustainment components. The unique needs of fielded AM repair systems make the need for rapid AM inspection and qualification a critical component in the overall life cycle's value chain, without which the customer adoption of AM for sustainment cannot be supported.

Figure 1 summarizes the multiple applications of AM to sustainment, synergy with issues for AM for new production, and management complexity of enablers of the entire process.

Considerations

AM within a maintenance and sustainment environment presents a unique opportunity for public-private partnerships across the entire aerospace and defense supply chain. Selective investments are needed in the capital and operational knowhow to maintain the industrial base in partnership with the government-run depot and deployed forces. The business model for licensing, reimbursement and liabilities for access and/or use of technical data is just one example of many business considerations that need to be addressed parallel to technology development and qualification and/or accreditation. But more important, the business case needs to support use of AM where it makes sense in terms of cost and readiness outcomes, rather than just wanting the latest and greatest technical "toys" without justification.

Art of the Possible and the Future

Dan Cernoch, chairman of the Aerospace Industries Association's Product Support Committee, provides a good

Putting together the solution relies on technical data management, application of industry standards for interoperability, and data rights considerations.

summary of the art of the possible: "Additive manufacturing is a disruptive technology that, when matured, will dramatically reshape sustainment, improving system availability and affordability through reduced cost and logistics footprint associated with distribution, stowage and management of spare part inventories. Additionally, mission readiness of needed warfighting capabilities will be improved by effectively eliminating logistics delays."

Changes are required, beginning at the university level, to prepare engineers for future industry openings. This includes design for AM as well as design for entire life-cycle sustainment. Fewer parts to remove and replace can impact life-cycle costs. Repairing parts with corrosion issues has focused on application of coatings, and welding technology has expanded the future for these industries.

The pull from the DoD customer is driving acceleration of AM adoption. This requires parallel planning for machine technology, manufacturing and sustainment processes, quality, and airworthiness to harvest the benefits and agility of these technologies while managing risk. This quickly becomes a systems issue, not just a parts challenge. The right "hybrid" blend of subtractive and additive technologies applied across parts, tools, and tooling and casting, combined with innovative qualification and certification technologies, will help move industry toward the future. However, this is not technology for the sake of technology; without a strong case and demonstrated best technology for the best value, our efforts to propel the diverse benefits of AM into our aerospace and defense industrial base cannot be supported by our government partners. &

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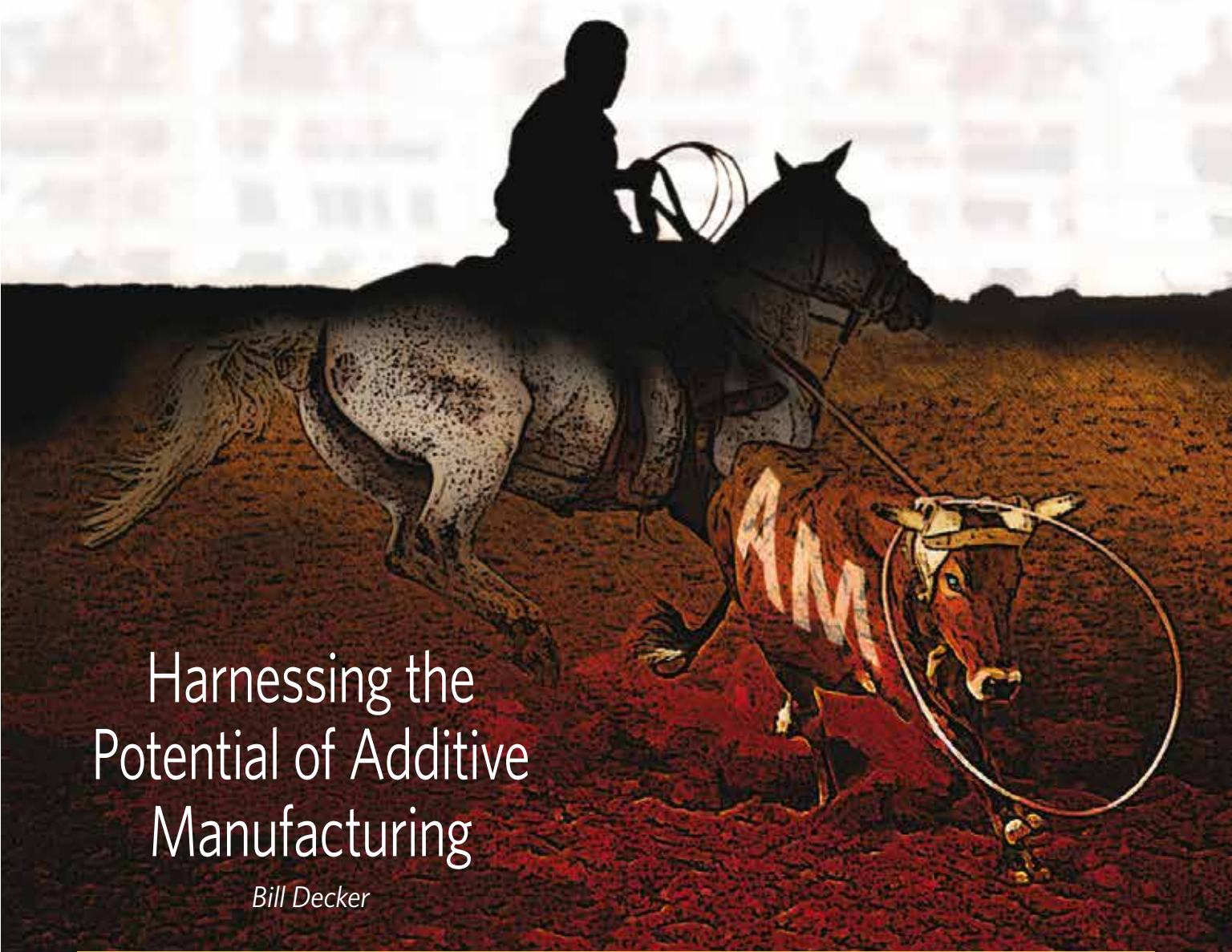
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Harnessing the Potential of Additive Manufacturing

Bill Decker

Additive manufacturing (AM) has the potential to enable the Department of Defense (DoD) to manufacture parts and components closer to the point of need, offering a huge opportunity to streamline the supply system. This could lead to the reduction, or eventual elimination of warehouses, wholesale stock, moving the point of sale from the original equipment manufacturer (OEM)/supplier to the point of use. Inventories of finished spare parts would be reduced, with commensurate reduction in facilities and staff to manage them, realizing significant savings for the DoD.

The significant challenge to the AM community is the DoD's desire to maintain competition not only on the acquisition but also on the sustainment side of what is purchased to support our warfighters. The guidance provided by our leaders is to "enable competition throughout the products' life cycle." The goal is to avoid "vendor lock"—i.e., the situation in which only one vendor can meet the requirements. This can arise when only one supplier can provide the required equipment or when technical data rights are insufficient to use another contractor.

Decker is director of Technology Transition Learning at the Center of Excellence in the Defense Acquisition University's South Region in Huntsville, Alabama.

We notice several ongoing but incomplete efforts to bring the industry from the “Wild, Wild West” of unbridled innovation into the modern manufacturing age, which is dominated by standards for materials, processes and process control.

As we look at the current state of the AM community, we notice several ongoing but incomplete efforts to bring the industry from the “Wild, Wild West” of unbridled innovation into the modern manufacturing age, which is dominated by standards for materials, processes and process control.

Conventional manufacturing is based upon a design that is documented either in a drawing or a computer-aided design (CAD) file. The manufacturing team then develops a documented public or private process for producing and replicating the part. A full performance specification for the item also is developed, along with the tests that must be passed to demonstrate the performance of the item and the repeatability of the process to produce it. A number of standards developed over the years and codified by International Standards Organization (ISO) and/or the former American Society for Test and Materials (ASTM) are used in the process, including the standard(s) for the raw material(s), process standards for each material, test standards and performance standards. Whenever possible, the standards cited are industry standards. Competitors who desire to produce the item must demonstrate that they are compliant with the design, testing, standards and meet the performance requirements. These standards enable competition in the manufacturing of spares and repairs, with multiple suppliers able to order materials from many sources and use machines from different suppliers to make an item. This approach enables the DoD to achieve its goal of competition throughout the acquisition life cycle.

When we look at additive manufacturing, we have a much different environment. To date, ASTM has only published standards for two metal materials. Summaries of the two ASTM standards:

Standard Specification for AM Production of Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion. This specification covers additively manufactured titanium-6 aluminum-4 vanadium (Ti-6Al-4V) components using full-melt powder bed fusion such as electron beam melting and laser melting. It indicates the classifications of the components, the feedstock used to manufacture Class 1, 2 and 3 components, as well as the microstructure of the components. This specification also identifies the mechanical properties, chemical composition and minimum tensile properties of the components.

Standard Specification for AM Production of Nickel Alloy.

This specification covers additively manufactured nickel alloy (UNS N07718) components using full-melt powder bed fusion such as electron beam melting and laser melting. The components produced by these processes typically are used in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification often, but not necessarily, are post processed via machining, grinding, electrical discharge machining, polishing and so forth to achieve desired surface finish and critical dimensions.

Please note a couple of things. First, these standards cover only two materials. Second, these only apply to materials processed in a full-melt powder bed fusion process. (Note: A standard also exists for a plastic material.) An additional standard exists (ISO/ASTM) for the software file format to operate the AM machines.

Let’s study the impact of this immature environment on the DoD and our policies. A hypothetical example:

An Army Program Manager (PM) for Trucks is challenged to address two requirements documented in the Capability Development Document:

1. Reduce Mean Time to Repair, which includes logistics delay time. Objective: 24 hours; Threshold: 48 hours.
2. Reduce footprint of spares by 20 percent in 2 years, 50 percent in 5 years (reduced inventory, reduced transportation, reduced management costs).

An acquisition strategy has been developed, including the following key points:

1. Implement Better Buying Power initiatives to the maximum extent possible
 - a. Maintain competition throughout the product life cycle.
 - b. Obtain technical data and technical data rights (including software) needed to support product with nongovernmental personnel.
1. The life-cycle sustainment plan must address the above requirements in all phases of acquisition.
2. Exploit new technology to provide the capability, wherever possible.


Implementing the Guidance Provided

The PM is considering using an AM process to produce the metal part of wheels) for the Army's trucks. The rationale is that wheels are large, heavy and not very sophisticated and thus are good candidates for AM. A thorough search did not find any suitable material for which an ASTM or ISO standard existed. (Neither of the above material standards is appropriate for the wheels.) The OEM produced the wheels using a stamping process, then qualified them for military use through testing and the application of current material standards. It agreed to deliver the software to enable the Army to make replacement wheels using AM, and negotiated a royalty of \$X per wheel to be paid upon production. To qualify the process, the OEM purchased raw material (metal powder) from Acme Materials and used Robots-R-Us' AM machine to make wheels for test/qualification as replacement wheels. For its machine, Robots-R-Us delivered the previously developed software that was compliant with the ASTM/ISO AM Format. The software

(He was vendor locked to Robots-R-Us and Acme!!) And the software delivered with the equipment could only be modified by government personnel. (However, it could be used, without change, by anyone.)

His boss, PM for Trucks, questioned why this could not be competed and how did the deputy PM plan to support these new AM machines? PM for Trucks, thinking he could amortize this investment across several spares, then directed the deputy to use the equipment to support the brake system, by making replacement brake calipers at the intermediate maintenance shops. On further thought, the deputy realized he now needed to direct the brake subsystem supplier, Westopem, to use Acme and Robot-R-Us, and to have more software delivered and licensed to make brake calipers.

At this point, the deputy realized that by directing the use of certain suppliers, the program would face higher costs from



If (or when) the government fully adopts the AM paradigm, OEMs will lose some or all of their operations and support revenue stream.

was delivered with Restricted Rights, as the government did not provide any funding for its development. More testing was required, as porosity was now an issue and the wheels had to be nonporous to prevent air from escaping. The wheels were approved for use on Army vehicles. Everything looked good at this point.

The Army decided to perform the production of replacement wheels at the Intermediate maintenance level (where staffing is a mix of military, government employees and third-party contractors) thus providing a responsive source for wheels, while only having to stock the raw material (metal powder). The deputy PM responsible for the replacement wheels realized he had a problem. There was only one qualified source of supply for this material (Acme) and only one machine that was qualified to produce replacement wheels (Robots-R-Us.) Furthermore, he now needed to provide the test equipment to qualify the wheels produced by machines operated by the Army, including porosity testing. The deputy PM now faced a major challenge: He had to equip all intermediate maintenance shops in the Army with tens of thousands of dollars worth of capital equipment and he only had one source of supply for the equipment and the raw material.

Westopem, as there would be no competition for several major pieces of equipment, software and raw materials. The deputy then went to the PM with the following:

Deputy PM's Summary of Problems

- Without standards for the raw material(s) required, it was nearly impossible to competitively procure the raw material to support AM, their current support concept.
- Without standards for the processes (such as the nickel standard above,) only machines from one manufacturer could be used, again eliminating competition. Although a standard exists for the software format, this is not sufficient to ensure consistent output, or enable the maintenance of the software by nongovernmental personnel.
- The lack of a method to qualify a machine so that every part did not require acceptance testing negated much of the cost saving.
- The costs of licensing and subsequent royalties are very difficult to control in a sole-source environment.

Deputy PM's Recommendations

- Encourage development of a robust set of standards for AM.

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- Work with contracting and intellectual property (IP) attorneys to develop an approach to licensing AM software and structuring royalties.
- Wait until the technology matures to plan on AM as a baseline for spare parts.
- Include, as an option, the technical data and software required to support an AM approach in the future.
- At this point, a demonstration program might be appropriate, but without the standards there is insufficient competition to keep prices reasonable. PM for Trucks may want to consider volunteering one of his intermediate maintenance sites as a demonstration site for developing and deploying AM.
- A related concern is how to motivate industry to accept this approach to life-cycle maintenance.

A quick discussion of the last point: Industry's business plans routinely count on the sales of spares, repairs and upgrades to the U.S. Government to obtain the return on investment (ROI) necessary to justify the investment for the initial contract. While there are precedents for licensing IP (patent license agreements are an example), these are commonly employed when the OEM either can't or won't make the quantity needed by the government. If (or when) the government fully adopts the AM paradigm, OEMs will lose some or all of their operations and support revenue stream. An approach is to use a licensing agreement, with a royalty paid for each component made, but this may be expensive. One of the government's needs is to ensure a viable defense industrial base. This can be done by providing opportunities backed up with policies and processes that promise attractive returns on investment and that entice our industry partners to invest in both research and development and in business development.

Summary

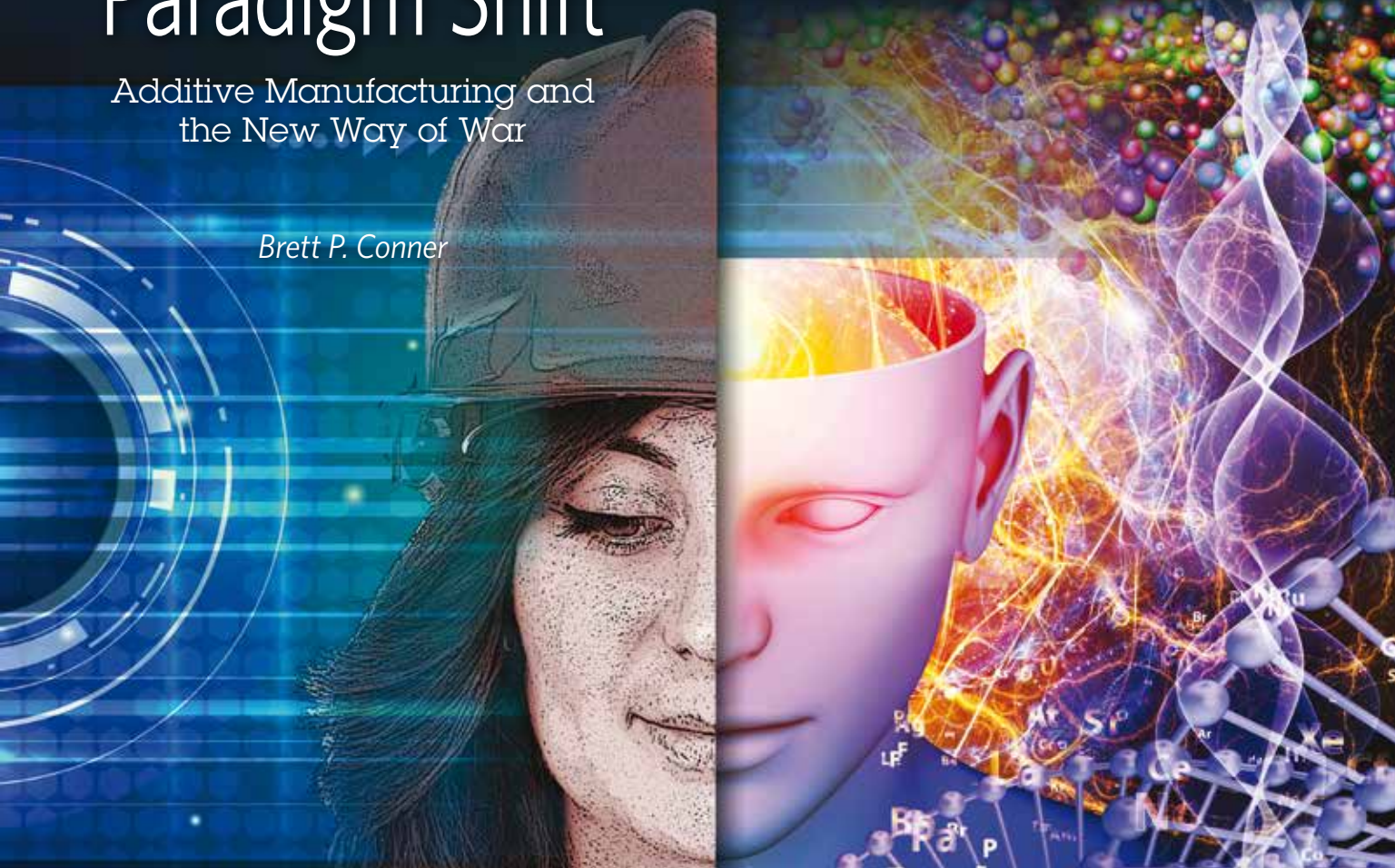
AM, as it exists today, delivers a product, and a process to replicate it by using the same materials and same material handling process at a location close to the point of consumption. The current approach is to specify a material (or materials) to be used by a specific machine to make that part and to require delivery of the computer file needed to run the machine. What has not been done is to develop the widely accepted standards for the industry, so that materials from Supplier X and from Supplier Y are totally equivalent. Widely accepted standards should also apply to the machines, for which there are many potential suppliers and no standard way to qualify them. The result is that if the DoD desires to make a part using AM, it is "vendor locked" to purchase the identical machine and identical material (from their respective vendors) and thus cannot benefit from the natural price controls that result from competition. As ISO and ASTM develop standards, different manufacturers will be able to produce the materials and machines needed to support scenarios similar to those above. IP rights issues and royalties will need to be addressed by our IP professionals, along with business models that motivate our defense industrial base. 

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Paradigm Shift

Additive Manufacturing and
the New Way of War

Brett P. Conner



The attributes of additive manufacturing (AM) enable tremendous value for the Department of Defense (DoD). In order to take advantage of those attributes, the DoD must actively pivot away from the acquisition, logistics, sustainment and contracting practices developed from more than 100 years of experiences in utilizing conventional manufacturing processes from the Industrial Revolution. To understand why, we first need to examine what the Industrial Revolution gave us.

