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Pathfinding Innovation for Legacy Munitions

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Pathfinding Innovation for Legacy Munitions

Laura Leichus—is a Strategy & Innovation Analyst at the Office of the Undersecretary of War for Acquisition and Sustainment and a Contractor with Booz Allen Hamilton. In her current role, she works to help facilitate surging munitions production through coproduction agreements and advanced manufacturing approaches.

Greg Sanders —is a Senior Policy Analyst at the Office of the Undersecretary of War for Acquisition and Sustainment and the Center for Strategic and International Studies. He also works to surge munitions production through coproduction and other means, with a particular interest in Modular Open System Approaches.

Abstract

Advanced manufacturing encompasses the innovation of improved methods for manufacturing existing products, such as components and parts, as well as the production of new products enabled by advanced technologies. Advanced manufacturing approaches, include robotic technologies, digital engineering, sensing, advanced materials, and 3D printing are reimagining manufacturing. The Pathfinding Innovation for Legacy Munitions Project seeks to understand the landscape of advanced manufacturing approaches and to identify processes that could be applied to legacy munitions to enable surging production of major weapons systems. In this paper, legacy munitions refer to munitions that are currently in production and have been deployed. Currently, many legacy munitions are manufactured using production processes that predate proven commercial approaches. Newer commercial approaches have the potential to improve the cost-effectiveness and efficiency of munitions production.

Executive Summary

A range of challenges impede implementing advanced manufacturing in legacy munitions but present efforts to ramp production mean that government and industry have reason to consider new solutions to pressing problems. Identifying which of these approaches can be economically applied to legacy munitions enables proven capabilities to reach the warfighter faster.

The projects findings are based on 18 interviews with acquisition and sustainment practitioners and subject matter experts (SME), including the Manufacturing Innovation Institutes (MIIs) Manufacturing x Digital (MxD) and Leading Innovations for Tomorrow (LIFT), and the Advanced Robotics for Manufacturing Institute (ARM). These interviews were used to determine where advanced manufacturing is being applied or is mature enough to apply to produce legacy munitions.

While examples of these technologies successfully applied to legacy munitions exist, many obstacles remain to their incorporation. These obstacles fall into the following categories:



Table 1. Potential Reforms and Best Practices for Implementing Advanced Manufacturing for Legacy Munitions

<u>Producer Financial Incentives</u>	<u>Departmental Process and Regulations</u>	<u>Culture and Workforce Constraints</u>
<ul style="list-style-type: none"> • Demand Signal and Boom and Bust • Limits of Incremental Adoption • Narrow Time Windows for Economical Adoption • Barriers to Competition • Intellectual Property and Business Models 	<ul style="list-style-type: none"> • Qualification and Testing Challenges • Safety Concerns • Contract, Requirement, and Design Inertia • Appropriations Process • Contract, Requirement, and Design Inertia • Appropriations Process 	<ul style="list-style-type: none"> • Resistance to Change • The First Mover Disadvantage for Programs • Workforce Requirements and Concerns

The project found that advanced manufacturing has mature approaches in the spaces of automation, digital engineering/sensing, and advanced materials. Robotics reduced the need for humans to handle repetitive or dangerous tasks. Digital twins and sensing technologies have reduced reliance on operators to determine the readiness of mixtures, as demonstrated at U.S. Army Combat Capabilities Development Command (DEVCOM) Armaments Center (AC). Lastly, the Advanced Metallic Production and Processing (AMPP) Center produced new metallics and alloys can performance enhancements. In addition, additive manufacturing and flexible manufacturing are promising future approaches.

Table 2. Mature Advanced Manufacturing Processes Showing Promise for Legacy Munitions

Type of Advanced Manufacturing	Facility / Location	Government Organizers	Details
Automation	Troy, AL	ARM Institute	Robotic sanding and finishing solution
	Wharton, NJ	U.S. Army DEVCOM AC	Container for handling energetics, robot code, and a supervisory system controller
	Wharton, NJ	U.S. Army DEVCOM AC and ARM Institute	Robot scoops and weighs powder
	Marion, IL, Hampton, AR, and Coachella, CA	DPAP	Robotic stations for production line
	Lincoln, NE	DPAP	Nondestructive inspection of SRM nozzles.
	Wharton, NJ	Army ManTech	Slurry loading
	Camden, AR, Orange, VA, and Huntsville, AL	DPAP	Robots move SRM cases and components
	Xenia, OH	DPAP	Producing SRM cases using additive manufacturing
Digital Engineering and Sensing	Wharton, NJ	MxD and U.S. Army DEVCOM AC	Machine-agnostic sensor kit that gathers data for analysis
	Wharton, NJ	U.S. Army DEVCOM AC and MxD	Digital twin for melt-pour process
Advanced Materials	Detroit, MI	LIFT AMPP	Creating custom alloys and feedstocks for metals



These examples show that advanced manufacturing has proven benefits that could transform parts of legacy munitions production. The paper identifies reforms and best practices to ease introduction.

