3D Printing Changes U.S. Government Operations and Procurement

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About the Editor

Michael Erbschloe has worked for over 30 years performing analysis of the economics of information technology, public policy relating to technology, and utilizing technology in reengineering organization processes. He has authored several books on social and management issues of information technology that were published by McGraw Hill and other major publishers. He has also taught at several universities and developed technology-related curriculum. His career has focused on several interrelated areas:

- Technology strategy, analysis, and forecasting
- Teaching and curriculum development
- Writing books and articles
- Publishing and editing
- Public policy analysis and program evaluation

Books by Michael Erbschloe

Social Media Warfare: Equal Weapons for All (Auerbach Publications)
Walling Out the Insiders: Controlling Access to Improve Organizational Security (Auerbach Publications)
Physical Security for IT (Elsevier Science)
Trojans, Worms, and Spyware (Butterworth-Heinemann)
Implementing Homeland Security in Enterprise IT (Digital Press)
Guide to Disaster Recovery (Course Technology)
Socially Responsible IT Management (Digital Press)
Information Warfare: How to Survive Cyber Attacks (McGraw Hill)
The Executive's Guide to Privacy Management (McGraw Hill)
Net Privacy: A Guide to Developing & Implementing an e-business Privacy Plan (McGraw Hill)

Introduction

Additive manufacturing—also known as three-dimensional (3D) printing—has the potential to fundamentally change the production and distribution of goods. Unlike conventional or subtractive manufacturing processes, such as drilling, which create a part by cutting away material, additive manufacturing builds a part using a layer-by-layer process. Additive manufacturing has been used as a design and prototyping tool, but the focus of additive manufacturing is now shifting to the direct production of functional parts—parts that accomplish one or more functions, such as medical implants or aircraft engine parts—that are ready for distribution and sale.

Support from federal agencies, such as the National Science Foundation (NSF) and the Department of Defense (DOD), was instrumental in the early research and development into additive manufacturing. According to the Science and Technology Policy Institute, since 1986 when it first began funding additive manufacturing, NSF has expended more than $200 million on additive manufacturing research and related activities.

Now, several federal agencies are involved with the research and development of additive manufacturing, including NSF, the National Aeronautics and Space Administration (NASA), NIST, DOD, and the Department of Energy. Within DOD, several research organizations are involved, including the research laboratories of the Army, Navy, and Air Force and the Defense Advanced Research Projects Agency (DARPA).

These federal agencies support research at federal laboratories, academic institutions, and small and large companies, sponsor technical conferences, and participate in standards development. To help guide research and development efforts, federal research and development agencies have supported the development of several technology roadmaps. Further, in August 2012, the National Additive Manufacturing Innovation Institute, also known as America Makes, was founded as a public-private partnership to accelerate the research, development, and demonstration of additive manufacturing and transition technology to the manufacturing industry in the United States. Its federal partners include the Departments of Commerce, Defense, Education, and Energy, NASA, and NSF. America Makes is part of a broader National Network for Manufacturing Innovation that is designed to stimulate advanced manufacturing technologies and accelerate their commercialization in the United States. The interagency Advanced Manufacturing National Program Office manages the network and includes participation from all federal agencies involved in U.S. manufacturing. It is designed to enable more effective collaboration in identifying and addressing manufacturing challenges and opportunities that span technology areas and cut across agency missions.

On October 15-16, 2014, the U.S. General Accountability Office (GAO), with the assistance of the National Academies, convened a forum to discuss the use of additive manufacturing to directly produce functional parts, including its opportunities, (2) key challenges, and (3) key considerations for any policy actions that could affect its future use. Forum participants included officials from government, business, academia, and nongovernmental organizations that were selected to represent a range of viewpoints and backgrounds.

Forum participants identified many opportunities for using additive manufacturing to produce functional parts and discussed benefits that have been realized in the medical, aerospace, and defense sectors. For example, they said that the medical industry is using additive manufacturing to produce customized prosthetics and implants, including cranial implants. Because it is made specifically for a patient, the part results in a better fit, which leads to a better medical outcome. In the aerospace industry, participants said additive manufacturing was used to design and produce a complex jet engine fuel nozzle as a single part, which will reduce assembly time and costs for the engine. Participants identified some future applications of additive manufacturing including enhancing supply chain management. Overall, participants concluded that additive manufacturing will not replace conventional manufacturing, but rather it will be an additional tool for manufacturers to use when it is appropriate from a cost-benefit perspective.