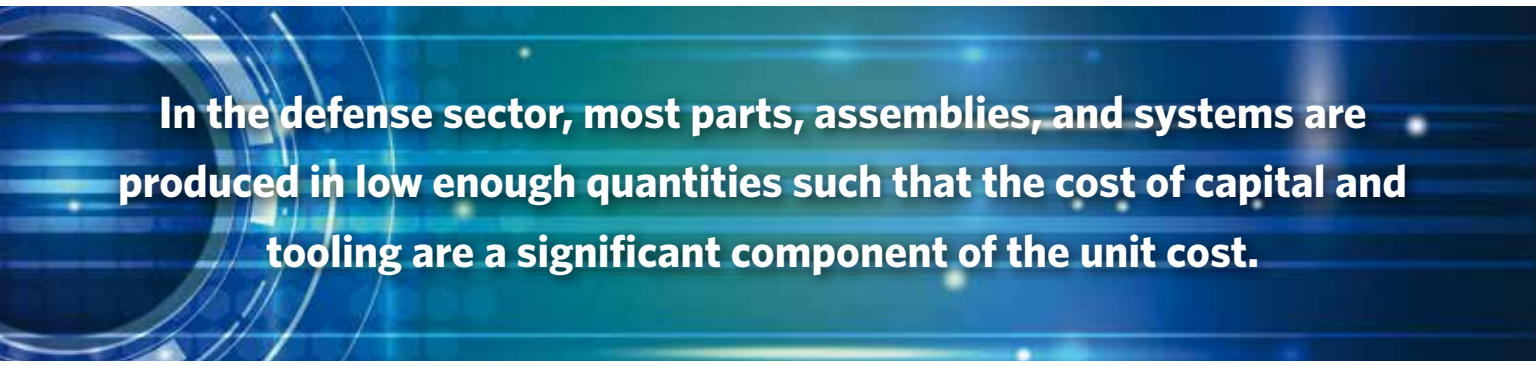
The Industrial Revolution resulted in a manufacturing framework predicated on the centralization of manufacturing in a facility called the factory. The factory is located ideally where desired labor skill can be found at reasonable cost, where energy and material costs are low and where transportation is available nearby. Inside the factory, the manufacturer will invest tens of millions of dollars to obtain specialized equipment. This equipment will use tooling to shape or assemble input material into a product. This tooling can cost tens of thousands or hundreds of thousands of dollars (or more) and take weeks or months to produce resulting in significant lead times. At times, the lengthy contracting process can be overlooked as the long lead times associated with tooling dominate production schedules.

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In the civilian commercial sector, mass manufacturing permits the cost of tooling and specialized manufacturing equipment to be amortized over the unit costs of hundreds of thousands or millions of an individual part or product. In the defense sector, most parts, assemblies and systems are produced in low enough quantities such that the cost of capital and tooling are a significant component of the unit cost. Design functionality is sacrificed to keep costs low: Simple parts are easier to make. Once a product design has been selected and tooling has been obtained, a change in design becomes too expensive to consider. As a result, customization is rare, and standardization is, well, standard.

plastic printed parts is generally quick and simple. With AM, there is no waiting weeks or months for tooling to get into place before production starts.

The limitations of existing tooling or subtractive machining on part shape or functionality can be lifted. As a result, part weights can be reduced, assemblies can be consolidated into single parts, functionality can be increased. The GE Aviation fuel nozzles produced for the LEAP commercial aircraft engine are examples where all of these benefits of design freedom are realized. The original fuel nozzle design contained 18 parts joined together by brazing. The new design enabled by AM



In the defense sector, most parts, assemblies, and systems are produced in low enough quantities such that the cost of capital and tooling are a significant component of the unit cost.

Once production starts, a typical approach is to fabricate sufficient quantities of parts for the production run of the weapon system as well as an additional quantity to satisfy a requirement for spare parts. This leads to a warehousing cost associated with storage of those spare parts. Both the factory and the warehouse for spare parts usually are distant from the war. Therefore, the “Iron Mountain” of spare parts must be moved into theater at the start of an operation, replenished during the duration of the operation, and returned to the warehouse at the end of operation.

Pivoting to AM’s New Paradigm

Contrast conventional manufacturing with AM. To start production, AM does not require the tooling, fixtures or jigs typically associated with conventional manufacturing. All that is needed is a three-dimensional (3D) digital solid model that can be converted into a 3D printable file format such as .STL or .3MF. Computer-aided drawing (CAD) is used to create the file. However, 3D scanning can be used to reverse engineer an existing part. Regardless of how it is obtained, the part file then is provided to a 3D printer’s processing software where the user orients the part and chooses the location to print the file within the 3D printer’s build envelope. That processing software slices the file into layers and then creates machine code that tells the printer where to deposit or fuse material. It also identifies locations to add support material if required. The machine code creation typically takes minutes. Machine code is then provided to the 3D printer. Depending on the size of the part and the 3D printing system being used, the printing process can take minutes to tens of hours. While metal AM post-processing (i.e., support removal and surface enhancement machining) can take a long time, post-processing for

metal printing is a single piece. The new nozzle is 25 percent lighter and has a novel, complex design containing intricate cooling channels that improve efficiency and performance. The AM fuel nozzle is also 5 times more durable than the conventionally manufactured nozzle. Consider the total life-cycle costs and benefits of having a lightweight, single-piece, more durable and more fuel-efficient part.

If the best approach to make a part involves conventional manufacturing such as sheet metal forming, plastic injection molding, metal casting, composite layup or other processes, then AM can make the tooling itself. Humtown Products of Columbiana, Ohio, recently demonstrated the use of 3D sand printing to make a very complex cast aluminum manifold. The 3D sand printing was used to make the molds and cores used to make the cavity to form the molten metal into the manifold. Using conventional processes to make metal casting tooling would have taken at least 10 weeks to design the tooling, fabricate the tooling, create the molds and cores and then cast the part. Using 3D sand printing, the entire job took 12 days and saved \$14,000 in nonrecurring engineering costs.

Whether it is tooling-less production or rapid low-cost tooling, AM takes away the cost and time barriers to custom production. At Youngstown State University, a group of mechanical engineering students recently created a 3D printed cast for a dog with a deformed leg. Working with a local veterinarian, the students 3D scanned a mold of the dog’s leg, designed a lightweight and flexible 3D printed cast, and worked in Cleveland, Ohio, with the firm of rp+m, which used a specialized printer to fabricate the new cast. Military members can benefit (and are likely benefiting today) from custom production of

medical casts, splints, prosthesis and implants. For the warfighter, custom wearable items such as blast-resistant helmets are certainly within the realm of the possible. And instead of completely standardized parts on platforms, mission tailorable 3D printed solutions can now be considered.

Instead of being half a globe away from the fight, the factory can now be moved to the point of need. Several AM polymer technologies such as material extrusion 3D printers are quite mobile. Such 3D printers were deployed as part of Rapid Equipping Force Expeditionary Labs (Ex Labs) supporting soldiers with rapid fabrication solutions. Other material extrusion 3D printers have been sent to sea including a recent deployment on the aircraft carrier USS *Harry Truman* (CVN-75). Even NASA has used polymer material extrusion 3D printers on orbit aboard the International Space Station. Metal AM technologies are not yet as mobile, but we should expect such systems in the near future. Instead of moving the Iron Mountain of spare parts, the focus shifts to moving raw materials and data into theater.

Enabling the Paradigm Shift

What could the DoD do to take advantage of AM? We can start the discussion with the need for a DoD strategy and vision for the implementation of AM. Stakeholders within the Office of the Secretary of Defense, the Joint Staff and the Services can examine models, regulations and practices relevant to the use of AM in support of acquisition, maintenance and sustainment, and logistics. From a technology standpoint, America Makes and its technology roadmap partnership with DoD can help identify many of the critical gaps common across all Services.


There is also need to encourage joint collaboration where applicable. The Services should continue to develop and implement their own strategies and visions that are relevant to their roles and missions. But there are areas that should be approached from a joint perspective. For example, joint certification processes could speed implementation of AM parts for aerospace applications. Perhaps inter-Service exchanges of engineers responsible for certification could help Services understand each other's processes and facilitate a common certification. The formation of joint AM communities of practice and sponsorship of user group meetings would allow crossflow of ideas.

As noted earlier, AM within the supply chain can happen faster than the speed of contracting. The DoD needs to develop agile contracting methods to ensure spare parts and 3D printing services can be rapidly obtained. For spare parts obtained through the supply chain, these contracting approaches can also incentivize the use of AM for tooling as well as for direct part production. General Services Administration Schedule 36 can be a starting place. For new weapon systems, the use of AM can be encouraged in the contracting process. There should be great thought as to how digital technical data packages (TDPs) can be included in the contracts for lifetime

weapon system sustainment. If the DoD chooses to produce AM spare parts organically at depots or at forward locations, new business models need to be developed that would provide a win-win for both industry and government. A starting point could be the findings and recommendations from a recent working group event sponsored by America Makes and Deloitte that examined the effect of AM on business models for maintenance and sustainment.

The DoD also should foster cultural changes to adopt AM and other digital manufacturing technologies. The workforce development for the AM cultural evolution will involve hands-on experience with AM equipment. At the grassroots level, the proliferation of makerspaces or fablabs should be encouraged at DoD installations globally. DoD makerspaces should target all communities that can take advantage of the technology: maintainers, logisticians, technicians, engineers, contract specialists, program managers and even operators. No amount of computer based training, PowerPoint presentations, and white papers will convey the digital thread, design freedom, customization and creativity needed to maximize the potential of this technology.

3D printing lifts people out of their cultural and organizational enclaves. Because of the "democratization" of making enabled by 3D printing, here at YSU we started a program called Launch Lab that brings together faculty and students from business, arts and the "STEM" fields of science, technology, engineering and mathematics. Collaborative problem-solving yields creative solutions for community services, theater productions, art displays, SAE Baja racing cars, local industry challenges, and business startups. What does this mean for the DoD? AM will not stay in the domain of the engineers and technicians. In fact, the DoD should also examine the operational impacts of having rapid manufacturing colocated with the warfighter. There is a rich history of soldiers, sailors, Marines and airmen making creative solutions on the battlefield. Digital manufacturing will move this beyond duct tape, bailing wire and bubble gum. There is likely a need for joint experimentation exercises and battlelab-type activities to bring together the technologists and the operators.

Moving forward, the DoD can consider these and other approaches to the implementation of AM. The payoff is that AM offers an opportunity for the DoD to move from the speed of conventional manufacturing to the speed of war. Air Force Col. John Boyd created the Observe-Orient-Decide-Act (OODA) loop model stressing the importance of rapid, accurate decision making and action. AM can enhance the DoD's ability to get inside of an adversary's OODA loop through rapid design and manufacturing. We need to do this; enable this capability now before our adversaries do, as they might not be constrained by bureaucratic processes created since the days of the original Industrial Revolution. 

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Metals Additive Manufacturing

Great Promise in Mitigating Shortages but Some Risks Remain

Drew Miller ■ Ed Morris ■ Greg Colvin

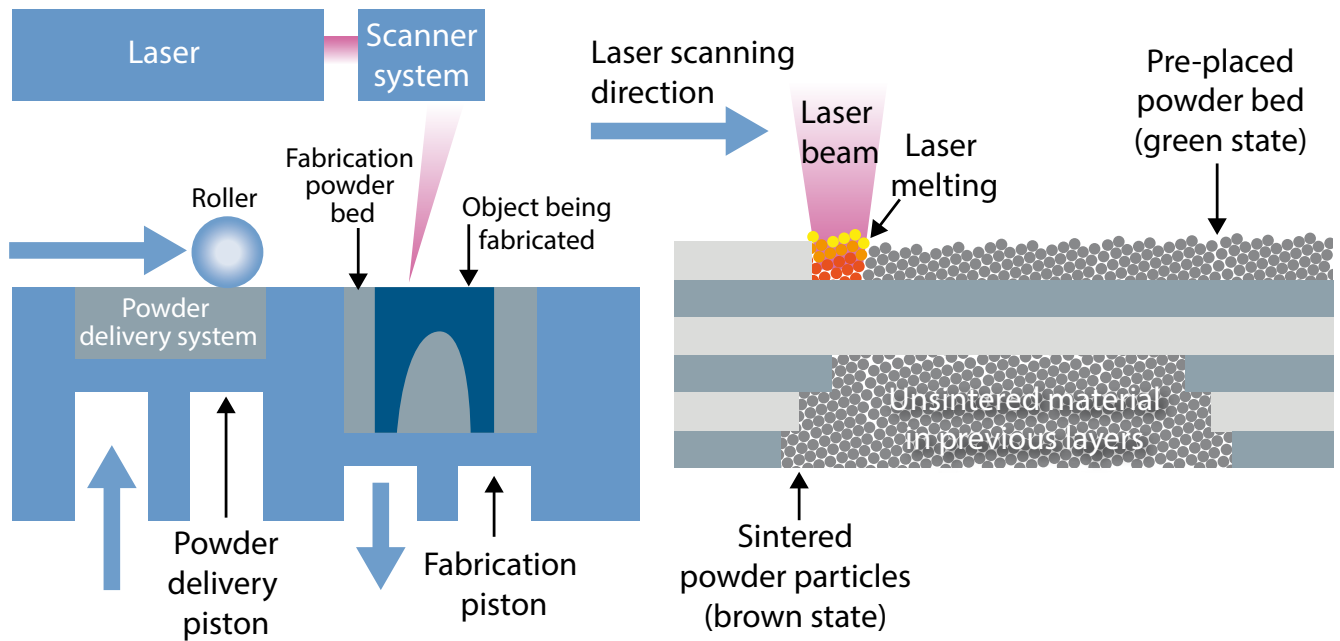
Additive manufacturing (AM) is revolutionizing the way parts are designed and manufactured, shrinking development and delivery cycle times, and yielding improved performance at a lower cost per part.

Shapes previously not possible and that have tailored properties and material compositions, can be produced on demand for specific military devices and platforms. AM's potential to provide real-time rapid response support to the warfighter may be unparalleled in our time relative to conventional manufacturing methods.

But while AM can help deal with Diminishing Manufacturing Sources and Material Shortages (DMSMS) problems, many experts interviewed for a recent report on research and development (R&D) advances impacting DMSMS warned that "AM is highly overrated." It is limited in what it can offer and poses some risks for obsolescence management. As we leverage the growth of this new technol-

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Figure 1. The Powder Bed Metal Fusion Additive Manufacturing Process



ogy, it will be critical for the Department of Defense (DoD) acquisition and sustainment practitioners to understand its benefits but also risks, challenges and maturity level as they consider AM for solving DMSMS challenges.

The DoD has been an active partner with the industrial base supporting AM through initiatives such as establishing “America Makes”—the National Additive Manufacturing Innovation Institute—and funding some AM-related Manufacturing Technology (ManTech) programs. Many of the DoD efforts in AM have concentrated on tooling and newly designed never before produced complex parts. However, due to its versatility and rapid response, AM may be uniquely suited in supporting sustainment requirements especially for DMSMS situations.

One AM technology of interest is using metal powder to create a part. Generally speaking, “Powder Bed Metal Fusion” AM processes are a “mini-melt” welding approach during which a computer-controlled laser or electron beam is moved over a bed of powder, fusing or sintering the powder selectively to make a part. As illustrated in Figure 1, after each pass, a new layer of powder is laid down using a recoater blade and the process continues until thousands of layers have been sintered to make the desired configuration. The resultant parts, although quite detailed in geometric complexity, still require secondary processing to be suitable for mechanical system application.

AM Challenges and Applications

As noted in a 2015 Government Accountability Office report, a “key challenge” to the DoD community for AM is “ensuring that manufacturers can repeatedly make the same part

and meet precision and consistent performance standards.” For quality comparison purposes, forging, rolling and traditional metal manufacturing and processing yield consistent, well-characterized properties and predictable processing responses.

The characterization and understanding of the materials properties for AM-produced components is at the very beginning stages. So far, AM-produced metals have had surprisingly strong mechanical properties yet their behaviors do not fit traditional metal processing behaviors. This is a serious constraint for DoD where repeatable strength, weight and highly reliable quality are critical. Experts estimate it may take a decade to achieve confidence and certification for some AM metal applications.

Because of the tremendous variation possible in AM metal fabrication which in effect involves thousands of “mini melt pools” in a single part, there is a larger potential for variability and property problems, especially if real-time in-situ process controls are not employed. For example, when industry develops a new alloy, even for well-proven traditional production processes, it can take more than 5 years and several million dollars to qualify the alloy. Metal AM with more variability and less experience likely will take longer.

Significant government-sponsored efforts have supported the AM community in developing consistent repeatable manufacturing processes. As an example, the National Institute of Science and Technology (NIST) is funding research to provide quality assurance of AM parts. The DoD Metals Additive Manufacturing Qualification and Certification Working Group

is developing standards and processes for material, process and product qualifications for AM.

AM is used for both metal and polymer parts. AM with polymers involves lower-risk applications and benefits from ongoing advances in polymers, so there are generally fewer problems with variances in material properties and greater near-term potential for DMSMS applications where the structural strength of a metal is not required.

The need to certify AM applications poses less challenges for tooling and prototype and development hardware applications. For replacing obsolete parts, polymer and metal AM has been estimated to be feasible for 5 to 10 percent of demand within the next 10 years. AM is an especially good means for making low-quantity, complex metal castings (with the caveat of unsmooth surface issues in some applications), such as the one shown in the photograph. The Agile Manufacturing Center for Casting Technologies at the Naval Undersea Warfare Center (NUWC) Keyport in Washington state can make castings faster and cheaper with AM. They can often be made better as well, though there are size limits with current AM machines. AM currently best fits very low volume production—such as replacing a few obsolescent parts or castings and building prototypes. In addition, AM is used to create special tooling in lieu of machining and assembly; AM also eliminates the need for storage. In all of these AM applications, NUWC Keyport has achieved order of magnitude improvements in cost and schedule.

Similar successes were obtained by the America Makes-funded project led by the Youngstown Business Incubator (YBI) that focused on accelerating the adoption of AM in the U.S. foundry industry. YBI assembled a large project team consisting of the American Foundry Society, Northern Iowa University, ExOne, Caterpillar, Humtown Products, Trumbull, XL Pattern Shop, Danko Arlington, Hoosier Pattern Inc., REFCOTEC Inc., and Product Development Analysis, and it produced the following equally large results:

- Reduced cost of materials for printed sand molds and cores by more than 80 percent.
- Increased speed to market: 3 weeks versus 12 or more weeks.
- Increased affordable quantities for three-dimensional (3D) sand printing of simple castings by 50 percent.
- Enabled part optimization for improved performance.

Significant workforce training now is under way to spread the project findings across the U.S. foundry industry.

AM to date has been particularly successful in commercial industry for General Electric’s jet engine fuel nozzle where a high-value, sophisticated component lends itself to combining multiple components and eliminating joints and cost. While subject to high heat stress, it has relatively little physical stress and, therefore, few certification requirements. Where a single metal AM-produced part can replace multiple complex parts, it can be economical for high-volume production to supply low physical stress situations. GE Aviation plans to produce more than 100,000 AM-produced fuel nozzles by the year 2020 for its LEAP engine.

Some AM advocates have suggested deliberately abandoning large production runs and stockpiled inventories. The Defense Logistics Agency (DLA) lists AM as a priority in its R&D Strategic Directive. In a 2015 slide presentation, 3D printing is featured with the notation, “Store data, not parts.” In the long term, we may be able to reduce spare part production and inventory as an effective solution for DMSMS and life-cycle cost effectiveness. This will not be feasible in the near term for it will still be cheaper to mass produce and store inventories of the vast majority of parts through traditional manufacturing. Furthermore, because AM technology evolves very rapidly, technical data formats change as well. This potentially means the technical data will be unusable if not properly maintained and updated.