Table 3 Potential Reforms and Best practices for Implementing Advanced Manufacturing for Legacy Munitions

<u>Producer Financial Incentives</u>	<u>Departmental Process and Regulation</u>	<u>Culture and Workforce Constraints</u>
<ul style="list-style-type: none"> • Create a steady demand signal • Invest in research lab efforts • Derisk and pilot applications • Encourage MII, SRL, and consortium collaboration • Use OTAs, fixed price contracting, and multi-year contracting • Distribute orders 	<ul style="list-style-type: none"> • Share testing data • Change the qualification process • Accept manufacturer and supplier data • Accept sensor data and digital twins • Use OTAs to support prototyping, partnerships, and distributed contracting 	<ul style="list-style-type: none"> • Educate Communities • Data Driven Decision-making • Training and Workforce Development

JPAC is engaging partners on promising approaches and launching a pilot to surge production and expand use of advanced manufacturing approaches by the defense industrial base. This project will focus on fostering proactive failure analysis detection and mitigation.

The Introduction

The United States Defense Industrial Base (DIB) is unable to surge munitions production to build weapon stockpiles within an acceptable timeframe. Business-as-usual munition production rates pose strategic and operational risks. The study supports the Joint Production Accelerator Cell’s (JPAC) mission to determine how the United States can surge the production of critical munitions and ensure that the United States is prepared to counter the pacing challenge and evolving threats within an acceptable timeframe. Business as usual munition production rates lead to strategic and operational risks.

One way that the Department of Defense (DoD) could accelerate production is by applying advanced manufacturing approaches to the production of already established weapons systems, known as legacy systems or legacy munitions. Examples of this include using automation in place of manual tasks, using sensing data to collect and organize data to optimize manufacturing in real-time, and using advanced materials to support parts production and address supply chain vulnerability. These legacy munitions are already in use and have well-established production lines and supply chains, reliant on older technologies and processes. Changing manufacturing approaches for legacy munitions is expensive and time-consuming. However, applying innovative technologies, such as advanced manufacturing approaches, could make legacy munitions manufacturing cheaper, faster, and more agile, unlocking the potential to surge production capability. In the case of energetics, advanced manufacturing techniques can enhance worker safety by removing as much human exposure to energetics materials as possible.

Study Approach

The Pathfinding Innovation for Legacy Munitions project is studying how and when advanced manufacturing approaches can be efficiently applied to improve production capacity for the legacy munitions enterprise. The project employed five overarching research questions to conduct 18 interviews with Manufacturing Innovation Institutes (MIIs), outside researchers, and experts within the Department to identify the challenges the DIB faces in implementing



advanced manufacturing. Interviews were with Program Managers, Engineers, Technical Advisors, Special Assistants, Directors, Chief Executive Officers, and Chief Technology Officers, amongst other experts. These interviews identified challenges with producer financial incentives, departmental processes and regulations, and culture and workforce constraints. These research questions are as follows:

- What advanced manufacturing approaches or commercial technologies are currently being applied to enhance the producibility of legacy munitions?
- What advanced manufacturing approaches or commercial technologies are relevant and mature, but not yet applied to legacy munitions?
- Why are advanced manufacturing approaches not more widely used in the DoD? What could be done to change that?
- What challenges are industrial partners that employ advanced manufacturing approaches facing when working with the DoD or legacy munitions?
- What are the limitations for advanced manufacturing approaches in terms of producibility?
 - Is there a need for more testing to mature the technologies?
 - Are the advanced manufacturing approaches difficult to qualify?
 - Is cost a limiting factor?
 - Is there a need to incorporate advanced manufacturing approaches early to avoid the need to modify processes or designs? Is this causing problems with producibility or manufacturing?

The Obstacles

There are many reasons that advanced manufacturing is not more widely applied and integrated throughout the Department. These issues, summarized in Table 1, include a lack of incentives to adopt new methods, inertia in current processes, and cultural resistance from some parts of the munition enterprise and IB. Incorporating advanced manufacturing can introduce risks to balance-sheets production lines, and performance and safety requirements and may encounter cultural resistance when being introduced into the manufacturing process for legacy systems. Resources and effort more easily flow to new systems that can incorporate these approaches at the start. However, as subsequent sections will discuss, JPAC has found that the DoD misses essential opportunities due to a lack of integration of promising emerging technologies.