Forum participants identified three broad groups of challenges in using additive manufacturing to produce functional parts: (1) ensuring product quality, (2) limited design tools and workforce skills, and (3) supporting increased production of functional parts. First, they identified challenges related to building quality parts, such as the need to improve the quality control of the additive manufacturing process. Second, they said that existing design and analytical tools combined with an insufficiently skilled workforce could limit the use of additive manufacturing and its ability to reach its potential for greater innovation. Finally, participants identified challenges that affect the increased production of functional parts, such as the need for an improved industrial infrastructure, including more robust supply chains of machines and materials.

Forum participants identified key considerations for potential federal policy actions that could affect the future use of additive manufacturing, including industry challenges, areas affected by additive manufacturing growth, and tradeoffs. Although there was no consensus on specific policy actions needed and many participants suggested caution on potential government action, participants discussed several areas of potential government involvement, such as coordinating standards setting, considering risks for infringement of intellectual property rights with regard to additive manufacturing products, and encouraging a national dialogue about the government's role and its goals.

Additive manufacturing is a layer-by-layer process of producing 3D objects directly from a digital model unlike conventional or subtractive manufacturing processes, such as drilling or milling, which create a part or product by cutting away material from a larger piece, additive manufacturing builds a finished piece in successive layers, generally without the use of molds, casts, or patterns, which can potentially lead to less waste material in the manufacturing process.

While the concepts have existed for decades, commercialization of additive manufacturing began in the mid-1980s and its first uses were primarily for presentation purposes. For more than 20 years, the technology has been evolving as a design and prototyping tool. Additive manufacturing offers the ability to rapidly create prototypes that can help validate the fit, form, and functionality of proposed products, which has provided both great time and cost savings in the product development cycle. As the technology has matured, the use of additive manufacturing has become more widespread and has expanded into more applications. For instance, one of the significant applications for additive manufacturing has been the production of tools and casts for conventional manufacturing. Lower manufacturing tool costs have allowed manufacturers to produce in lower volumes that previously may not have been cost-beneficial.

The use of additive manufacturing for prototyping and manufacturing tooling has helped to improve the efficiencies of conventional manufacturing processes, and the use of additive manufacturing is now shifting to the direct production of goods that are ready for distribution and sale. The emergence of desktop equipment for additive manufacturing has enabled the production of jewelry, art replicas, toys, models, and other artistic products. However, it is the potential to use additive manufacturing to produce functional parts and products, particularly in critical applications such as medicine and aerospace, that has generated a lot of attention

(Link: http://gao.gov/products/GAO-15-505SP)

How 3D Printers Work

Not many years ago, printing three-dimensional objects at home might have sounded like a thing out of *The Jetsons*. But in just a few short years, 3D printing has exploded -- shifting from a niche technology to a game-changing innovation that is capturing the imagination of major manufacturers and hobbyists alike.

3D printing has the potential to revolutionize manufacturing, allowing companies (and individuals) to design and produce products in new ways while also reducing material waste, saving energy and shortening the time needed to bring products to market.

What is 3D printing?

First invented in the 1980s by Chuck Hull, an engineer and physicist, 3D printing technology has come a long way. Also called additive manufacturing, 3D printing is the process of making an object by depositing material, one tiny layer at a time.

The basic idea behind additive manufacturing can be found in rock formations deep underground (dripping water deposits thin layers of minerals to form stalactites and stalagmites), but a more modern example is a common desktop printer. Just like an inkjet printer adds individual dots of ink to form an image, a 3D printer only adds material where it is needed based on a digital file.

In comparison, many conventional manufacturing processes -- which have recently been termed "subtractive manufacturing" -- require cutting away excess materials to make the desired part. The result: Subtractive manufacturing can waste up to 30 pounds of material for every 1 pound of useful material in some parts, according to a finding from the Energy Department's Oak Ridge National Lab.