There is a risk that many programs may decide not to mass produce backup parts in favor of easily printing them later to save money up front on new systems. This approach for spares is only practical if the original part is made using AM.



A sample 3D printed sand mold and the resulting cast part from America Makes project led by the Youngstown Business Incubator.

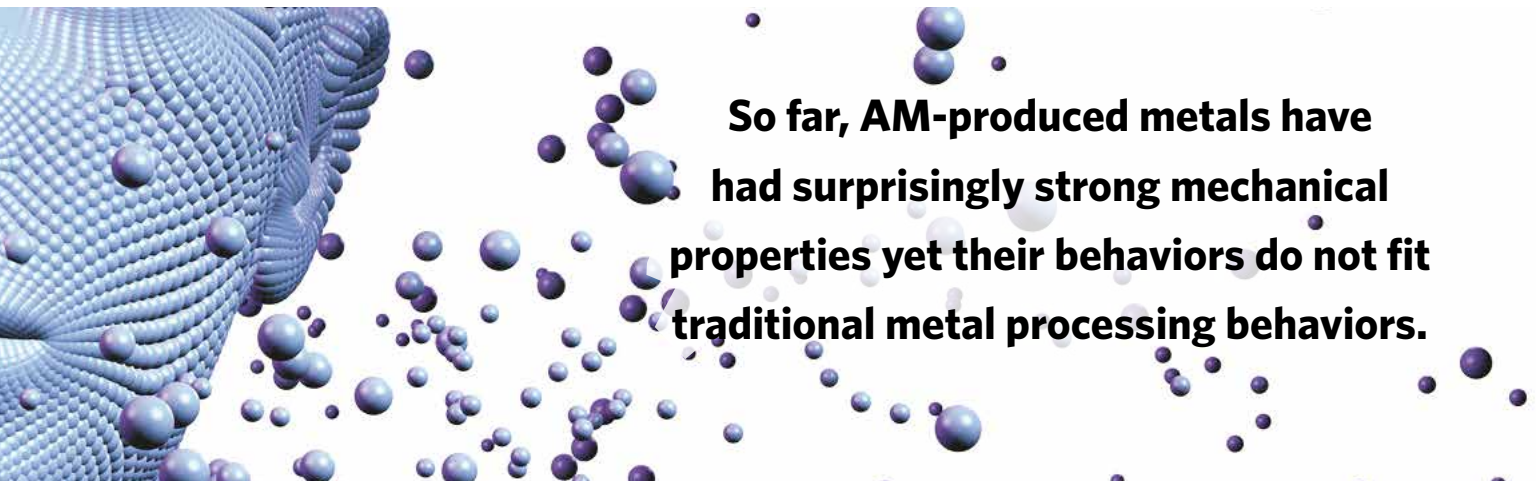
Photo courtesy of The ExOne Company

Otherwise, the temptation for program managers to cut spares for traditionally manufactured parts will generate downstream life-cycle cost problems for sustainment, especially if the cost savings of traditional mass production of spares during production are significant and re-engineering and qualification testing are required for the AM-produced spare part.

Another risk is that AM for DMSMS may increase the risk of encountering counterfeit problems. The fact that an AM metal or polymer part may look the same, but have far different properties and potentially much lower strength and durability may yield another big realm for dangerous counterfeit parts. They may contain cheap internal material, with the proper material

scrapped due to inactivity or the manufacturer is no longer in business. Replacement of casting and/or forging tooling often requires months and significant upfront investment. AM provides unique value via its rapid response, geometric flexibility and lack of specialized tooling relative to other typical manufacturing options. For example, the AV-8B Hard Landing and Repair C-Channel Brackets repair was done in 1 week with 3D solid computer-aided design modeling and AM.

A third common DMSMS scenario occurs when required delivery schedules are unachievable using conventional manufacturing. Unachievable schedule requirements to produce and deliver products are a common cause of no-bids from



So far, AM-produced metals have had surprisingly strong mechanical properties yet their behaviors do not fit traditional metal processing behaviors.

just a coating, or there may be voids and defects. The low investment requirement for AM production versus traditional metal manufacturing also means it is cheaper and easier for counterfeiters to become involved. DoD production of fewer spares in favor of later AM production of replacement parts also would increase the risk that we will be offered counterfeit or substandard parts.

DMSMS Scenarios for AM

DoD acquisition and sustainment practitioners have successfully leveraged AM as a viable option for solving DMSMS obsolescence issues.

One common root cause for DMSMS is a low purchased part count relative to normal conventional manufacturing quantities. Conventional manufacturing processes such as casting and forging are designed to produce large numbers of parts. When the DoD requires smaller quantities (e.g., fewer than 100) the nonrecurring engineering expense of starting up a casting or forging process is often significant, driving up the part's unit price. AM is particularly suited to these situations as one of its core competencies is its ability to make parts without dedicated direct-to-shape tooling.

Another frequent DMSMS scenario is when the original production tooling is no longer available. This situation may arise because the tool wore out during normal production, was

vendors. AM's rapid response capabilities are unparalleled in other manufacturing processes. For example, the Navy recently needed a circuit card clip for the J-6000 Tactical Support System Servers that is installed onboard Los Angeles-class nuclear submarines and Ohio-class nuclear-powered guided-missile submarines. Learning that the clip is no longer produced by its original manufacturer—NUWC—Keyport used AM to create a supply of replacement parts to keep the Fleet ready.

AM Readiness for Shortage Management

What is the "state of the art" regarding AM? Note that this discussion lumps together all metals AM such as Selective Laser Melting, Laser Cutting, Direct Metal Laser Sintering and Electron Beam Melting (EBM) and collectively refers to them as "Powder Bed Metal Fusion."


When considering AM for potential sustainment and DMSMS opportunities, the availability of the AM raw materials is important. Powder for AM currently is available in a few standard alloys such as titanium (Ti-6Al-4V), Nickel Superalloy (IN718), and stainless steel (304). There are a number of common casting, forging and extrusion and plate stock alloys not available in powder forms suitable or proven for use with AM. As an example, powder feedstock for very common aluminum alloys such as 6061 are not yet proven for either raw material supply or AM Metal Powder Bed Fusion processes. In summary, those

considering AM should start with asking the question, “Is the metal we want to make the parts from available in AM?”

Next the practitioner must determine if their particular alloy has been developed and characterized for AM. Note that significant work has been sponsored by the DoD and commercial industry to develop AM processes for several important materials used in military applications, including nickel based alloys IN718, iron-based 304 stainless steels and 17-4ph stainless steel. However, AM processes have not been developed for many common casting and forging alloys. Those considering AM as a DMSMS solution must determine if AM processes have been developed for that specific alloy.

Assuming these first two criteria have been met, the practitioner next must determine if AM can produce the shape required. One of AM’s “best in class” attributes is its geometric capabilities. AM has unparalleled abilities to produce a custom product, with complex internal shapes not producible via traditional, subtractive processes. There are limitations however, such as size. Currently “Metal Powder Bed Fusion” has a maximum commercially available machine size—a 15-inch cube. A larger part would require manufacturing individual sections joined together using a process such as brazing or welding—or changing to an alternate AM process that can accommodate larger metal parts.

Another question is affordability. The AM process cost depends on parameters too numerous to illuminate fully in this article. One significant cost driver is the required quantity of parts. Lower output numbers favor AM as the process does not demand the upfront investment in tooling and engineering relative to traditional metals manufacturing processes. Conversely, larger part quantities tend to favor traditional manufacturing processes. Other critical cost factors are part material type and the final part weight versus the raw material required—both factor into the yield calculation (weight of produced parts versus overall material usage). A third factor is part shape. The greater the number of parts that can be built at once through AM, the less expensive the per-part cost. If the part is shaped and sized in such a manner that multiple parts can be fit into a single build then the per-piece price is reduced. DLA projected cost savings of 33 percent to 50 percent for AM casting of core tooling of airfoils (blades and vanes).

Properly managed, AM will play an increasingly important role in DMSMS resolutions. The risks of AM, including new counterfeit threats, especially for metal, need to be anticipated and mitigated. The quality control and certification problems with metal AM must be resolved. AM should not be used as an excuse to avoid upfront large spares purchases or life-of-need buys unless the original part already is additively manufactured. 

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SECTION 3685, TITLE 39, U.S.C. SHOWING OWNERSHIP, MANAGEMENT, AND CIRCULATION

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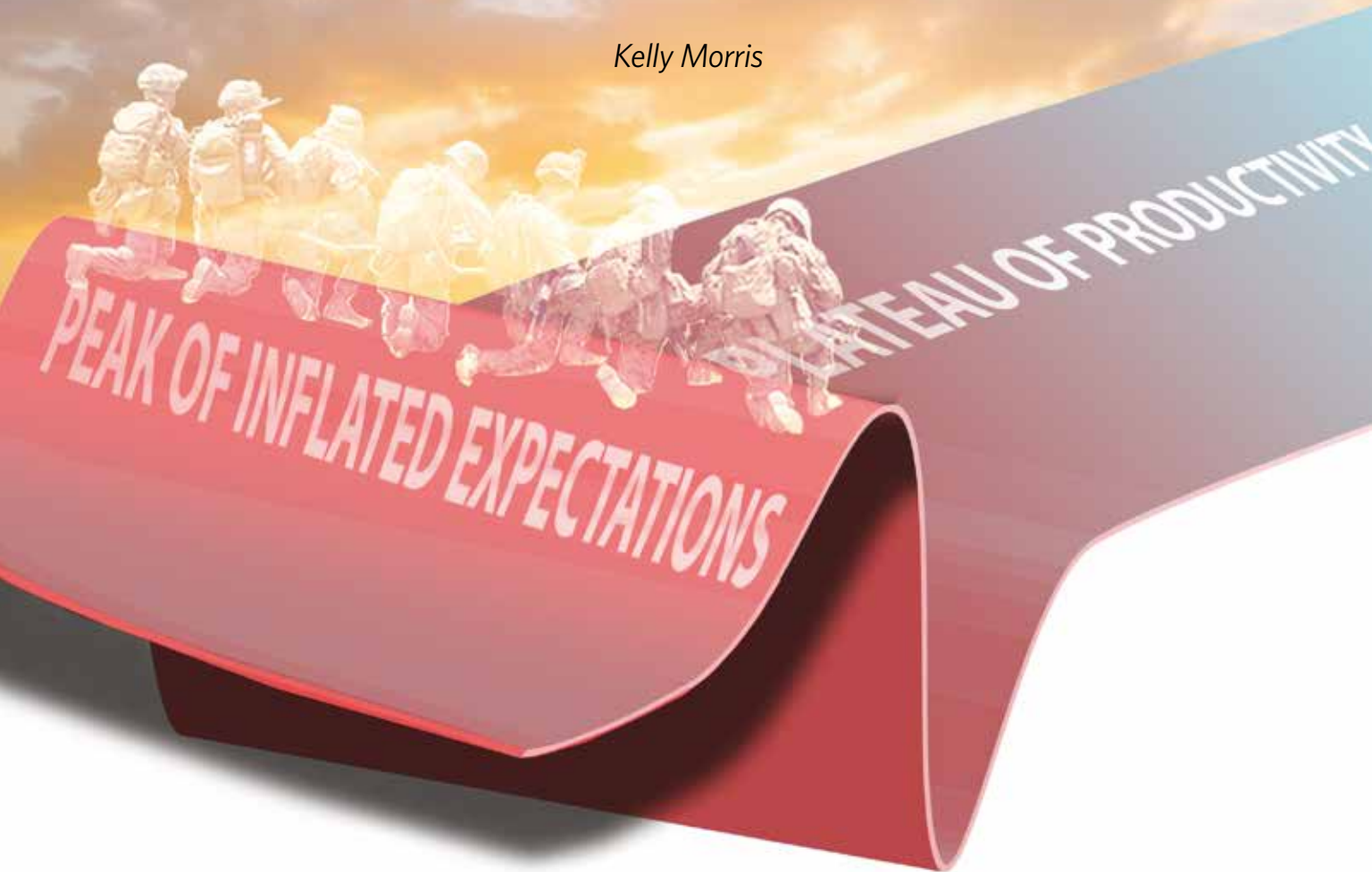
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Driving **Innovation** to Support the Warfighter

Additive Manufacturing Initiatives Within the Defense Logistics Agency

Kelly Morris

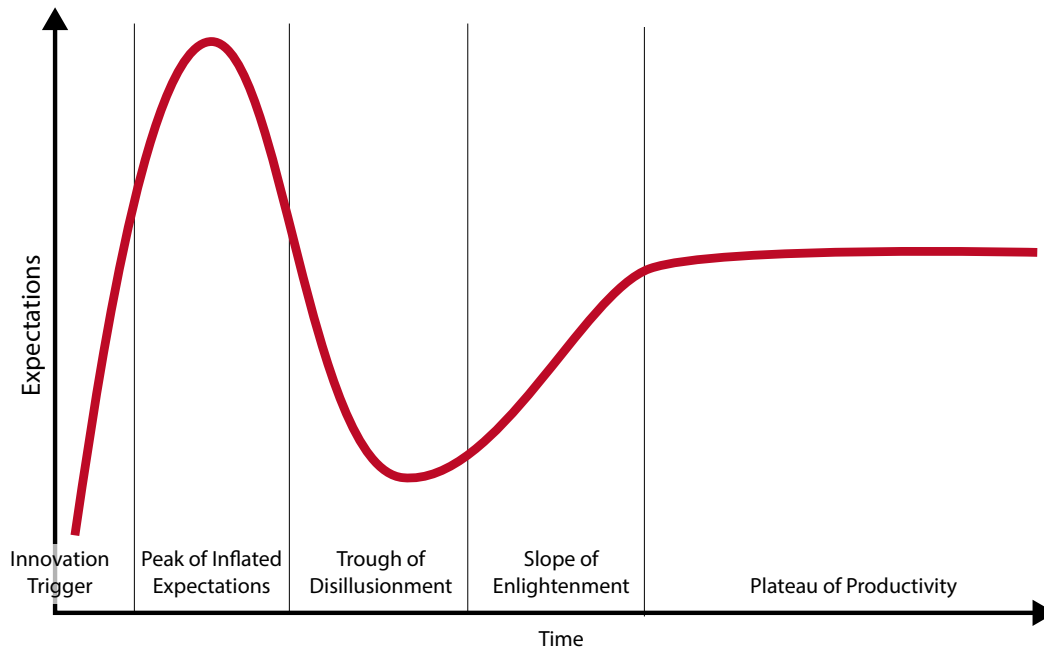


The spotlight is on for additive manufacturing (AM) in the commercial sector, but it is also intense for the Defense Logistics Agency (DLA), which hopes to capitalize on the promise of innovation to improve readiness and support to the military. As it tracks AM through the Gartner Hype Cycle, which depicts phases that innovations move through from the initial “Innovation Trigger” through the “Plateau of Productivity,” is DLA headed down the “trough of disillusionment” or up the “slope of enlightenment” to a “productive plateau” for AM investments? (See Figure 1.) The productive plateau is where mainstream adoption starts to take off. Criteria for assessing provider viability are more clearly defined and the technology’s broad market applicability and relevance are clearly paying off.

Morris is chief of research and development for the Defense Logistics Agency at Fort Belvoir, Virginia. She has a Master’s Degree in National Resource Strategy from the Industrial College of the Armed Forces in Washington, D.C.

Figure 1. Gartner's Hype Cycle

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to bulk petroleum, the DLA provides items and logistics support in peacetime and wartime. The mission to provide Class IX spare parts for aviation, maritime and land combat systems is perhaps, the most challenging, especially when weapon systems have been called to serve much longer than originally planned. Spare parts often are hard to procure, have long lead times, are frequently back ordered, and finally become obsolete and nonprocureable. Regardless, the items are still needed to keep the weapons systems in combat mode.

One of the DLA's roles is to provide Class IX spare parts to maintain Department of Defense (DoD) weapons systems. However, this is not as easy as it might seem. Parts may become hard to source because they become obsolete or have long lead times. They may also be back ordered because of diminishing sources or because contractors do not bid on producing them. The Research and Development (R&D) team in DLA Logistics Operations has worked with industry to build a prototypical tool that filters on critical logistics and technical parameters to identify target problem parts for AM. The DLA has also partnered with the Navy and industry to further identify hard-to-source parts and build the respective three-dimensional (3D) technical data packages (TDPs) and AM plans. The DLA is tackling the tough issues to move AM into the realm of the possible. The agency is investigating storage and protection of 3D model diagrams, qualification and certification of AM-produced parts, supplier qualifications and integration of the AM procurable parts into the supply chain to support the military. The DLA's integrative role in the supply chain allows it to leverage its procurement and distribution capabilities to capitalize on the potential new efficiencies of AM.

Background

The DLA is a combat support agency within the DoD. In 2015, the DLA had \$38 billion in sales to military and federal civilian customers; the agency supports 24 distributions centers worldwide and operates in almost all 50 states. Its mission is expansive. The DLA supports every aspect of the supply chain, including distribution and disposition. It is responsible for nine different supply chains covering six classes of supply to support the warfighter. From troop support items such as uniforms, rations, medical supplies and special equipment

Research Efforts and Reality Check

AM or 3D printing may well be the solution to the hard-to-source parts issue. The DLA first started a partnership with Naval Air Systems Command (NAVAIR) and Naval Sea Systems Command (NAVSEA). Both organizations have parts that are hard to source and are looking to AM as a solution. In December 2014, the DLA and NAVAIR conducted their first demonstration to identify and make two parts in 4 weeks. The two parts, a bracket and an insulator plate, were both made of polymers. Working with DLA Aviation, NAVAIR reverse engineered the parts, developed the TDP for the parts using an AM methodology, then built, qualified and tested the repeatability of the process using its warfare centers.

With the process in place, the next step was to really buckle down and identify parts that were in the hard-to-source category. Another effort, this time through a contract with LMI Research Institute, was established to develop a prototype tool to aid in identifying those parts. LMI developed a database-like tool that would sort through the hundreds of thousands of DLA-managed national stock numbers. From these, LMI filtered on physical attributes (materials and dimensions) and logistics attributes (availability of TDPs, days on back order, production lead times, demand, criticality, etc.). The logistics and physical attributes of the parts were then compared to technical attributes such as AM machines and materials that were obtained through a commercial open source available from Senvol. The resulting list of parts would be candidates for AM usage, with an emphasis on hard-to-source parts. The list included not only polymeric parts, but also metallic and flight critical parts.

Another R&D contract was awarded to Alion Science to capture the state of the art in the manufacturing industry and gather lessons learned for DLA. Industry feedback from an Alion survey indicated that AM still was an immature manufacturing method. Few standards in the industry exist—cost and time to manufacture vary from machine to machine; machines use stereolithography (STL) files, but companies prefer native computer-aided design (CAD) files or Standard for the Exchange of Product Data (STEP) files to share 3D models between users with different CAD systems. Companies generally are performing visual inspections and not materials testing. While these issues may not be problematic for tooling or quick fixes in industry, they are huge when it comes to making spare parts for a DoD weapon system, especially critical safety items.