Producer Financial Incentives

Demand Signal and Boom and Bust

Legacy munitions, by definition, have existing production lines, and those production lines were scoped based on industry and program expectations of current and projected demand from the United States and licensed exports. Unless there are deactivated and preserved tools, lines, or facilities, changing or expanding scope using traditional or advanced manufacturing methods requires major capital investments and does not address potential workforce constraints. Meanwhile, for a sole source provider, demand backlogs often represent revenue pushed into the future rather than foregone revenue. As a result, it is not economical to expand production facilities to meet a temporary spike in demand that will vanish after stockpiles have been refilled.



Without robust forecast or assurances that there will be demand for the legacy munition, industry cannot be confident that investments in advanced manufacturing that are specific to a certain munition will be profitable. Slack capacity is sometimes intentionally maintained in government-owned facilities, but this is a choice that must compete with other priorities, such as facilities that could better support higher performance or affordable mass munitions now under development. The problem for both the private and publicly owned facilities is that munitions manufacturing is prone to boom-and-bust cycles. Guaranteed government interest through multi-year contracting or minimal purchase guarantees are two statutory tools to manufacturers and suppliers that there will be a sustained need for the approach, munition, or component.

Limits of Incremental Adoption

Achieving the full benefits of advanced manufacturing often requires investments in infrastructure, new supply chains, professional staff time, and data. Cultural change also undercuts piecemeal adoption of advanced manufacturing. Similarly, established public and private sector suppliers also often lack the know-how to modernize their outdated infrastructure. The culture and expertise challenges are discussed later in this paper under *Culture and Workforce Constraints*. Ideally, advanced manufacturing approaches involve not just capital expenditure but also infrastructure that supports the process. Physical infrastructure often needs to be transformed to support advanced manufacturing techniques.

For example, robots may be able to handle materials or work enable agile automation but rely on sufficient space or leveraging digital engineering. Digital engineering is an integrated approach that uses digital models, data, and advanced computing technologies as a continuum across disciplines to support the entire life cycle of a system, from concept through disposal. For digital engineering to be employed, there needs to be a digital foundation and digital framework to provide factories with integrated technological infrastructure, systems, and data management frameworks that enable digital manufacturing environments and data-sharing. A key challenge for legacy munitions is that if engineering data was not created in a digital format during initial design or subsequent modifications, the extent of potential digital engineering is limited. Even if the data is available, the difficulties associated with integrating a digital foundation mean that many discussions about employing advanced methods are only had during the construction of a facility or ordnance plant. These locations are reluctant to make costly updates to their outdated infrastructure, which makes it challenging to integrate new approaches.

A key early step to a digital foundation is networking. A networked advanced manufacturing approach significantly increases speed and reduces cost through enhanced efficiency, real-time data flow, automation, and improved decision-making across the entire product life cycle. Factories need execution software and network communications to ensure data can be collected in real time and to provide insights that enable quick adjustments to avoid latency, lags, and machinery downtime. Many current production sites have machines or computers that have no network interfaces or are otherwise not connected to wired or even wireless networks, referred to as “air gapping.” Air gapping also makes it difficult to apply security patches to software and make technological changes. Similarly, air gapping prevents machinery from recording and reporting data in real-time, and can lead to data being recorded on paper, which hampers analysis and process control. Manual data collection is often cumbersome, which prevents it from occurring or being employed. This isolation of machines or computers may be the result of industrial design approaches that pre-dated digital engineering or specific cybersecurity or safety concerns. Production lines with isolated machines face significant friction when employing digital engineering. One interviewee cited a successful demonstration at Rock Island of 3D printing an antiquated part. Commercial experts in the audience noted that the machine was not connected to anything, which would make it difficult to further iterate on the success.



Deviating from established manufacturing plans has many cost implications beyond infrastructure upgrades. Manufacturers face costs in both time and money for establishing supply chains with suppliers that can support new technologies. New technologies may depend on materials and alloys that cannot be domestically sourced, are in high demand, or have long lead times, all of which hinder production. Often, incumbent vendors will purchase only from a limited, highly qualified supplier base.

These interconnected modernization requirements can present an additional challenge to government-owned facilities, referred to as the organic industrial base (OIB) and private sector facilities. Munition plants in the OIB typically lack the funds to modernize. For OIB facilities to support advanced manufacturing, they need updated infrastructure, hardware, and software. When the OIB facility is not the only potential source the DoD often prefers to rely on private industry rather than upgrading and investing in OIB facilities. Often the DoD is working with other partners, and those partners can make needed upgrades to their facilities. Likewise, the DoD may take approaches that spread funding across many facilities rather than making a difficult choice of which one or two to upgrade. This allows for incremental adoption but makes it difficult to make wholesale changes.