With some 3D printing processes, about 98 percent of the raw material is used in the finished part. Not to mention, 3D printing enables manufacturers to create new shapes and lighter parts that use less raw material and require fewer manufacturing steps. In turn, that can translate into lower energy use for 3D printing -- up to 50 percent less energy for certain processes compared to conventional manufacturing processes.

Though the possibilities for additive manufacturing are endless, today 3D printing is mostly used to build small, relatively costly components using plastics and metal powders. Yet, as the price of desktop 3D printers continues to drop, some innovators are experimenting with different materials like chocolate and other food items, wax, ceramics and biomaterial similar to human cells.

How does a 3D printer work?

Additive manufacturing technology comes in many shapes and sizes, but no matter the type of 3D printer or material you are using, the 3D printing process follows the same basic steps.

It starts with creating a 3D blueprint using computer-aided design (commonly called CAD) software. Creators are only limited by their imaginations. For example, 3D printers have been used to manufacture everything from robots and prosthetic limbs to custom shoes and musical instruments. Oak Ridge National Lab is even partnering with a company to create the first 3D printed car using a large-scale 3D printer, and America Makes -- the President's pilot manufacturing innovation institute that focuses on 3D printing -- recently announced it was providing funding for a new low-cost 3D metal printer.

Once the 3D blueprint is created, the printer needs to be prepared. This includes refilling the raw materials (such as plastics, metal powders or binding solutions) and preparing the build platform (in some instances, you might have to clean it or apply an adhesive to prevent movement and warping from the heat during the printing process).

Once you hit print, the machine takes over, automatically building the desired object. While printing processes vary depending on the type of 3D printing technology, material extrusion (which includes a number of different types of processes such as fused deposition modeling) is the most common process used in desktop 3D printers.

Material extrusion works like a glue gun. The printing material -- typically a plastic filament -- is heated until it liquefies and extruded through the print nozzle. Using information from the digital file -- the design is split into thin two-dimensional cross-sections so the printer knows exactly where to put material -- the nozzle deposits the polymer in thin layers, often 0.1 millimeter thick. The polymer solidifies quickly, bonding to the layer below before the build platform lowers and the print head adds another layer. Depending on the size and complexity of the object, the entire process can take anywhere from minutes to days.

After the printing is finished, every object requires a bit of post-processing. This can range from unsticking the object from the build platform to removing support structures (temporary material printed to support overhangs on the object) to brushing off excess powders.

Types of 3D printers

Over the years, the 3D printing industry has grown dramatically, creating new technologies (and a new language to describe the different additive manufacturing processes). To help simplify this language, ASTM International -- an international standards organization -- released standard terminology in 2012 that classified additive manufacturing technologies into seven broad categories. Below are quick summaries of the different types of 3D.

- **Material Jetting**: Just like a standard desktop printer, material jetting deposits material through an inkjet printer head. The process typically uses a plastic that requires light to harden it (called a photopolymer) but it can also print waxes and other materials. While material jetting can produce accurate parts and incorporate multiple materials through the use of additional inkjet printer nozzles, the machines are relatively expensive and build times can be slow.
- **Binder Jetting**: In binder jetting, a thin layer of powder (this can be anything from plastics or glass to metals or sand) is rolled across the build platform. Then the printer head sprays a binding solution (similar to a glue) to fuse the powder together only in the places specified in the digital file. The process repeats until the object is finished printing, and the excess powder that supported the object during the build is removed and saved

for later use. Binder jetting can be used to create relatively large parts, but it can be expensive, especially for large systems.

- **Powder Bed Fusion**: Powder bed fusion is similar to binder jetting, except the layers of powder are fused together (either melted or sintered -- a process that uses heat or pressure to form a solid mass of material without melting it) using a heat source, such as a laser or electron beam. While powder bed processes can produce high quality, strong polymer and solid metal parts, the raw material choices for this type of additive manufacturing are limited.
- **Directed Energy Deposition**: Directed energy deposition can come in many forms, but they all follow a basic process. Wire or powder material is deposited into thin layers and melted using a high-energy source, such as a laser. Directed energy deposition systems are commonly used to repair existing parts and build very large parts, but with this technology, these parts often require more extensive post processing.
- **Sheet Lamination**: Sheet lamination systems bond thin sheets of material (typically paper or metals) together using adhesives, low-temperature heat sources or other forms of energy to produce a 3D object. Sheet lamination systems allow manufacturers to print with materials that are sensitive to heat, such as paper and electronics, and they offer the lowest material costs of any additive process. But the process can be slightly less accurate than some other types of additive manufacturing systems.
- **Vat Photopolymerization**: Photopolymerization -- the oldest type of 3D printer -- uses a liquid resin that is cured using special lights to create a 3D object. Depending on the type of printer, it either uses a laser or a projector to trigger a chemical reaction and harden thin layers of the resin. These processes can build very accurate parts with fine detail, but the material choices are limited and the machines can be expensive.
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Creating a country of Makers