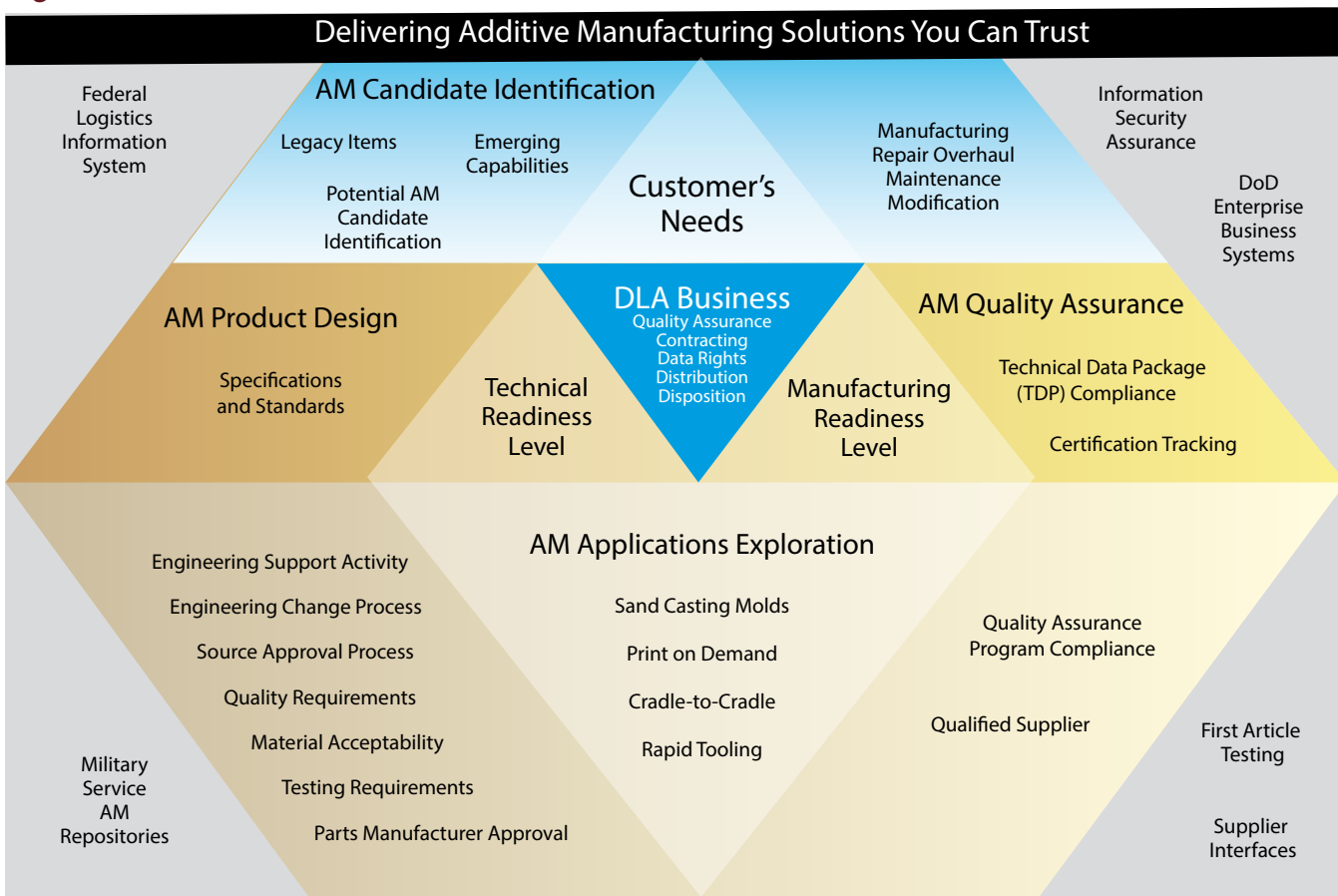
Alion was asked to collect manufacturing capabilities and survey the industry to determine market forces and establish a vendor list that the DLA could rely on for hard-to-source spare parts made by using AM. Alion also tested if the Navy's process could be replicated. Using the 3D models and TDPs built by the Navy for the bracket and insulator clip, Alion sourced the requirements to industry to test the repeatability of the process to build the parts via AM. Many vendors declined to participate. Those vendors who did participate were not fa-

miliar with the Acrobat 3D Portable Data File (PDF) provided by the Navy. They preferred STEP files and drawings. For both parts, thickness and open porosity varied from the specification. None of the openings were in tolerance for the insulator plate, and the dielectric strength was significantly lower than specified. The results seemed to show that AM was sliding down the "trough of disillusionment."

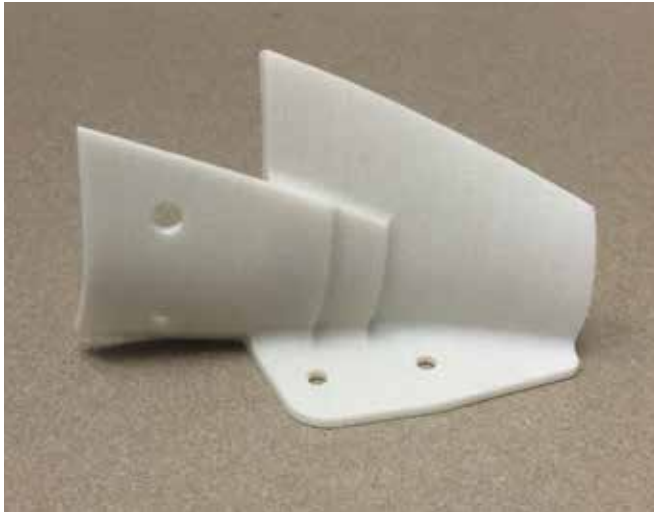
Subsequently, DLA contracted 2Is Inc., a small business out of Boston, to work on the AM production of hard-to-source parts. The people at 2Is Inc. used their own data to identify six hard-to-source parts, included one metal part as well as a critical safety item that would be manufactured by AM. One part on the list was the Navy's Leading Edge Root Extension (LERX) for the Harrier AV-8B. This part is really hard to source or repair for the Navy. Contractor 2Is Inc. developed the TDP for AM and built this part through 3D Systems (see photo left, next page). NAVAIR also built the part through Stratasys Ltd. The LERX part will now go through NAVAIR's Engineering Support Activity (ESA) approval process.

The firm 2Is Inc. also designed a 3D model for a ball fitting (see photo at right, next page) for the CH-53E helicopter, a metallic critical safety item that has been hard to source. This is a particular case where AM shows more flexibility in fabri-

Figure 2. The DLA View of AM



Source: The Defense Logistics Agency.



Left: LERX or Leading Root Extension. Right: 3D model for a ball fitting
Photos Courtesy of 2Is Inc.

cation, since the original part had numerous welds. Designing it for AM production would make one stronger, single piece. The part was delivered in April by 2Is Inc., which is working to get the ball fitting qualified and certified through the Navy Engineering Support Activity before the end of 2016.

A Vision for Moving Forward

The results of the preliminary R&D efforts helped the DLA craft its vision—“A secure digital network that contains all the technical qualifications, logistics and supplier base data needed to certify AM as an option to procure hard-to-source parts, reduce production lead time and meet the warfighter’s needs” (see Figure 2).

In order to “deliver additively manufactured solutions you can trust” (see Figure 2) in the DoD supply chain, the DLA is working to:

- Establish an Additive Part Candidate Identification Tool. Identify the parts for an AM investment that make sense and support the customer in the maintenance depot or the warfighter at the tip of the spear.
- Turn AM-produced part candidates into 3D models using a repeatable process that qualified suppliers can replicate. The DLA must also establish and ensure qualified sources. The agency’s vendors are critical for the success of AM as a new paradigm of manufacturing support to the warfighter. Because of the variability in machines, materials, costs and capabilities, the DLA wants to make sure it contracts with qualified suppliers for AM-produced parts, ensuring compliance with TDPs and source approval authority quality assurance parameters for the parts.
- Get models into a data repository using an AM-defined format. The DLA wants to store the data, not the parts.
- Establish a secure digital information framework and repository of data that contains all the standards, qualifications and certifications by Service engineering support activi-

ties, and logistics and supplier base data needed to enable delivery of certified AM-produced items where and when needed. The DLA supports the military Services and industry in efforts to improve the technological readiness level of the product design, materials and equipment to be used for AM, and then provide a secure environment for the data.

- Establish a repeatable process with military Services’ engineer support activities for qualification of TDPs and AM-produced parts. This includes a vendor qualification plan, first article testing and other quality measures that can be included in policy and acquisition guidelines.

Expanded Partnerships

The DLA is expanding military Service partnerships with NAVSEA, the Army Research, Development and Engineering Command, and the Air Force Life Cycle Management Center to further identify hard-to-source parts that can be produced through AM. An agreement was signed with NAVSEA to work on hard-to-source parts as well as demonstrate AM capabilities to build sand casting molds, an important capability for producing hard-to-source parts. The DLA will further outline opportunities for AM research with other federal agencies, as appropriate. All the R&D efforts in this area will help push AM up the “slope of enlightenment” to the “plateau of productivity.” At the strategic level, the DLA worked with America Makes, the National Additive Manufacturing Innovation Institute and Deloitte to refine its vision and roadmap for AM. The R&D team also worked with America Makes and representatives from the Army, Navy, Air Force and Marines to build a DoD-level strategic roadmap for AM. Both the DLA and DoD roadmaps are near completion.

The Realm of the Possible

The DLA’s near-term priorities for its R&D on AM are to move its prototypical tool for identifying hard-to-source parts into a production environment, standardizing the process and incorporating the tool into everyday use. The agency also will


Figure 3. Delivering Always and On Time Through AM

Near Term Far Term		
R&D Focus	AM Parts Flow	Supply Chain
Identify process to deliver AM hard-to-source and long-lead-time parts	Align AM TDPs with AM demand and vendor manufacturing capacity	Opportunities to reduce DLA storage footprint
Technical Digital Data Interface	Leverage In-Theatre Capability	
Receive, protect and direct TDP	Print-on-Demand Capability	

Source: The Defense Logistics Agency

establish a data repository solution with the military Services, and ensure vendor quality of AM-produced parts. However, this is just the beginning. The DLA wants to integrate parts and solutions into the supply chain that use AM. Print-on-demand is a viable opportunity to get parts to the military faster. The DLA would like to explore with military Service partners the capability to send a TDP anywhere in the world, in a cyber-safe manner so that a spare part can be printed on demand, either by military Service qualified personnel or a qualified vendor. There are opportunities to reduce links and nodes in the supply chain and expedite delivery of critical parts where needed. The DLA also has an opportunity to store the data and not necessarily the parts. Inventory space would no longer be needed for obsolete or hard-to-source parts. Finally, the DLA has an opportunity to extend the operational reach of the military by supplying TDPs in theater to be made by advanced manufacturing labs of the Army or fabrication labs on ships in the Navy, or by vendors. Combined with other advanced technologies, parts might even be delivered in theater by drones. See Figure 3.

able for AM production. Working with the Navy to establish the standards and process for certification of the parts through the Engineering Support Activity has also been an imperative. Ultimately, the DLA also must have vendors to supply spare parts needed in the repair and maintenance of weapon systems. The DLA is working to establish a viable contractor base, experienced in AM and able to meet quality standards for AM-produced parts. This will provide the DLA a valuable solution set for hard-to-source parts. Integration of these capabilities into the supply chain is yet to come.

Although the hype for AM is intense, the DLA is diligent in its approach, and its R&D shop is working to push this technology into the “plateau of productivity” in DoD logistics. 

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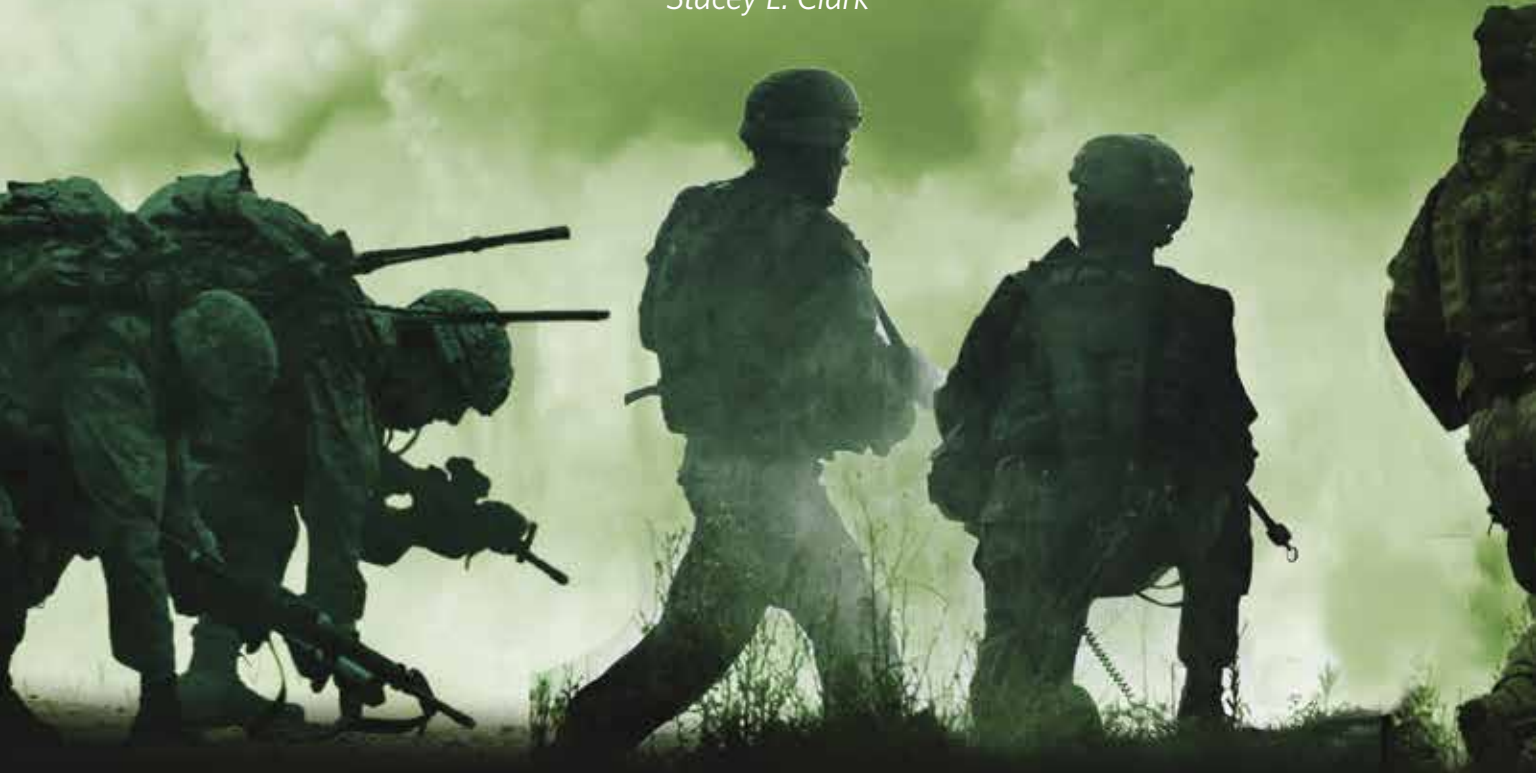
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Getting AM Up to Speed

Across the Army Life Cycle

Stacey L. Clark



The U.S. Army, along with the Defense Logistics Agency (DLA), manages thousands of unique items, called materiel, in order to support its land force mission. This materiel can be broken into several portfolios: platforms, payloads and equipment. Platforms, such as helicopters and tactical vehicles, are weapon systems that can transport payloads and equipment. Payloads, such as missiles and armaments, deliver lethality to a target. Equipment includes communications systems, tools, body armor or other ancillary gear that a soldier may have to carry.

Clark is deputy director of Systems Engineering for the U.S. Army Research Development and Engineering Command at Aberdeen Proving Ground in Maryland.



For every piece of materiel that the Army acquires, it must also look at how to maintain and sustain that materiel through an extensive logistics chain. It is across these two domains, acquisition and logistics, in which the Army seeks to improve its materiel through the strategic use of additive manufacturing (AM). The Army Additive Manufacturing Strategic Roadmap, developed earlier this year in conjunction with America Makes and Deloitte, will be used to define what specific actions the Army needs to take.

In general, the Army is interested in the promise of AM for the following reasons:

- Point-of-use manufacturing—the ability to produce spare parts, in the field, for immediate repair to support a mission. (Additive Manufacturing Cost-Benefit Analysis, U.S. Army Logistics Innovation Agency, HQDA G-4, October 2015.)
- Weight reduction—reducing the weight of platforms can save on fuel costs and reducing the weight of equipment can reduce the load a soldier must carry.
- Reduce internal volume of payloads—using new AM technologies, such as flexible printed electronics, can reduce the internal volume of payloads that currently are taken up by printed circuit boards and increase lethality.
- Multi-use materials—structural materials used for external packaging on equipment can be designed to incorporate materials used to harvest electricity, as an example.
- Repair—larger items that may take too long to be cast or forged through the typical acquisition process may be repaired using laser cladding or cold spray.

Table 1: Acquisition vs. Logistics Domain Challenges

Acquisition Domain	Logistics Domain
Cost is often a driver	Time is often a driver
All parts must meet inspection and acceptance criteria	Not all parts are “critical”
Manufacturing processes must be reproducible	“Onesies” and “twosies” are OK

Source: The author

Implementing AM in the Army depends greatly upon which domain, acquisition or logistics, deploys this technology. For example, Table 1 below shows the pros and cons of using AM for each domain. In acquisition, producing a number of parts in a consistent manner is critical for part acceptance. However, in logistics, producing only a few parts quickly that are “good enough” may be more critical to meet mission needs.

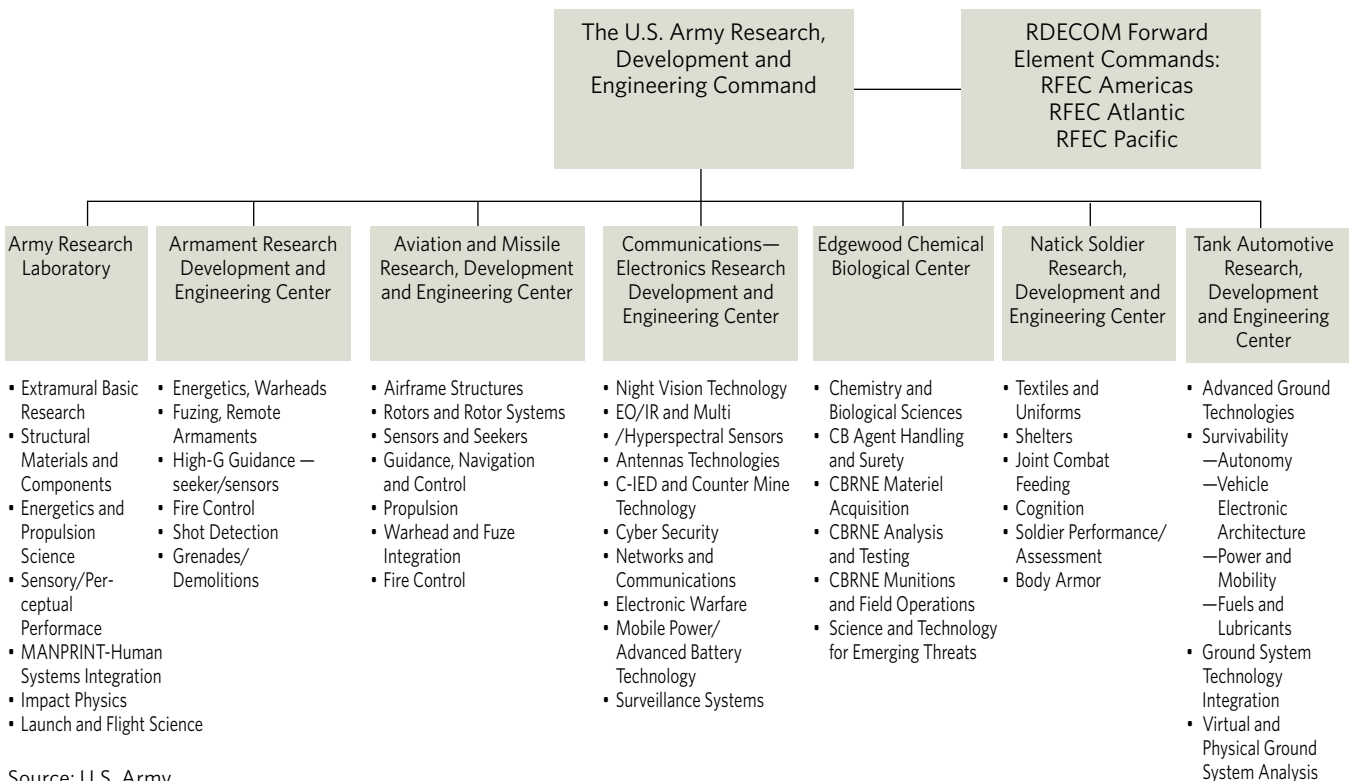
Regardless of which domain is used to obtain an AM part, the use of three-dimensional (3D), fully annotated models is essential in order to specify part geometry, manufacturing data and inspection criteria. Some minimal standards, such as Military Standard 31000A, exist to guide the use of 3D

models— however, the Army still does not consider these to be official data. Therefore, in the acquisition domain, more engineering work is needed to better define what standards should be used in Data Item Descriptions (DID) and Contract Data Requirements Lists (CDRL) in order to acquire a 3D model. Just as important is the Army’s ability to verify and validate the accuracy of the 3D model delivered for acceptance. The Army ManTech Office has established a pilot program called the Net-Centric Model Based Enterprise (MBE) to examine the state of the art to manufacture items from 3D fully annotated models, which is essential for AM.

To support wider adoption of 3D models and digital engineering information, the Army is initiating a project called Life-cycle Product Data Management (LPDM). LPDM will provide an integrated capability to manage Army weapon systems and end item data throughout the life cycle and provide an End-to-End solution. It will increase collaboration, especially between the acquisition and logistics domains, by using common data formats and workflow processes. By providing authoritative Bills of Materials (BOMs), LPDM will reduce cost and risk across the Army life cycle through the use of sharing and reusing both engineering and operational data.

As of yet, there are no additively manufactured items in the Army inventory that have achieved full materiel release. To date, AM has been used successfully only by the Rapid Equip- ping Force and depots for spares, repairs and tooling. Whether

Table 2. U.S. Army Research, Development and Engineering Command



Source: U.S. Army

a platform, payload or equipment, various AM techniques have been demonstrated successfully for repair purposes.

Cold spray is an AM coating deposition technology that hypersonically drives solid powders to impact and adhere to a substrate. One payload, the UH-60 helicopter, experiences corrosion issues in the transmission and gearbox housings. These housings typically are made of cast magnesium which are expensive and take a long time to procure. However, as demonstrated by the Army Research Lab (ARL), cold spray can be used to repair these housings quickly and cheaply when compared to traditional parts replacement using procurement.

(see Table 2). The portfolios are broken out into platforms (aviation; tank and automotive; soldier), payloads (armaments; missile) and equipment (communications and electronics; chemical and biological) with the ARL supporting each portfolio with applied research. RDECOM also has chartered an Army Additive Manufacturing Community of Practice to further harmonize efforts to leverage equipment and training investments.

To fully implement the Army AM Technology Roadmap, efforts need to be synchronized across the Army to include all activities across the life cycle. Looking again at the five activity


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While cold spray AM technology does not necessarily require the use of 3D models, to fully implement it for widespread use on Army systems, it will require the development and adoption of standards to guide the specifications for the powders, process and final inspections.

To aid in the development of standards and specifications for AM, the U.S. Army is making targeted investments in engineering development. This past spring 2016, the Army ManTech Office, part of the Research, Development and Engineering Command (RDECOM), worked with America Makes and Deloitte to produce the U.S. Army Additive Manufacturing Technology Roadmap. The roadmap is broken up into five activity areas: Design, Material, Process, Value Chain and AM Genome. Each of these five activities can be used to support both the acquisition and logistics domains of the Army. For example, investments in the Process activity might be used to produce a new platform, payload or equipment in the acquisition domain or produce a new repair technique in the logistics domain.

Since AM is still a developing technology, it often is necessary to determine which platform, payload or equipment would derive the most benefit from an engineering project even if it is not clear which domain would be the greater beneficiary. Thus, RDECOM is broken out into seven Research, Development and Engineering Centers (RDECs) and the ARL that have the task of inserting AM technology according to what is within their respective portfolios

areas in the roadmap—Design, Material, Process, Value Chain, and AM Genome—it is apparent that implementing AM is not solely an engineering challenge. While Design, Material, Process and AM Genome are more likely to be engineering efforts, Value Chain requires more engagement from other organizations across the Army that are involved with soldier training, generating operational requirements, developing policy and usage guidance for use of AM in weapons systems and for crafting language involving the use of intellectual property (IP) for acquisition. Value Chain tasks include the “AM acquisition process,” “robust supply chain” and “develop continuous learning model,” which fall just outside the traditional engineering efforts yet need to be synchronized.

The Army seeks to develop and exploit the advantages that AM can bring to the soldier: point-of-use manufacturing; weight reduction; increased lethality; multiuse materials; and quicker, cheaper repair processes. Currently, most of the work in AM is performed by the engineering organizations to better understand the state of the art and guide implementation into platforms, payloads and equipment. However, as AM technology matures, along with the digital engineering information it requires, the Army will need to synchronize efforts across the entire life cycle from operational doctrine and training to the acquisition and logistics domains in order to implement the U.S. Army Additive Manufacturing Technology Roadmap. 

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Great Expectations

in the Joint Advanced Manufacturing Region

Dan Green ■ Kristin Holzworth, Ph.D.

Too many new assets are mired in outdated bureaucratic practices that were developed for another era. As we enter the age of cyber, unmanned systems and advanced manufacturing, we cannot allow these overly complex, form-over-substance, often useless, and too often harmful, practices to slow or prevent development of some game changers, while simultaneously giving our potential adversaries the competitive advantage."

**—Navy Secretary Ray Mabus
DoN Innovation Vision**

Last year, in response to the Secretary of the Navy's direction to accelerate innovation across the Department of the Navy, a number of individuals responded with a hearty "Aye, Aye" and volunteered for duty on the Secretary's Innovation Task Force. The goals were aggressive: Challenge the status quo, reclaim a position on technology's leading edge, and defend it from our adversaries. The Vision represented clear guidance, a willingness to innovate, and a desire to slay bureaucratic demons. However, it was unclear how the engineers, scientists and junior military personnel in the field would tackle the Secretary's challenge from within the bureaucracy itself.

Buoyed by optimism and undeterred by sequestration logic, the individuals uttered a collective "damn the torpedoes" and set out to constructively disrupt the status quo. This article is a case

Green is a research associate in the Office of the Secretary of the Navy and serves on the Naval Innovation Advisory Council. His home assignment is with the Space and Naval Warfare Systems Command. **Holzworth** is the director of the Joint Advanced Manufacturing Region. She is a material scientist and project manager at the Space and Naval Warfare Systems Center Pacific. She has a Ph.D. in Mechanical Engineering, Solid Mechanics from the University of California at San Diego.



Table 1. The Smart Manufacturing Grid

Digital Manufacturing Network	Distributed Manufacturing Topology	On-Demand Value Chain Management
<ul style="list-style-type: none"> ▪ Information Technology ▪ Operation Technology ▪ Cyber-Physical Systems 	<ul style="list-style-type: none"> ▪ Node Location ▪ Physical Logistics ▪ Capacity/Mix Optimization 	<ul style="list-style-type: none"> ▪ eProcurement ▪ eCommerce ▪ Enterprise Resource Planning ▪ Software Configuration Management ▪ Product Life-Cycle Management

Source: Author.

study. It is one team’s story. It represents risk, failure, success and, most importantly, an experience curve typical for individuals and organizations desiring to build and sustain a culture of innovation.

Playing Big

A number of engineers and scientists had been working together informally on projects that they knew to be more advanced than the programed baselines being delivered through acquisition and procurement processes. Individually, these projects represented new sensing, information processing, material science and automation paradigms. However there was no trigger, no Joint Urgent Needs Statement, no project funding or highly motivated Program of Record to provide a demand signal to mature these concepts beyond organizationally limited, stovepiped proofs of concept.

Solving the Fleet’s hard problems requires bold plans and, sometimes, fighting above one’s weight class. The Naval Innovation Vision represented a bold plan. Execution was being pushed to the deck-plate level and feedback was returned, largely unfiltered, to the senior staffs. In order for the individuals to contribute effectively, they realized they would need to band together, forgo heroics, and serve as a team.

Using the Navy Secretary’s guidance as top cover, they decided to work together to try to integrate leading-edge, commercially available manufacturing technology into a regional fabric that could support military forces and diversify the defense industrial base. After scratching out a few acronyms on the back of a napkin, they decided to call their effort the Joint Advanced Manufacturing Region (JAMR) and manage it as an Integrated Product Team (IPT).

Gaining Situational Awareness

JAMR initially focused on establishing a dialog with other government, industry and academic community members. The first objective was to determine the general state of manufacturing and to gain a clearer understanding of what each group meant by the term “advanced.” Definitions varied by manufacturing subsector, but an initial review of available literature

revealed that the manufacturing sector itself was experiencing a renaissance. The IPT realized it might be tapping into a vibrant “ecosystem” of emerging, complex, potentially groundbreaking capabilities that extended beyond the manufacturing sector itself. In fact, this convergence of advanced technologies is a megatrend that the World Economic Council refers to as the Fourth Industrial Revolution.

This new revolution is a framework for understanding where the forward line of technology—the technological edge—actually is located. Industrial

consortia such as Industrie 4.0 in Europe, China’s “One Belt One Road,” and the Industrial Internet in the United States already vie for comparative advantage in this space. Geopolitically, the new industrial revolution has sparked competition for domestic and international markets that could contribute to healthy global trade or result in comparative disadvantage for countries that cannot maintain the pace of adoption. The JAMR IPT members knew they had to explore the key themes of this broader industrial revolution in order to engage with the sector and to understand how manufacturing was being disrupted by innovation.

Thinking Globally, Acting Locally

The inaugural JAMR meeting was a teleconference of about 50 people. It included briefs by industry and academia on cyber-physical security, advanced materials and smart manufacturing. There was great interest shown by nondefense corporations, other federal departments and the academic community in collaborating with the Department of Defense (DoD) to mature advanced industrial concepts. The establishment of manufacturing institutes under the President’s National Network for Manufacturing Innovation (NNMI) created strong anticipation that new business models and a new competitive landscape were emerging across the DoD and the U.S. Government.

The IPT’s problem was that the opportunity was too broad to be addressed by a small team. As an ad hoc community of practice, JAMR opted to focus on adoption rather than theory. The IPT decided that its value-adding function would be continuous experimentation and risk reduction prototyping. The entire manufacturing life cycle—design, testing, product development, security, integration—was open for consideration. But the effort needed to be restricted and focused on a micro-experimentation platform that allowed collaboration across the life cycle. Borrowing lessons from the Smart Energy Grid, team members crafted a similar concept for a smart manufacturing grid. When mature, the Grid would allow small, medium-size and large manufacturers to become part of a mutually reinforcing ecosystem that could respond effectively to distributed manufacturing supply and demand cycles.

The Department of Energy (DoE) and the National Energy Reliability Corporation (NERC) concept of “microgrids” also resonated with the IPT. Microgrids allow alternative power providers and citizen-owned power sources (e.g., solar panels) to augment the power distribution infrastructure managed by the electric utilities. This contributes to dynamic capacity management and increased resilience in the power network. Micro-manufacturing capabilities appeared functionally equivalent. Therefore, the IPT incorporated small-batch niche manufacturing companies and the regional leaders of the Maker Movement into the dialog to see how they might benefit from being trusted suppliers on the grid.

“Smart” is a contemporary term technologists use to describe the integration of sensors, cloud computing, big data and predictive analytics into traditional operations (i.e.,

JAMR meetings continued through summer 2015, with as many as 250 registered attendees representing companies, universities and other federal agencies willing to share their ideas. However, by mid-autumn no external funding had been secured and the continuous experimentation planning came to a standstill. Industry, Federal Lab and university partners became discouraged by the lack of capital. Running out of collegial goodwill, the IPT members could think of only one thing to do. They called in the Marines.

In late October, the JAMR effort pivoted from its broad public-private partnership goals to a narrow government-led, platform-integration approach. Headed by a former Marine who had completed two combat tours in Iraq, and a former University of California, San Diego, research scientist who was brand new to the government, the IPT decided to continue as

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Smart Cities, Smart Ports, Smart Power). Smart Manufacturing incorporates the Information Technology elements of sensing, networking and analytics with Operation Technology breakthroughs in mechatronics, material science and robotics. When coupled with an on-demand business model, it is the Smart Manufacturing Grid—an infrastructure that enables distributed, digital manufacturing.

As originally conceived, the Smart Manufacturing Grid was comprised of three major components:

- The real-time, industrial protocol stack
- Physical manufacturing node topology
- On-demand eManufacturing contracting and procurement model

Like the Smart Power Grid, the Smart Manufacturing Grid would enable disconnected local operations (i.e., shipboard, field operations, individual factory), as well as broad area, networked manufacturing operations. In the Smart Manufacturing Grid, security must be built in, must accommodate machine-to-machine transactions and must allow for distributed, automated workflows.

Test-Bed Development

Armed with new information and confidence about what was possible, the IPT set out to leverage existing efforts that could serve as the experimentation venues and elements of the Grid.

an information exchange venue but double-down on a specific government project to stimulate creation and integration of nodes on the Smart Manufacturing Grid.

Other government employees and interns, with funding underwritten by their parent commands, were given leadership roles to extend the IPT’s reach. To help amplify the message, the IPT leveraged DoD and public interest in 3D printing or AM. Using 3D printing as a use-case for the broader distributed, digital manufacturing paradigm, the IPT believed it could help decision makers more rapidly internalize the value of the broader paradigm.

The IPT’s primary objective was modified to focus on delivering some form of new manufacturing capability to local Fleet Forces as quickly as possible. The goal was not to define acquisition quality requirements but to convert operational need directly into capability at a price-point and along a tactically significant timeline. To that end, the total schedule for concept development, equipment procurement, redesign, testing and organizational approval was compressed to approximately 9 months.

Based on the operational needs for expeditionary maintenance and repair experienced by the Marines in Iraq and Afghanistan, the JAMR Team secured a 20x8x8-foot tactical shelter and christened it the Expeditionary Manufacturing Mobile Test Bed (EXMAN). The first unit, EXMAN TB-100, was a

JAMR projects such as EXMAN benefited from strong Marine Corps and Navy senior leadership, a healthy tolerance for limited risk and the innate “can do” attitude of junior personnel.

prototype mobile facility designed to support the continuous experimentation of advanced manufacturing tactics, techniques and procedures under actual operational or combat conditions. The EXMAN prototype served as a benchmark for standard deployable and embarkable advanced, digital manufacturing capabilities that conform to existing logistics processes and lift constraints. The prototype shelter was an ISO (International Organization for Standardization) Certified, 1 TEU (twenty-foot equivalent unit) container that was road, ship and air transportable. The 1 TEU footprint allows modular expansion of the units to accommodate field manufacturing requirements based on characteristics of the mission.

Rapid Adoption

After Alpha testing in early 2016, Marine Corps leadership was able to secure more funding from Navy Secretary’s Task Force Innovation. EXMAN was deployed by the Navy’s Space and Naval Warfare Systems Center Pacific to the 1st Maintenance Battalion at Camp Pendleton in early March. Once on station, the pace of experimentation accelerated rapidly. Over the subsequent 60 days, the IPT conducted formal computer-aided design training for a dozen Marines, held onsite 3D printer assembly and operations events, drafted the initial bill of materials for additive and subtractive manufacturing equipment, negotiated license agreements for software, initiated new assembly designs and completed fabrication of several components.

Live capability demonstrations were conducted by junior enlisted Marines for the Commandant of the Marine Corps, the Commanding General, I Marine Expeditionary Force, the Assistant Deputy Commandant for Installations and Logistics, and the Commanding General, 1st Marine Logistics Group. In about 3 weeks, all four general officers personally visited the EXMAN shelter to understand the potential implications of the capability. Based on their initial impressions and with ongoing daily prototyping efforts, EXMAN TB-100 was scheduled for testing during an operational exercise. The results and lessons learned from that experiment will inform Marine Corps decisions relating to EXMAN sustainment and program objective memorandum planning.

It is too early to speculate on the full implications of adoption of digital manufacturing for maintenance and repair operations at the battalion level. However, the JAMR IPT estimated that the breakeven point for recovering the cost of the EXMAN TB-100 was reached during the initial 60 days of experiments. All subsequent experimentation is being calculated as Type I savings (e.g., direct) and Type II (e.g., cost avoidance) savings that represent a compounded return on investment. Most important, however, was a measurable improvement in opera-


tional readiness based on the Maintenance Battalion’s ability to prototype, and in some cases produce, nonprocurable end-use items in the field.

Epilogue

JAMR is a story of enablement. Over 18 months, many JAMR members opted in and out of the IPT to create a healthy ebb and flow of ideas, challenges and needs. The dynamic nature of the community let the IPT leaders gauge commitment and the relative value of each stakeholder’s contribution. It allowed the IPT as a whole to pursue promising leads and to abandon nonvalue-adding dead ends. JAMR projects such as EXMAN benefited from strong Marine Corps and Navy senior leadership, a healthy tolerance for limited risk and the innate “can do” attitude of junior personnel.

The Smart Manufacturing and Industrial Internet communities that originally influenced the Smart Manufacturing Grid effort continue to mature rapidly. Smart Manufacturing is the newest DoE-sponsored National Manufacturing Institute, and the Navy is now an official member of the Industrial Internet Consortium. The Maker-Mentor project, initiated under the JAMR IPT and being executed by Open Source Maker Labs, was recognized by the White House Office of Science and Technology Policy (OSTP) as an example of the emerging value of maker spaces for the revitalization of American manufacturing.

JAMR itself is an ongoing experiment. JAMR allowed a diverse, ad hoc team of stakeholders to experience the thrill of rapid learning and to contribute to the national dialog on innovation in a meaningful way. It highlighted the value of rapid prototyping and the chronic challenges of resource scarcity that often prevents scalability and sustainment. It reinforced the notion that human dedication and commitment are still the most important determinants of IPT success regardless of how promising or attractive the newest technology seems. Finally, it validated leadership’s notion that we collectively need to nurture our culture of innovation to regain and maintain a dominant position on technologies’ leading edge.

The IPT reflected and shared these lessons learned with the OSTP as part of a broader dialog on manufacturing innovation at the White House in June. All agreed that the JAMR mission remains important, but like advanced manufacturing itself, the IPT is evolving. JAMR’s next phase will involve collaboration through the regional Advanced Manufacturing Partnerships, the Industrial Internet Consortium and other national organizations. 