While 3D printing isn't new, recent advancements in the technology (along with the rise in popularity of sites like Esty and Kickstarter) have sparked a creative manufacturing renaissance -

- where anyone with access to a printer is a manufacturer and product customization is nearly unlimited.

3D printers and other manufacturing technologies are turning consumers into creators -- or makers of things. This movement, often called the Maker Movement, is helping spur innovation and creating a whole new way of doing business. Products no longer have to be mass manufactured -- they can be made in small batches, printed on the spot or customized for an individual's unique needs.

This new way of thinking is also trickling down into the classroom through access to 3D printers. Students aren't limited to imagining cool, new ideas -- they can make them a reality, and it's inspiring them to go into STEM (science, technology, engineering and math) fields. To educate students about additive manufacturing and the potential it holds, the Energy Department, Oak Ridge National Lab and America Makes donated almost 450 3D printers to teams competing in the FIRST Robotics competition this year.

The rise of the Maker Movement -- embraced by both the young and old -- represents a huge opportunity for the United States. It can create a foundation for new products and processes that can help revitalize American manufacturing. To celebrate this potential, President Obama hosted the first White House Maker Faire -- allowing innovators and entrepreneurs of all ages to show what they've made and share what they've learned.

The future of 3D printing

Additive manufacturing isn't just impacting the Maker Movement, it's also changing the way companies and federal agencies do business.

Companies are turning to additive manufacturing to build parts that weren't possible before -- an example that many point to is GE's use of 3D printers to create fuel nozzles for a new jet engine that are stronger and lighter than conventional parts -- and federal agencies are exploring ways to use the technology to better meet their missions. The U.S. Department of Health and Human

Services created the NIH 3D Print Exchange to better share biomedical 3D-printable models across the medical community while NASA is exploring how 3D printing works in space.

Yet, this is just the tip of the iceberg when it comes to additive manufacturing's potential. For manufacturers, additive manufacturing will enable a wide range of new product designs that can increase industry competitiveness, lower industry energy consumption and help grow the clean energy economy.

From helping fund America Makes, a public-private partnership designed to make the U.S. the leader in 3D printing, to establishing the Manufacturing Demonstration Facility at Oak Ridge Lab, the Energy Department is providing companies with access to 3D printing technologies and educating them -- and future engineers -- about the technology's possibilities. To ensure the technology moves forward, the Department's National Labs are partnering with industry to create new 3D printing technology. Lawrence Livermore National Lab recently announced a collaboration to develop new 3D printing materials, hardware and software, and Oak Ridge National Lab is partnering to develop a new commercial additive manufacturing system that is 200 to 500 times faster and could print plastic components 10 times larger than today's commercial 3D printers.

As the prices drop and the technology becomes faster and more precise, 3D printing is poised to change the way companies and consumers think about manufacturing -- much in the same way the first computers led to the rapid access to knowledge that we now take for granted.

(Link: https://energy.gov/articles/how-3d-printers-work)

Digital manufacturing paves the way for innovation, mass customization, and greater energy efficiency as part of the national all-of-the-above energy strategy. sAdditive manufacturing techniques create 3-D objects directly from a computer model, depositing material only where required. These new techniques, while still evolving, are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, reduce energy use, and shorten time to market. The process is often called 3-D printing or digital manufacturing because of similarities to standard desktop printing.

Interest in additive techniques has grown swiftly as applications have progressed from rapid prototyping to the production of end-use products. Additive equipment can now use metals, polymers, composites, or other powders to "print" a range of functional components, layer by layer, including complex structures that cannot be manufactured by other means.