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Implications of AM for the Navy Supply Chain

CAPT Armen Kurdian, USN



As the U.S. Navy continues to advance and become more integrated, our success relies on the balancing of the intricate interdependencies woven into the fabric of our Service. The underlying support structure that allows our Fleet units to perform their duties in support of U.S. national interests rely on the innovation and hard work of our uniformed and civilian personnel up and down the supply chain. That is why the

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strategic deployment of additive manufacturing (AM) machines throughout the supply chain, coupled with the right business model, is an imperative need in order to fully achieve the benefits of this technology.

The research and development communities within the Systems Commands (SYSCOMs), Office of Naval Research, together with private industry and other organizations, are leading a charge of rapid technological maturation. With the right operations plan that requires changes to our business decision modeling and the tools used to manage the supply chain, including Navy Enterprise Resource Planning (ERP), the Navy will be able to take full advantage of these technological advances. This is why the Naval Supply Systems Command

(NAVSUP) will play a significant role in planning to leverage AM's full potential.

Business Case Analysis

Once SYSCOMs have identified parts that can be produced by AM to a specified level of technical performance and within tolerances, a business case analysis (BCA) must be performed before a determination is made to build and supply via AM. For example, printing a wrench is technically easy from an AM perspective, but the cost and time to make that part by using AM, coupled with limited throughput, would not be cost effective, as the wrench is a ubiquitous item and cheap to mass produce. However, a more complex part with low inventory demand could be an excellent candidate. A cooperative effort

Table 1. Additive Manufacturing Business Model Factors

Incurring Costs	Cost Savings	Other Considerations
Material Cost: Cost of material to produce and cost of waste.	Inventory: No stocking requirement means no cost for shelf space, inventory management or personnel.	Lead Time: Clock starts from initiation of demand signal to a finished and usable part. Time savings in both Administrative and Procurement Lead Time (ALT/PLT).
Operations and Maintenance: Assigned share of cost to operate and maintain the system to produce that particular part; includes training of personnel.	Waste: No expired inventory, no over-buy; make what you need when needed.	Post-processing: Capacity to post-process at or downstream of PoM.
Post-processing: Cost to post-process a part, such as by finishing or coating it.	Shipping: Commercial versus organic, would decrease as the AM machine point of manufacture (PoM) is deployed closer or even at point of demand.	Performance: If a disparity exists between performance or service life of an AM as opposed to a traditionally manufactured part, would that be acceptable in that use case to the Fleet user?
AM Technical Data Package: There are unique aspects to developing a package suitable to a particular AM machine, such as topology, .stl file, or the electronic instructions or program to build the part. This cost may be nontrivial and would need to be amortized across a portion of a part's expected run.		Shipping Time (T_s): Transit time for the usable product to the end user.
Source Approval Process: Regardless of whether a commercial vendor or the government is building an AM part, it needs to be tested and certified, and there is a cost to doing so. A commercial vendor would amortize that into the per unit cost. For organically produced parts, the government could opt to absorb it.		Contracting: Appropriate contracts should be in place. Desire is to avoid writing up a purchase order/request every time a vendor gets an order to make an AM item.
Cost of the Capital Asset: The more capable an AM machine, the more it costs, upward of \$1M each in some cases. This also needs to be amortized.		
Intellectual Property: License or royalty fees incurred.		

to develop a standard BCA template, taking into consideration the parameters in Table 1, should be undertaken to reduce or eliminate variability in the decision-making process.

As can be seen, even quantitative measures, such as lead time, can take on a subjective measure of importance. The priority of the demand signal could act as a weighting factor to favor one option over another (i.e., shorter lead time but higher total cost) to automatically route the order to a Point of Manufacture (PoM) appropriate for that request. The bottom line is the business decision to adopt AM for a particular part should be made first, weighing the factors in Table 1, to ultimately determine if the return on investment and readiness improvements make it worthwhile. In October 2015, the U.S. Army Logistics Innovation Agency completed a study assessing BCAs for AM-produced parts. However, that study performed a large-scale analysis focused on any stocked item that could be made via AM, versus the more targeted and specific focus of lower demand parts within the Navy's efforts. Therefore, Navy BCAs should be done on a case-by-case basis to determine whether cost/time savings make sense for that particular part. At NAVSUP Weapon Systems Support (NAVSUP WSS), in cooperation with Penn

State Applied Research Laboratory's development of an AM Supply Chain Modeling and Simulation tool, an AM feasibility assessment was performed for 150 H-53 components. A BCA model could be tested on those items.

With reduction or elimination of the requirement to stock an item, at the very least at the wholesale level, the introduction of a direct to manufacture demand signal leads to a paradigm shift in Supply Chain Management (SCM) philosophy. To date, decisions to reorder have been based on predictive demand, force deployment, or in reaction to unplanned stockouts or significant fluctuations in demand. We could apply the concept of just-in-time (JiT) inventory to noncommercial items with low demand, greatly reducing or even eliminating the need to maintain a level of wholesale and possibly retail inventory.

JiT Inventory

Currently, when a demand signal is introduced to the system, this requisition goes through the ERP front-end processor before getting routed. The ERP Sourcing Module will then determine whether an order needs to be filled, killed or backordered. A second module captures data refreshing demand forecasts quarterly. Finally, a buy/repair module determines whether a new order from the vendor is necessary and informs the planner. The algorithms which drive the logic reside within each ERP module and dictate how much inventory needs to be kept on the shelf at the wholesale and

retail level and when to reorder. However, the lead time for manufacture is still a significant factor in inventory planning. Naval Aviation is suffering due to critical high-priority back-ordered parts that have grounded a significant number of our aircraft. Similarly, ship Casualty Reports of back-ordered extremely low-demand items reduce a ship's mission capability and take 1 to 3 years to fill.

One key advantage of AM is the potential for drastically reducing lead time to manufacture to possibly a mere 24 hours followed by some time to post-process if necessary. So the Logistics Information Technology business systems that manage the Navy's SCM will need to be configured to take full advantage of JiT.

Table 2. Aircraft Supported by NAVSUP WSS

F/A-18 A-D	E-2C	H-1	P-3	C-130
F/A-18 E/F	E-2D	H-53	P-8	AV-8
EA-18G	C-2A	H-60	V-22	EA-6B

where contractor logistics support is used, such as the E-6B and other trainer aircraft.

After a requisition hits ERP, that demand signal would get routed to the appropriate AM machine. The machine would report back to ERP when that part was built, burdened cost and how much raw feedstock was used, machine status, and

We could apply the concept of just-in-time inventory (JiT) to noncommercial items with low demand, greatly reducing or even eliminating the need to maintain a level of wholesale and possibly retail inventory.

ERP considers Administrative Lead Time (ALT) and Procurement Lead Time (PLT) when deciding whether to re-order. ALT is the time to put out a contract or purchase order to a vendor, and PLT is the time between award and/or obligation and first delivery. AM could reduce that time significantly if the right contract vehicles were in place, the business logic appropriately modified, and AM machines were strategically deployed at the critical points in the supply chain.

For example, PoM has never been a real consideration in making a business decision in Navy Supply, since we usually are limited to one vendor, or more rarely two vendors, approved and/or on contract to make a part or subassembly; the system doesn't care where the part originates (PLT much greater than shipping time or T_s). Once the digital AM thread is established and secure, demand signals for a new subset of AM producible parts should be routed to a location most geographically suited to manufacture and ship that part based on T_s plus the capacity to post-process the part at or downstream of the PoM. A systems monitor would be alerted as to the build order, plus the part's destination, and would prepare the shipping container and materials in advance of completion.

Updated Process Flow

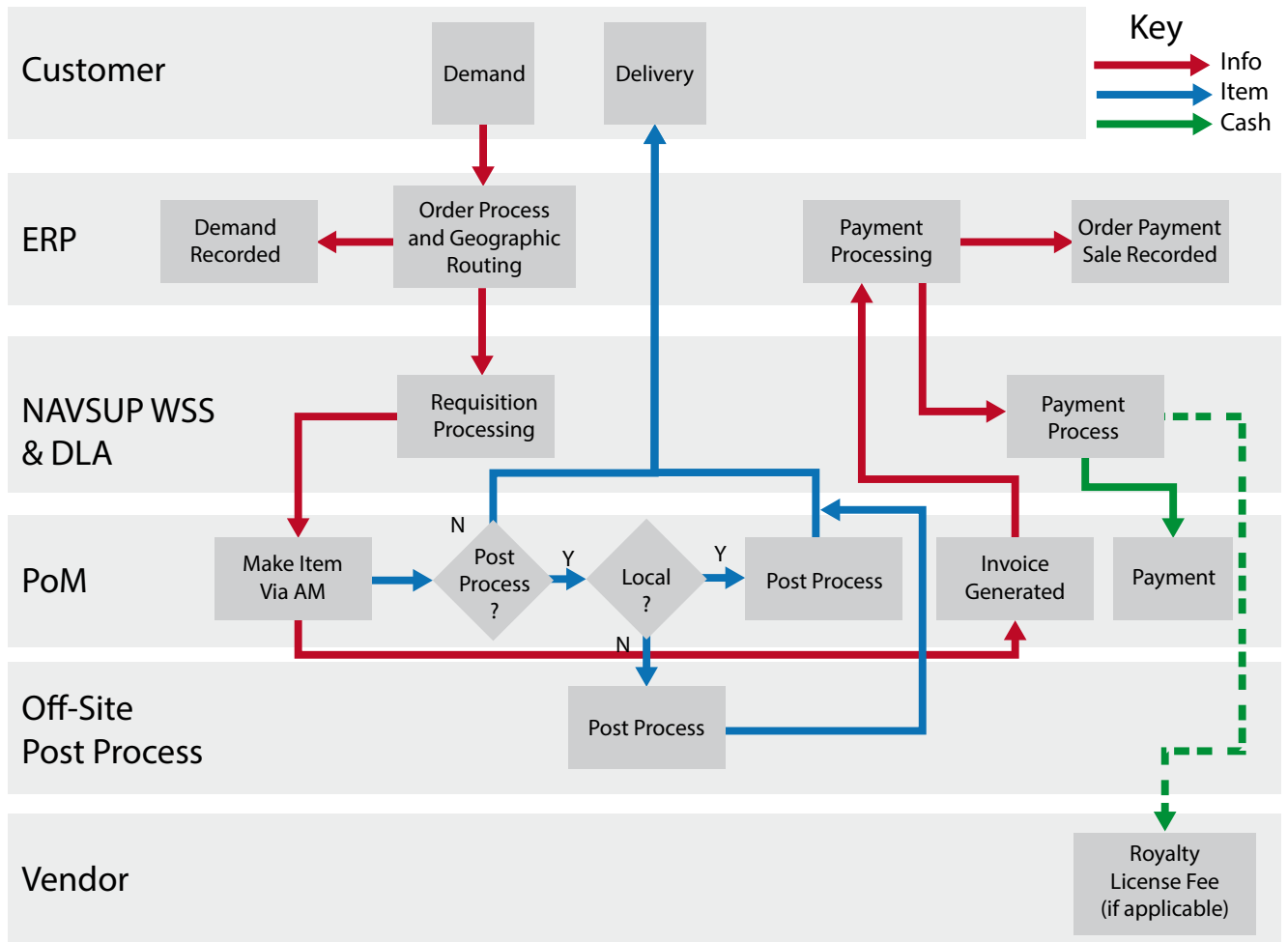
A future order flow for ERP incorporating AM could follow the diagram in Figure 1. This flow currently is limited to certain type model series (Table 2), and does not include aircraft

expected shipping date. The ERP Module records the demand. Finally, AM feedstock, in the form of powders or polymers, is continuously assessed within ERP across the entirety of the supply chain to ensure sufficient stock is available.

To maintain proper cost accounting, this evolution should result in a series of invoices that direct the appropriate financial resources or charges levied as necessary. This flow should be more or less the same as it is now when a Fleet Readiness Center completes work on a Depot Level Repairable and either sends it to a Fleet unit or back to a system stock point, but it must become more automated. The receiving unit pays a burdened rate for the AM-produced part, including materials, shipping, royalties and all other apportioned costs.

A variation on the updated process flow introduces the complexities of a hybrid model in cases when the the machine is government owned and operated but a vendor retains data rights. In this case, NAVSUP WSS or the Defense Logistics Agency could pay the vendor a license fee after the part is manufactured. Establishing a long-term contract with a vendor specifying such fees for a specified item would eliminate the need for individual purchase orders, avoiding the time and cost associated with cutting that document. Vendors simply would be notified when an order for one of these parts comes through and then again when the part is made. The government could then on an agreed-upon

Figure 1. Updated Navy Enterprise Resource Planning Order Flow



periodic basis pay the vendor what is owed, and ERP would record everything. This shares some similarities with current contractual constructs for Performance-Based Logistics (PBL) efforts in which the government pays a vendor to maintain a level of readiness, not for individual procurement or repair orders.

The model becomes much simpler when the order goes directly to a vendor. Once a vendor has a working machine and sufficient feedstock, each government purchase order should look the same. A long-term Indefinite Delivery Indefinite Quantity (IDIQ) construct would be used, delineating a single base price for manufacture and shipping while allowing for small annual increases due to inflation.

Constraints

As laid out, there are several major areas throughout the supply chain that will require changes or upgrades prior to implementation, running the gamut from technical, algorithmic, logical, to legal and contractual. They should not be insurmountable, but identification of all the constraints is critical to successful AM integration into SCM.

For example, IDIQ contracts and ERP compliance require that we identify which items we intend to buy and approximate quantities over the ordering period. AM makes the process more open-ended, although quantities for expected demand should not vary significantly, at least in the short run; AM is only supplanting a previous method of manufacture for a part, not increasing the draw. The government generally is required to state ahead of time the minimum number of parts it agrees to purchase over the life of the contract, and the vendor needs to agree to the turnaround times, which would be significantly shorter than those of traditional manufacturing.

Delivery Orders (DOs) can take months to organize and award, pricing may vary based on tiered pricing tables, and a DO is not awarded until all the funds for full execution of that DO are in place and ready for obligation. In the proposed model provided, an overarching purchase contract would need to exist under which the government agrees to pay a vendor each time a part is ordered, whether it's "customer direct" to the vendor each time a part is made, or a license fee when the part is manufactured organically, with each DO cut automatically without human intervention. ERP does have


provisions for PBLs, but not necessarily a “pay for XX quantity of and unknown mix items at the end of period YY” outside of that construct. The government would award a contract based on a pre-determined amount of parts. Plus, that is very difficult to do outside of a cost type—PBL construct. At the end of each fiscal year, the contract could be reconciled based on the number of parts ordered as compared with how much was initially obligated. If demand significantly exceeds expectations, ERP would notify the contracting agency so that additional funds could be obligated if so desired.

As for licensing and royalty contracts, this has not been implemented on the proposed scale before. Although very rarely used, Federal Acquisition Regulation 31.109 covers the negotiation of Advance Agreements, while 31.205 discusses how to handle the cost element, and 27.202 goes to the specifics of reporting, adjudication and the Notice of Government at a licensee. The government and vendor should negotiate a fee that is a fair percentage of the AM production cost for that particular part. The first set of these contracts should be done with great care, as that negotiated percentage could set precedent for all future similar contracts.

Summary

Once issues of qualification and certification are overcome for a sufficient population of parts, AM has the potential to improve the Navy’s SCM and response in several ways:

- Shorter lead times
- Greater capacity to absorb positive and negative demand shocks
- Lower inventory carry costs
- Exact and near-real time correlation between supply and demand
- Reduced backorders

As with any new technology, understanding AM’s benefits, capabilities and limitations will be crucial to successful implementation. Both the government and our vendors will have to change mindsets, process and procedures to achieve AM efficiencies. Failing to adjust business practices and acquisition rules to AM’s unique aspects will result in our missing out on the revolutionary advantages the technology offers us to keep our ships sailing and our planes flying. 

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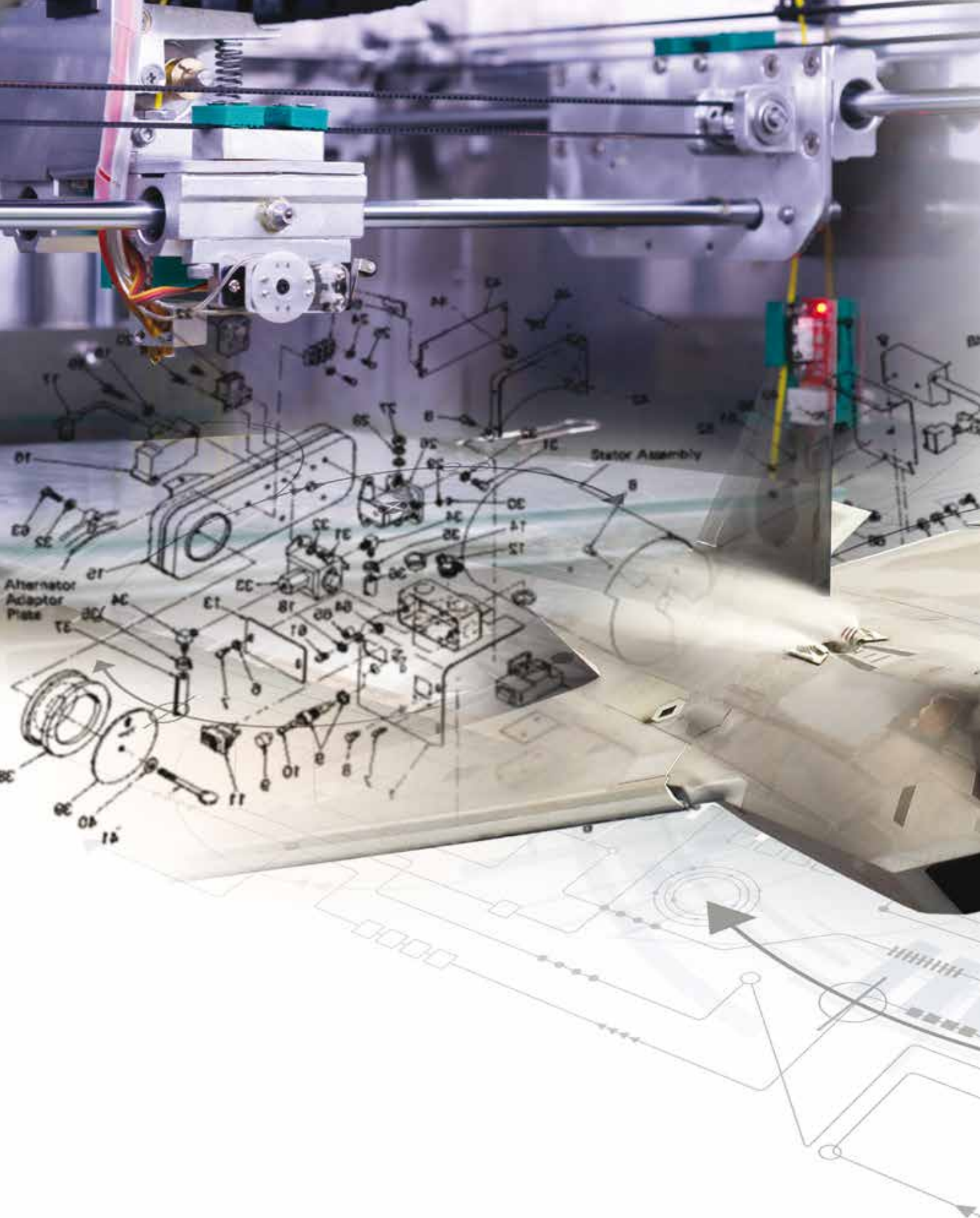
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Challenges of Enterprise-Wide AM for Air Force Sustainment

Debora Naguy



No one challenges the massive potential of Additive Manufacturing (AM) for high-tech aerospace components. It is a cost-effective, tool-less production that can address many current Air Force supply chain challenges. It also can reduce weight through lightweight design while potentially improving performance and reducing cost.

This technology can improve asset velocity to the Air Force supply chain network and improve mission readiness and availability. For the Air Force, the challenge is how to safely implement the technology for critical flight components and smartly implement an integrated cybersecure network of rapid, agile repair capabilities that will enhance mission generation.

The near-term potential of this game-changing technology for tooling, fixtures, support equipment and noncritical aerospace components can help the Air Force to establish a strong foundation for expanding AM to critical aerospace components. A strong enterprise foundation across the Air Force “ecosystem” is the critical first step to smartly leverage the technology and rapidly gain knowledge needed for further expansion. A deliberate, planned approach that focuses on establishing enterprise processes, enterprise tools and standardized equipment and skillsets across all major commands will allow the Air Force to realize infrastructure and support operational agility as called for in the Air Force Future Operational Concept

Naguy is chief of the Air Force Life Cycle Management Center's Product Support Engineering Division at Wright Patterson Air Force Base in Ohio.

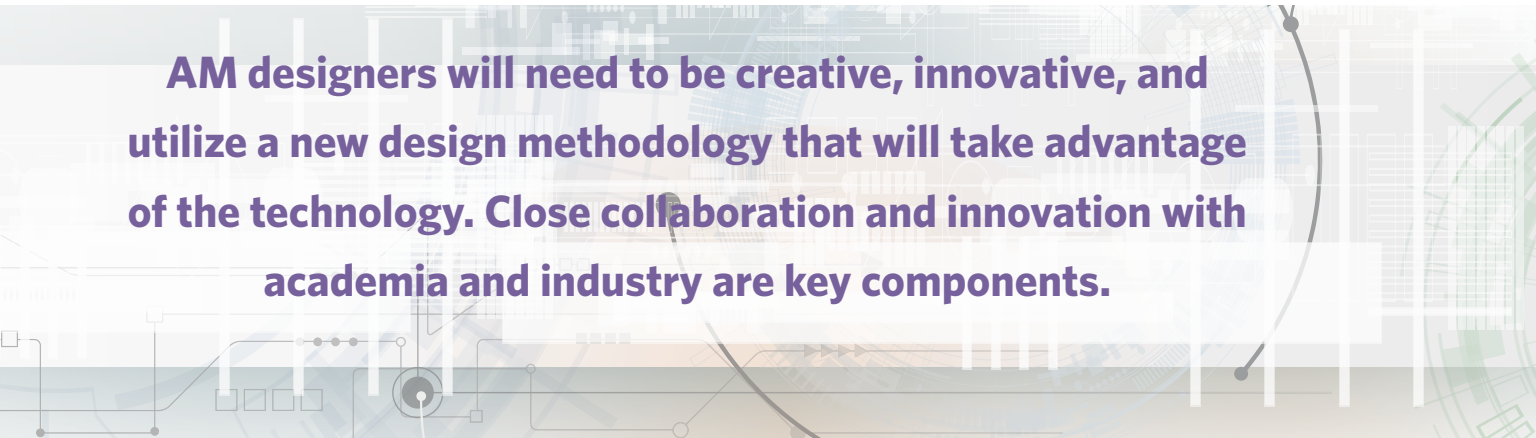
(AFFOC). By leveraging and expanding this technology smartly and quickly, the Air Force can acquire the advantage that this technology can provide today and into the future.

To truly capitalize on the full potential of AM, the Air Force Life Cycle Management Center (AFLCMC) in close collaboration with the Air Force Research Laboratory (AFRL), the Air Force Sustainment Center and the Air Force Nuclear Weapons Center (AFNWC) are aggressively addressing the challenges of AM while using a collaborative, enterprise approach to implementation.

The true potential of this technology will be realized through a centralized and global network approach leveraging both the Engineering and Logistic/Maintenance communities across the Department of Defense (DoD). The Air Force Materiel Command team developed an AM Implementation Plan

an end-use production part, understanding the application is the first step. There are hundreds of materials and numerous process choices to consider. The right choice for the application is critical to ensure desired mechanical properties can be achieved. Geometry, function and post processing are all considerations as well as end-item cost considerations.

The approach for material standards and quality include understanding powder characteristics, developing an enterprise material characterization database, and developing standards for powder requirements based on the component requirements. For example, an AM tool does not require the same level of material quality as a critical aerospace component. The other military Services, industry and academia also are working to address many of these challenges including material standards. The AMIP looks to leverage all work being done to ensure we capture all the knowledge that has already been



AM designers will need to be creative, innovative, and utilize a new design methodology that will take advantage of the technology. Close collaboration and innovation with academia and industry are key components.

(AMIP) that takes a deliberate approach to the various challenges associated with AM across the Air Force Enterprise employing collaboration and agile methodologies. The AMIP establishes a strong foundation using standardized equipment, processes, tools and procedures across the entire Air Force. Implementing an effective AM network across a large network of air bases throughout the world, maintenance and repair organizations, engineering disciplines, and numerous weapon system program offices requires new processes, leverages the Repair Network integration effort and allows the Air Force to utilize an agile deployment methodology.

Other challenges being addressed include developing material standards, skill-set development for engineers and operators, part selection methodologies, configuration control, reproducibility, standardized library of qualified parts with technical data packages (TDPs), cybersecurity, validation and qualification procedures, and reverse engineering. This article dives into each of these challenge areas in more detail.

Selecting the right AM material and process is a key foundational requirement in successful AM implementation and will directly affect the expected return on investment. Whether the AM product is for a prototype, first article testing, repair or

generated in this area to speed implementation. Standardized tools to help in selecting the materials are being investigated for adoption across the enterprise.

The aerospace community must invest in the skills of people who will design, build and use AM technology across the aerospace industry. The majority of today's engineers have been trained to utilize conventional engineering methods using subtractive design principles. Switching that paradigm will take time and deliberate steps. AM designers will need to be creative, innovative and utilize a new design methodology that will take advantage of the technology. Close collaboration and innovation with academia and industry are key components of the AMIP that will help shape the future aerospace workforce.

However, we also will need to rapidly retrain and rethink the way our traditional engineers were taught for conventional design. The target audience of the skillset development plan includes both new and experienced engineers, designers, operators, supply chain and maintenance communities. The AMIP includes leveraging partners across academia and industry to ensure new engineers and/or technicians entering the Air Force have the necessary AM foundational skills.

Internal Air Force training programs are being developed that will baseline and develop the workforce.

Training outputs include standardized understandings with strong AM foundations, including both technical and economic considerations. For both engineers and operators, advanced AM training is being developed and will focus on the design principles necessary to efficiently and effectively utilize AM. Focus areas for internal training will include fundamentals of AM designs, design strategies for AM, quality control, safety operations, AM materials selection, and hands-on design and print projects for Air Force AM components. This approach will allow the Air Force to effectively standardize tools, design principles, configuration control, quality control and validation procedures, while building a centralized library of qualified, validated designs.

The maturing of AM technologies has made possible broader AM application. The screening and selection of parts are other important and foundational processes necessary for each potential application. AFLCMC is developing a standardized, systematic approach to selecting parts, materials and processes for AM across the Air Force enterprise. The opportunity for cost-effective readiness is important, and using a value chain approach that takes into consideration both economic and readiness criteria will ensure the correct applications are pursued.

As an enterprise, the Air Force is identifying the critical criteria that must be considered during the selection process. We are using a crawl, walk, run approach to down-select and test the criteria on a small selection of initial parts.

As a whole, the DoD has different drivers and mission needs that will influence the part selection decision even when it is a non-economical choice to support the mission. Traditional manufacturing companies typically use cost or performance as a primary driver in making decisions. The Air Force is interested in new deployment concepts that leverage agile manufacturing to support our warfighters through reduced logistics footprints and agile deployment.

Our maintenance and repair organizations will be able to leverage the technology to help address the issues of diminishing manufacturing sources of supply and to increase asset velocity. Many of our legacy aircraft no longer have parts manufacturers, and therefore reverse engineering and rapid manufacturing are critical requirements. AM also may reduce our vulnerability to supply disruption if adequate cybersecurity is provided. These considerations are being included in the planning and down-selection process.

AFLCMC also is developing standard implementation plans, standard procedures, and standard configuration control processes for all aspects of the AMIP to ensure configuration control is maintained. Strong configuration control principles can ensure the current design and build state is known, good and

Material standards and availability. Creating AF specs and developing material properties database using enterprise approach, evaluating powder vendors

Part selection. Developing enterprise-wide down-selection tools and process guides

Skillset development. Evaluating standard AM design tools, developing AM training for engineers and operators in AM concepts/designs for enterprise deployment

Configuration control. Establishing centralized library, standard TDPs, standard process and policies for facility layout, quality control, and material evaluation

Reproducibility. Evaluating process controls and demonstrating manufacturing variations at major commands and depots

Cybersecurity. Developing program protection plans and evaluating secure digital design storage and data transfer to move files for cyber resiliency

Part validation and qualification. Establishing standard process for NDI and validation

Process validation and qualification. Establishing a robust and sustainable enterprise process

Reverse engineering. Evaluating tools and training for legacy part TDPs

trusted, meets the design intent and is repeatable. As the Air Force brings onboard new AM machines and post processing equipment, standard facility guides and safety standards and hazard risk assessments are being developed for each type of equipment. Configuration control across all aspects of design, print and qualification will be critical to ensuring correct and repeatable performance. Lack of configuration control could lead to a failure of a critical flight component and contribute to a catastrophic mishap. These standards will enhance system reliability and reproducibility through more rapid detection and correction of improper configuration that could negatively impact component design and build properties.

The ability to utilize standard asset identification, in-process monitoring, quality control procedures, and verification and validation principles is critical to safely implementing AM technology in critical aerospace applications. Cost-effective readiness will be achieved through detailed knowledge, documented across all configuration elements to ensure unnecessary duplication is avoided. This will allow the Air Force to achieve greater agility and faster implementation while decreasing risk, improving security, and ensuring that safe

practices are employed and do not produce new incompatibilities or potential failures.

A cybersecure library of digital AM designs with digital TDPs ready to print on any certified machine across the Air Force enterprise is another key component of the AMIP. An ability to share approved TDPs across the Air Force enterprise will reduce duplication, improve readiness, and better support the Air Force mission. It is essential that the digital TDP prints as designed ensure critical part performance across any of the network AM printers; this critical challenge is being addressed through the AMIP. For example, machine-to-machine variations will be minimized through tight configuration control and quality practices.

A critical step in the AM process is validating the integrity of building a part. Confident validation and qualification will be achieved by analyzing parts through Non-Destructive Inspections (NDI) and destructive testing in a systematic manner comparable with existing data. However, these techniques are costly and time consuming and require their own training and skillset demands.

As we build a multitude of parts and gain the knowledge and confidence of the AM process while monitoring the process, we will be able reduce our demand on these NDI technologies. And we will be able to establish lower-cost quality control technologies for quick verification and validation of parts produced by AM operators. This will enable us to respond faster



While the digital thread concept enables a more efficient design process, it also presents opportunities for cyber risk to disrupt our supply chain.

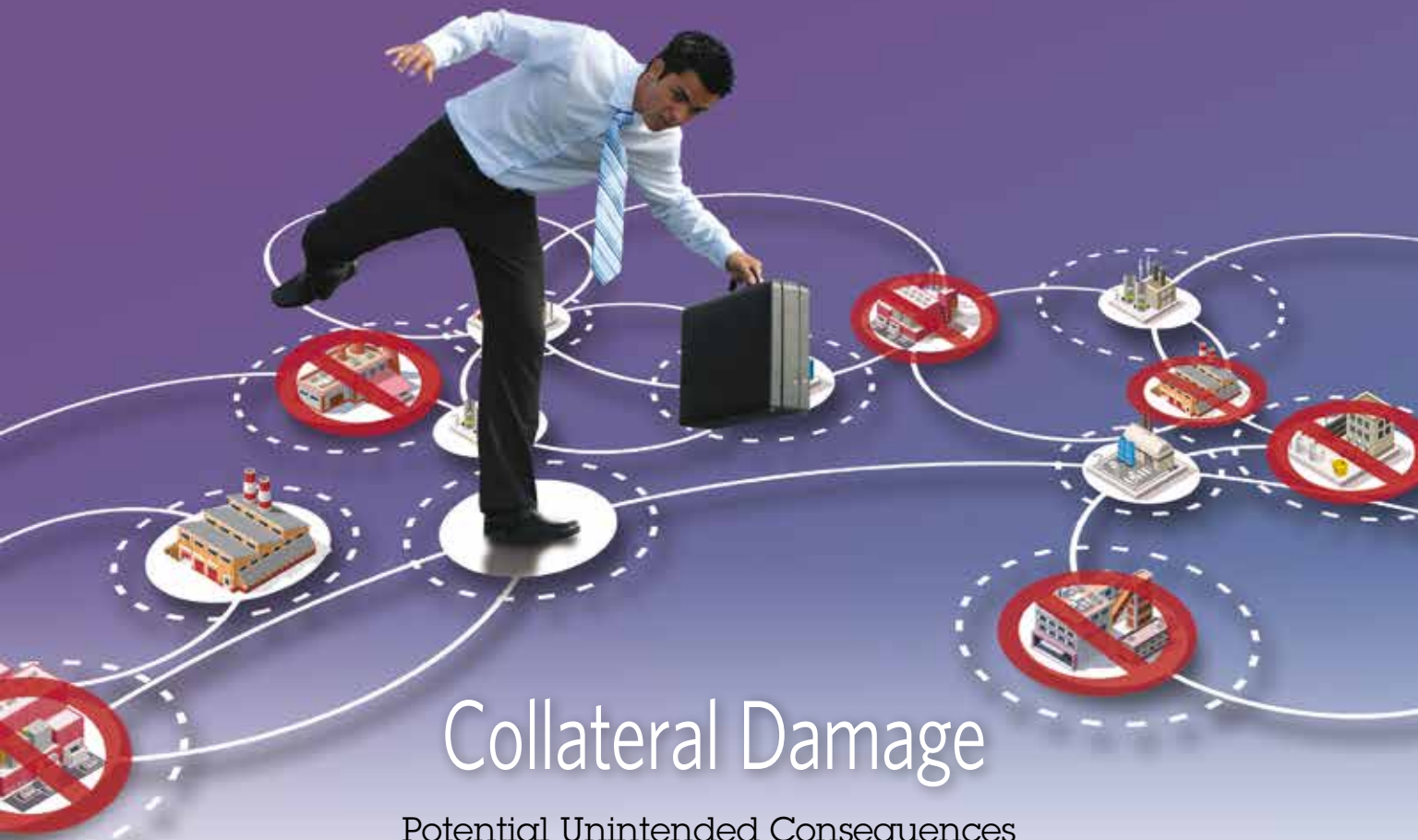
Cybersecurity is another challenge being addressed today in conjunction with digital data requirements in the AMIP. Vulnerability assessments across the entire AM process (both information technology and physical systems) are being performed and will be assessed continually. Program protection plans are being developed to ensure the technology, the TDPs and the standardized library do not become disrupted by our adversaries. We must understand the cybersecurity risks and challenges before implementing effective solutions. AFLCMC is addressing and building cyber safe practices into the AM capability early through the use of actionable intelligence.

While the digital thread concept enables a more efficient design process, it also presents opportunities for cyber risk to disrupt our supply chain. AFLCMC is leveraging a vast array of cybersecurity tactics and technologies to ensure safe AM deployment through real chain custody of authentication. A few examples include designing anti-tamper markings and serial identification built into part designs that must be validated prior to print. Equipment access will be restricted with state-of-the-art technology to ensure only certified operators on certified machines have access to the process. Ubiquitous data collection and pervasive analytics will be employed to detect disruption. Cyber Failure Mode, Effects, and Criticality Analysis will be accomplished to ensure every potential vulnerability is understood.

to supply chain demands. AFLCMC in close coordination with the AFRL will continue leveraging and participating in industry efforts to further expand this capability.

Using an enterprise approach to implementing AM will raise weapon system maintenance and sustainment to the power of "Collaborative Logistics." Successful integration of AM technology relies on a strong foundation of standardized processes that meet and address the AM challenges. These methods outlined in the AMIP will provide this enterprise approach and allow for a repository of fully validated, qualified AM designs, ensuring every 3D printed part meets or exceeds original design intent in a secure, digital environment. Using a converged integrated network will make possible the close collaboration and partnering that will advance the technology throughout the Air Force ecosystem quickly and safely. Starting with and proving the technology on noncritical parts will help manage risk while progressing the technology more quickly. And, by overcoming these challenges, we will create a solid foundation for a future supply chain with a vastly increased potential to support readiness. The benefits of AM are numerous and will allow the Air Force to adapt swiftly to the threat by using an agile infrastructure supporting operational agility through a smaller footprint, increased flexibility and on-demand supply support. 

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Collateral Damage

Potential Unintended Consequences in Aerospace and Defense Industrial Base

Kenneth W. Sullivan, Ph.D., P.E. ■ John Rice ■ Phillip Farrington, Ph.D. ■ Theodore Mayeshiba

Researchers at the University of Alabama in Huntsville (UAH) and the Defense Acquisition University-South Region conducted separate studies (Sullivan, et al., 2015 and Rice, 2016) that evaluated the potential impacts of additive manufacturing (AM) on the U.S. rocket propulsion industrial base. The combined efforts provide a deep dive into a question that has arisen with the increased interest in AM technology: “Could adverse impacts or collateral damage to the aerospace and defense industrial base emerge as AM expands throughout the U.S. manufacturing sector?” The primary objective of the studies, and this article, is to begin determining AM’s applicability to the aerospace and defense industry and the risks and opportunities for the U.S industrial base.

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Right: AM model contrasted with computer numerical control (CNC).

Facing page, left: Traditional machining via CNC.

Photos courtesy of Ace Clearwater Enterprises in Torrance, California

Facing page right: A 3D-Printed RL10 Rocket Engine Gearbox.

Photo by author with permission of Aerojet Rocketdyne



The study concluded that the rocket propulsion industry was an attractive market for the AM sector due to the low volume and potential part reduction for complex parts (thus potentially increasing the factors of safety); however, process certification and qualification standards would have to be developed. In fact, certification and qualification in this domain is the major issue that concerns the Federal Aviation Administration, NASA, and the Department of Defense (DoD). Of specific concern is the integrity of AM processes used and repeatability of resultant products for same (or better) quality as the part produced through traditional manufacturing. The study concluded that injectors, thrust chambers, nozzles and housings were the best candidates for the use of AM technology in producing propulsion systems.

As a disruptive technology, AM could have the following impacts on the propulsion industry, all of which could foreshadow similar and more extensive disruptions in the broader aerospace and defense industries:

- AM technologies could allow original equipment manufacturers (OEMs) to produce parts in-house rather than rely on the current manufacturing industrial base.
- The ability to produce more complex designs may lead to redesign of subassemblies that could result in overall part count reduction. This could reduce the demand for the services provided by small and medium-size manufacturers, causing further reductions in the industrial base.
- Manufacturers of non-propulsion parts could shift to using AM, potentially eroding the need for traditional manufacturing processes (e.g., computer numerical control (CNC) machining). This could, in turn, result in consolidation or even closures of suppliers who supply parts to the propulsion industry.

Table 1 provides a more complete list of the possible impacts of AM technologies on the aerospace and defense industrial base and the potential collateral damage of these

Table 1. Potential Impacts on the Aerospace and Defense Industrial Base

Possible Impact	Potential Collateral Damage
Fallout from AM benefits	Reduced tooling, piece parts, etc.
Impact on lower-tier suppliers	Reduced castings, forgings, material processing
Impact on raw material suppliers	Material to be provided in powder form
OEM performing additive manufacturing (AM) in-house	Reduction in subcontractor manufacturing
Suppliers loss of non-DoD business to AM	Increased overhead cost or even closure due to business base erosion

impacts. The remainder of this paper will review each of these in more detail.