The ability to modify a design online and immediately create the item—without wasteful casting or drilling—makes additive manufacturing an economical way to create single items, small batches, and, potentially, mass-produced items. The sector-wide ramifications of this capability have captured the imaginations of investors.

Revolutionary Speed, Efficiency, Optimization

Additive manufacturing has the potential to vastly accelerate innovation, compress supply chains, minimize materials and energy usage, and reduce waste.

Lower energy intensity: These techniques save energy by eliminating production steps, using substantially less material, enabling reuse of by-products, and producing lighter products. Remanufacturing parts through advanced additive manufacturing and surface treatment processes can also return end-of-life products to as-new condition, using only 2−25% of the energy required to make new parts.

- *Less waste:* Building objects up layer by layer, instead of traditional machining processes that cut away material can reduce material needs and costs by up to 90%.
- *Reduced time to market:* Items can be fabricated as soon as the 3-D digital description of the part has been created, eliminating the need for expensive and time-consuming part tooling and prototype fabrication.
- *Innovation:* Additive manufacturing eliminates traditional manufacturing-process design restrictions. It makes it possible to create items previously considered too intricate and greatly accelerates final product design. Multi-functionality can also be embedded in printed materials, including variable stiffness, conductivity, and more. The ability to improve performance and functionality—literally customizing products to meet individual customer needs—will open new markets and could improve profitability.

- *Agility:* Additive techniques enable rapid response to markets and create new production options outside of factories, such as mobile units that can be placed near the source of local materials. Spare parts can be produced on demand, reducing or eliminating the need for stockpiles and complex supply chains.

Applications

Industry is taking advantage of additive manufacturing to produce plastic, metal, or composite parts and custom products without the cost, time, tooling, and overhead required in the traditional machining or manufacturing processes. This technology is particularly advantageous in low-to-moderate volume markets (defense and aerospace) that regularly operate without economies of scale.

Today, additive manufacturing is reducing the aerospace industry's important materials measure, the "buy-to-fly" ratio—pounds of material needed to make one pound of aerospace-quality material—by more than half. For example, engineers are taking advantage of additive manufacturing to simultaneously reduce material requirements and easily create engine parts with complex internal structures. Jet ducts in Boeing F-18 fighters can be made with smoothly curving channels that allow more efficient air and fluid flow than those created with the difficult traditional method of boring through solid structures.

Many military applications also often require miniaturized, custom-designed units in relatively small numbers. Additive manufacturing also supports rapid development and production to meet the military's specialized functional requirements.

For the automotive industry, additive manufacturing holds great promise. Vehicle bodies and engines could be made using fewer parts and rapidly redesigned to minimize failures. The traditional assembly line could even become a thing of the past for some industries.

The healthcare industry is investing in tailored prosthetics, dental implants, hearing aids, and other types of medical devices and tools. Manufacturers of many consumer products may soon be using additive techniques in their production processes to embed electronic components and circuits in substrates, reduce device weight and volume, and improve electrical performance.

Challenges

While some manufacturers have been using additive manufacturing to make prototypes, improved additive processes are gaining acceptance in some markets. To achieve a wider range of applications, research will need to overcome some key challenges, including the following:

- *Process control:* Feedback control systems and metrics are needed to improve the precision and reliability of the manufacturing process and to increase throughput while maintaining consistent quality.
- *Tolerances:* Some potential applications would require micron-scale accuracy in printing.
- *Finish:* The surface finishes of products manufactured using additive technology require further refinement. With improved geometric accuracy, finishes may impart corrosion and wear resistance or unique sets of desired properties.
- *Validation and demonstration:* Manufacturers, standards organizations, and others maintain high standards for critical structural materials, such as those used in aerospace applications. Providing a high level of confidence in the structural integrity of components built with additive technology may require extensive testing, demonstration, and data collection.

The full potential of additive manufacturing will be realized when the technology is integrated into broad manufacturing solutions. In applications where additive manufacturing is competitive, 50% or more energy savings can be realized. Companies that explore the potential of these game-changing techniques and introduce novel products can earn a competitive edge in global markets.

(Link: https://energy.gov/sites/prod/files/2013/12/f5/additive_manufacturing.pdf)