Possible Impacts

Fallout from AM Benefits: Early discussions regarding the benefits of AM focused on the cost savings due to part count reduction and the elimination of tooling. However, the uncertainty still to be addressed is, “where are the savings coming from?” If parts and/or subassemblies are manufactured using AM, then the reduction in work leads to the questions, “who is not making the tooling?” and “who is not making the reduced parts?”

Impact on Lower-Tier Suppliers: Utilizing AM will also impact secondary providers. A recent study by two of the authors focused on the impact of AM technology on the forging sector of the DoD industry base. Based on the interviews with forging industry leaders, the authors did not perceive an immediate threat to their market. However, they did believe the casting industry is more vulnerable in the near term, especially for



Table 2. Machine Shop Supporting Aerospace and Defense Industrial Base (Example)

Sales	Metrics
Energy	20% of Business Base (\$20M)
DoD OEM 1 (criticality one hardware)	20% of Business Base (\$20M)
DoD OEM 2 (criticality one hardware)	20% of Business Base (\$20M)
Commercial Aviation	40% of Business Base (\$40M)
Current Overhead Rate	175%
General and Administrative Rate	10%

OEM = original equipment manufacturer

mid-size to small production runs. Supporting this conclusion, initial testing indicates that the “sweet spot” of AM-produced parts falls between cast and forged parts. That is, AM-produced parts appear to be stronger than cast parts but not as strong as forged parts. This study also found that lower-tier suppliers impacted could be those organizations that do heat treatment and other surface processing. The impact will be dependent upon the material characterization and function of the AM-produced parts.


Impact on Raw Material Suppliers: With greater widespread use of AM, raw material will no longer be purchased in billets from mills. Depending upon which material of the AM-produced parts has the highest success rate, a determination will follow as to which type mills (aluminum, steel, etc.) are initially impacted. Also, as AM use becomes more ubiquitous, demand may increase for powder and/or wire. This is not a problem at present since early studies indicate that AM currently only accounts for 1 percent of the demand for metal powder. But, as the industry grows, this will change.

OEM Performing AM In-House: According to a study by the Massachusetts Institute of Technology, OEMs subcontract more than 70 percent of their manufactured hardware. However, with the increased use of AM by OEMs, the unscientific observed trend has been for them (e.g., General Electric) to build the AM-produced hardware in-house. Should this prove to be a trend, the percentage of subcontract work will decrease

as AM grows. Thus, industries with higher use of AM could see greater vertical integration.

Supplier Loss of Non-DoD Business to AM: A key issue for the DoD is the reduction in the industry base at large. This is partially driven by low quantities that the DoD requires compared to commercial product OEMs. The data in Table 2 exemplify the percentage of the business base generated by aerospace and defense sectors. As shown, the DoD typically only accounts for about 20 percent of a small machine shop’s business; its commercial business generates sustaining income. Thus, if the commercial OEMs’ in-house use of AM increases, it could further erode business, resulting in small machine shops closing—eliminating them as DoD suppliers.

Table 2 represents a machine shop that supports the DoD. Owing to reduction in DoD demand, the firm must diversify to other sectors to maintain its business base. Assuming that its



While AM technologies are exciting and could revolutionize manufacturing, we should not be so naive as to think that this “revolution” will be painless.

commercial aviation customer reduces its orders (from utilizing AM) by 75 percent, the the revenue stream shrinks to \$10 million instead of \$40 million. The immediate impact on the overhead rate and the general and administrative (G&A) rate sees them rise to 200 percent and 15 percent, respectively. Given a typical firm fixed-price environment, the other jobs can easily shift from profitable to unprofitable just through rate adjustments. Unless the machine shop quickly replaces the lost work or reduces overhead and G&A cost (and it is challenging to do so in a machine shop due to capital investments), it probably will yield a loss for that period. In addition, the increased overhead rate can affect the shop's estimates and the likelihood of its success on contract bids. This could easily start a downward spiral toward consolidation or closure.

Impacts of Previous Disruptive Technologies: “The past is prologue,” so the downside to existing suppliers is predictive. Similar cases of disruptive technologies have included space transportation, plastics in the automotive industry, and advanced composite materials in aviation and aerospace.

The Space Transportation System (i.e., the Space Shuttle) introduced disruptive technologies to traditional parts and assembly manufacturers. The need for lighter, stronger structural materials to reduce the cost of a delivered pound to orbit, disrupted conventional rocket manufacturing and material sourcing. Advanced alloys and specialty metals yielded improved strength and reduced density of highly stressed components. This translated into a disruption among stainless and aluminum machine shops supporting product development for launch vehicles.

Plastics in the automotive sector substituted for metal components resulting in lighter, more flexible molded assemblies. The plastics manufacturing process is more straightforward, with parts typically injection-molded or blow-molded from

plastic resin, as opposed to the welding, stamping and other processes for shaping metal in automotive manufacturing. This, of course, resulted in higher fuel efficiencies compared to earlier models and forced traditional metal manufacturers to reassess their core businesses.

Advanced composite materials in aviation and aerospace led to lighter, stiffer airframe characteristics for significantly improved performance. Traditional flight structure manufacturers were forced to adapt, consolidate or liquidate as a consequence of the fiber/resin technology.

Preparing for AM

While AM technologies are exciting and could revolutionize manufacturing, we should not be so naive as to think that this “revolution” will be painless. This article seeks to raise awareness and stimulate thinking regarding the risks associated with the insertion of this disruptive technology. Leaders across the aerospace and defense supply chain need to consider and prepare for the possible AM impact on their businesses. Below are organizational considerations based on positions in the supply chain.


The U.S. Government and prime contractors need to collaboratively monitor supply chain (at all levels) to determine if their existing business base is at risk with the growth of AM. Further, the U.S. Government and suppliers need to determine if the prime contractor's strategic plan for AM involves outsourcing or performance in-house. And government and OEMs may need to assist a firm's subject-matter experts (SMEs) in becoming “hybrid” shops, combining both AM and traditional manufacturing.

Given insourcing opportunities, the government should determine if organic capability exists (possibly across Services) as supplier capabilities decrease. It should also assess whether organic capabilities can support demand or new AM process need to be certified.

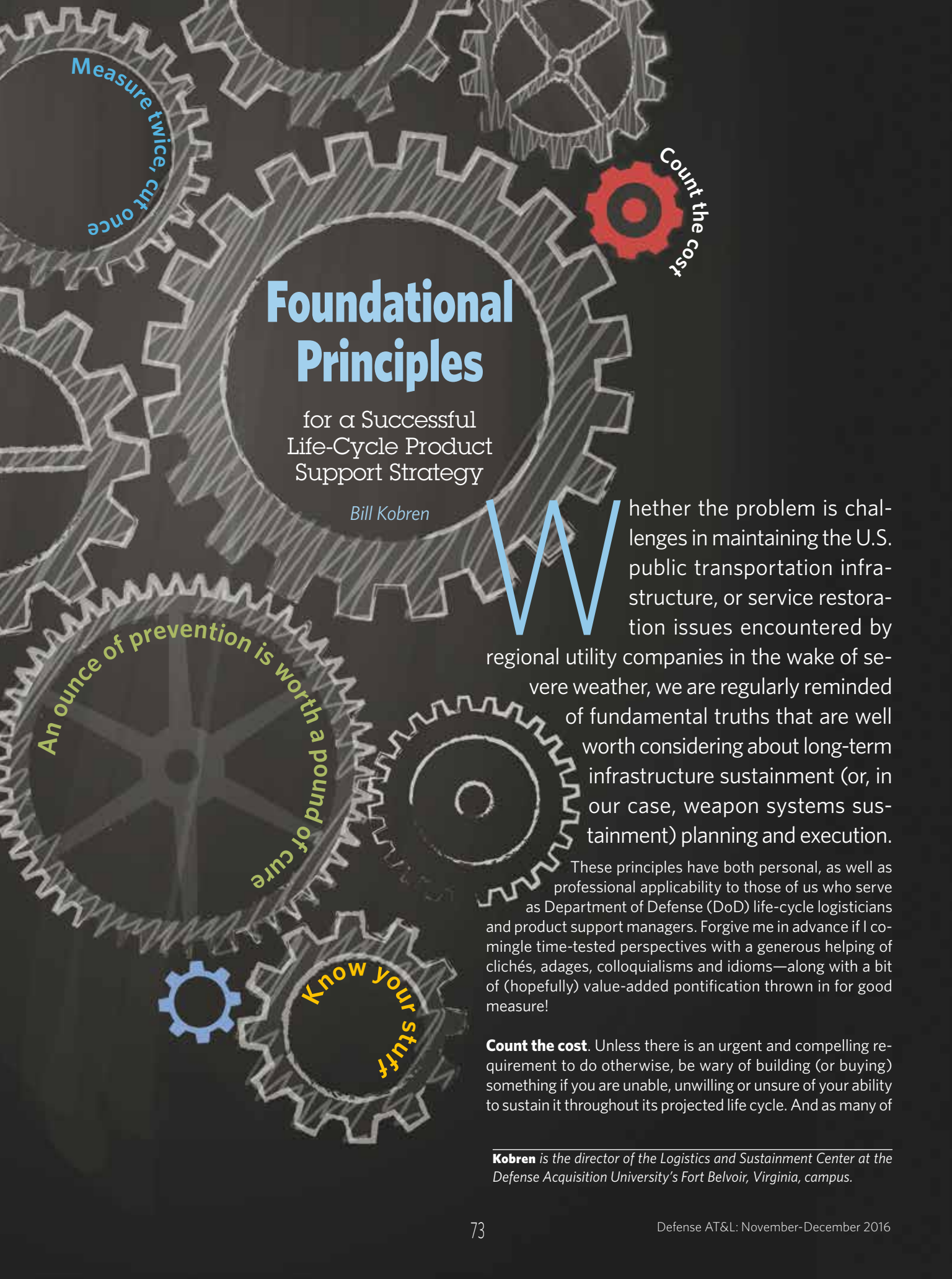
Finally, SMEs need to investigate if products they manufacture for their customers or the material they use to manufacture their hardware is a candidate for AM.

Conclusion

While the authors fully support the use of AM technology, more attention should be given to the development of strategies and policies that will mitigate risks to the aerospace and defense industry. We hope this article provides a foundation and compelling case for further discussions on this topic.

Note: For further information on AM, DAU's AM Community of Practice includes related processes and procedures; organizations and consortiums; reports, papers and articles; and professional development opportunities. Please visit <https://acc.dau.mil/am>. 

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Measure twice, cut once

Count the cost

An ounce of prevention is worth a pound of cure

Know your stuff

Foundational Principles

for a Successful Life-Cycle Product Support Strategy

Bill Kobren

Whether the problem is challenges in maintaining the U.S. public transportation infrastructure, or service restoration issues encountered by regional utility companies in the wake of severe weather, we are regularly reminded of fundamental truths that are well worth considering about long-term infrastructure sustainment (or, in our case, weapon systems sustainment) planning and execution.

These principles have both personal, as well as professional applicability to those of us who serve as Department of Defense (DoD) life-cycle logisticians and product support managers. Forgive me in advance if I commingle time-tested perspectives with a generous helping of clichés, adages, colloquialisms and idioms—along with a bit of (hopefully) value-added pontification thrown in for good measure!

Count the cost. Unless there is an urgent and compelling requirement to do otherwise, be wary of building (or buying) something if you are unable, unwilling or unsure of your ability to sustain it throughout its projected life cycle. And as many of

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you know all too well, the operative word here is “projected”—as long as budgets are tight, service life extensions are very often a fact of life.

Don't put off until tomorrow what you can do today. No time like the present. Let's get on with it. It's never too late to start planning for the future. This is particularly true of long-term product support and sustainment.

Plan for the future. Be disciplined. Defer gratification. To lose weight, exercise more, eat less. To retire comfortably, save more, spend less. There are many ways to sustain a system, some more costly than others. Invest in the future by designing for supportability. Design in reliability and maintainability. As the Director of the Cost Assessment and Program Evaluation so eloquently said a few years back, “The cost of operating and maintaining a system over its useful life is driven primarily

Into each life some rain must fall. Longfellow essentially was telling us that, sooner or later, it's going to rain. Instead of worrying about “if,” start planning for “when.” Oh, by the way, in case you haven't noticed, weapon systems age. Obsolescence is a fact of life, both inside and outside of your program. Rather than admiring the problem, focus instead on figuring out how you're going to proactively deal with the inevitable rather than denying reality or deferring critical decisions.

Waste not, want not. Enough said.

Be careful what you ask for (because you just may get it). Incentivize the right behaviors. Outcome-based, performance-based product support strategies and product support arrangements proactively leverage both incentives and remedies to positively motivate behavior and deliver long-term results that transactional-based sustainment strategies may not.

Rather than admiring the problem, instead focus on figuring out how you're going to proactively deal with the inevitable rather than denying reality or deferring critical decisions until later.

by system design and reliability and maintainability decisions, which are typically made before production.”

An ounce of prevention is worth a pound of cure. Invest early and often. Don't mortgage the future to subsidize today. Think long term. Although successful execution very often is a tactical activity, think strategically. Think life cycle. Think in terms of decades. What will the world be like? The threats we face? The technology advances? The operating environment? Priorities? Total life-cycle systems management is enshrined in DoD policy (DoD Directive 5000.01, Para E1.1.29) for a reason.

Remember the Golden Rule. Treat people the way you would want to be treated. This includes not only customers, but co-workers, employees, stakeholders, and many others. And don't forget your successors, some of whom you may never have a chance to meet but who will be living with results of decisions you make (or don't make).

Communicate. Communicate. Communicate. And don't forget that effective communication includes a healthy dose of listening.

Make hay while the sun shines. Work while you can. Before the next conflict. Before the budget gets tight. Before the unanticipated arises. By the way, for some reason these things generally seem to happen when it's most inconvenient or when you least expect them.

A skilled craftsman doesn't blame the tool. Tools, processes and guidance are powerful enablers. Continuous Process Improvement. Risk Management. Condition Based Maintenance Plus. Product Support Business Model. Earned Value Management. Open Systems Architecture. Technology Refreshment. Failure Modes Effects and Criticality Analysis. Proactive Diminishing Manufacturing Sources and Material Shortages. And Obsolescence Management. Reliability, Availability and Maintainability Analysis. Performance-Based Logistics (PBL). DoD Product Support Strategy Process Model. Reliability Centered Maintenance. Public-Private Partnering (PPP). Supply Chain Management. And the list goes on. Learn them. Understand them. Apply them.

The grass is (not) always greener on the other side of the fence. Poor performance by an organic product support integrator or product support provider is not necessarily grounds for dropping them or transitioning to another organization. Something so drastic, I would contend, should be an action of last resort—essentially after all other options to alleviate the issue(s) have been exhausted. Before making such a decision, it's very likely to be in everyone's best interest to first have a clear understanding of exactly what the issues are that are driving customer dissatisfaction through a thorough root cause analysis. Poorly defined requirements? Unrealistic expectations? Poor communication? Cost? Performance? Schedule? Product? Process? Responsiveness? Quality? Priorities? Metrics? Issues resulting from such a move could potentially

be worse than what you have now. Or you might experience a degradation in performance during the transition period. Before doing something possibly rash, make sure you have identified all potential issues, being sure to separate symptoms from causes. When conducting this evaluation, stick to the facts and base decisions on data—leave emotion, opinion and anecdotal evidence out of the equation. Conduct a rigorous root-cause analysis, bringing in subject-matter experts to assist as required. Evaluate the situation thoughtfully and clearly, considering both near- and long-term implications. Same goes for identifying and implementing potential solutions. Process improvements? Lean events? Benchmarking? Reviewing successful execution examples at same or other providers? PPP arrangements? PBL product support arrangements?

The buck stops here. Broadly speaking, our mission is to plan, develop, deliver and provide affordable readiness to our warfighter customers. We're each called upon to provide best-value product support to our soldiers, sailors, airmen and marines while simultaneously being good stewards of the taxpayer's dollars. We're each responsible. We're each accountable.

Measure twice, cut once. This old carpenter's adage is actually a vitally important principle that undergirds the product support business case analysis. It helps you to be sure you have identified, fully understand and carefully assessed available options. It helps ensure successful translation of product support requirements into cost-effective product support strategies and product support arrangements that meet and often exceed warfighters expectations.

A penny saved is a penny earned. Who could have imagined Ben Franklin would be one of the earliest proponents of Better Buying Power will-cost/should-cost management? A wise, visionary Founding Father indeed!

There's also a vitally important personal, professional and leadership aspect to be considered:

Never stop learning. Strive to be intellectually curious. Stretch yourself. Don't view training or education as a "square to be filled," a "box to be checked" or a task to be endured. Training and education make us better people, better employees, better logisticians, better acquisition workforce members. View Defense Acquisition Workforce Improvement Act (DAWIA) certification training and 80-hour continuous learning requirements as just a starting point. Sign up for Defense Acquisition University (DAU) training courses and continuous learning modules in areas you may not be familiar with, or on subjects where a training course was deployed after you were certified. View DAWIA certification requirements as opportunities to grow—as thresholds, not objectives! In other words, do more than the required minimums.

Be a reader. As a corollary, read. You'll be the better for it; not only more well-rounded, but more insightful and knowledge-

able. If you're looking for professional reading materials, check out our recommended reading list on the home page of the DAU Logistics Community of Practice.

Know Your Stuff. Be the subject-matter expert. Be the "go-to" person. Educate your colleagues in other functional communities about the importance of life-cycle management, long-term product support planning, designing for supportability, developing, fielding, and sustaining supportable systems, investing in long-term reliability, maintainability, and operations and support cost-saving measures, and the value proposition of life-cycle logistics. Also be a good teammate. Support your systems engineering, cost estimating, contracting, test and evaluation, and, of course, your program manager in achieving program success.


Mentor the next generation. Be a mentor. Be a coach. Be a cheerleader. Be a motivator. Be a leader. Share your knowledge, insights, perspectives, and perhaps most importantly of all, the lessons you've learned from the "school of hard knocks." A significant percentage of our functional community already is retirement eligible, or within 10 years of being so. The need for successful mission accomplishment will still be there after each of us has moved on. Let's make sure we've done our part in preparing our successors for the handoff.

Character counts. Integrity matters. Do what's right. Don't cut corners (another carpenter's adage). Or to paraphrase the West Point Cadet Honor Code, do not lie, cheat, steal or tolerate those who do. This adage will serve you well, regardless of your experience level, DAWIA certification, duty title, level of responsibility, pay grade, rank or number of people you supervise.

Treat government service as a sacred trust. Give an honest day's work for an honest day's pay. If you wouldn't do it at home, don't do it at work.

Deeds not words. In a nutshell, "talk is cheap." Get on with it. Define the requirement, develop a plan, and execute. Exceed expectations. Under-promise and over-deliver. As Sophocles said, "It was my care to make my life illustrious not by words more than by deeds." Or as William Shakespeare wrote, "Talking isn't doing!"

Contagious enthusiasm. A corollary to "deeds, not words," contagious enthusiasm motivates teammates, inspires colleagues, takes organizations to new levels of productivity and facilitates success. Get fired up! Get on with it! Vince Lombardi once said, "Confidence is contagious. So is lack of confidence."

Take it for what it's worth. Remember that the advice is worth what you paid for it, you generally get what you pay for, and these observations are intended as food for thought! 

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Defense AT&L

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