Narrow Time Windows for Economical Adoption

For government or industry to invest in a new advanced manufacturing approach, it needs to make sense financially. Legacy munitions rely on existing facilities, production lines, and weapon system designs. The return on investment is most favorable if advanced manufacturing adoption aligns with upgrade opportunities in the life cycle of a facility, production line, or weapon system. Even for commercial manufacturers already using advanced manufacturing, manufacturing for the DoD accounts for only a small share of the business's revenue and therefore investing in re-engineering or re-tooling existing military-specific production lines may not yield a return on investment. Changing a manufacturing approach can also lead to tooling costs, which often requires a high initial investment. Tooling is often amortized over 10 to 15 years, and tools may take that long to be paid down. For both supply chains and capital equipment, manufacturers do not want to incur costs they did not budget for and that will not be reimbursed for. Specifically, the return on investment cost of adopting advanced manufacturing will often vary based on whether investments in current approaches or equipment are still depreciating.

Advanced manufacturing approaches do produce a range of benefits that should contribute to corporate revenue and help the OIB better perform its mission and meet contractual requirements. However, this business case is complicated for legacy munitions because to realize the full benefits of advanced manufacturing, manufacturers would need to commit to it early in the process, possibly before standing up facilities. Manufacturers may have passed the risky decision to adopt an approach that seemed immature when they first stood up a production line. Yet, if the approach is not adopted early, it can be hard to implement changes without disrupting production. Deciding to adopt an approach earlier is an easier decision if the approach has more advanced technological or manufacturing readiness levels. However, for advanced manufacturing approaches not yet applied in a military or commercial context, even mature advanced manufacturing approaches may require Research, Development, Testing, and Evaluation (RDT&E) spending or private internal R&D investments.

Barriers to Competition

The commercial industry uses a range of advanced manufacturing approaches often because it provides an edge over competitors. Commercial technologies can be brought to market much faster and therefore speed of innovation is rewarded. The DoD frequently relies on sole-source production contracts, and those contractors are only incentivized to meet the



requirements. Even if a contractor captures additional revenue by expanding production, the necessary investments may lead to lower profit margins in a sole source environment. The difficulty in finding the correct scale to bundle contract orders is another problem. Large commercial companies are often uninterested in making the transition to becoming government contractors to win the quantities the government solicits because they are not large enough to yield a desirable return on investment. Small vendors are often unable to produce the required quantities and therefore do not bid.

Intellectual Property and Business Models

The typical business model for DIB vendors rewards closely holding intellectual property (IP) and data rights rather than licensing production to other manufacturers, even if that other vendor may be capable of employing an advanced manufacturing approach. Incumbent vendors often hold proprietary designs and institutional knowledge that new entrants lack. New entrants seeking to become second source suppliers already face high upfront costs and regulatory requirements. If IP licensing is expensive or unavailable it may be impractical to become a second source for another company's product. Additionally, Original Equipment Manufacturers (OEMs) often have a vested interest in holding close information on the integration and final assembly of a product. This applies when the OEMs are subcontracting and is magnified when they manufacture the component themselves.

Unless the acquisition official in charge anticipated potential advanced manufacturing applications for a given legacy program, the DoD will typically not have clear rights to the Detailed Manufacturing or Process Data (DMPD) of the products it buys, which creates a dependence on the company that supplies the technology is purchased from. Even in those cases where the government has rights to DMPD, critical technical data might be lost or have contested usage rights. In these circumstances, government investments in process improvements may primarily benefit the recipient vendor's bottom line. If a vendor or the government seeks distributed production, concerns related to intellectual property and data rights would have to be worked out prior to working together. This may be costly for legacy munitions, as the IP Guidebook for DoD Acquisition warns, "buying the data, outside of competition and well into program execution, could be extremely expensive." A range of flexible IP arrangements is possible and discussed within the IP Guidebook, but this is another domain where applying advanced manufacturing is far easier for programs early in their life cycle or at very least undertaking incremental upgrades.

Departmental Process and Regulations

Qualification and Testing Challenges

Vendors that want to certify advanced manufacturing processes to meet DoD standards must go through the qualification process.¹ Vendors wishing to adopt advanced manufacturing approaches must ensure the methods they intend to use are appropriately vetted, mature, and ready for use. New materials need to be verified and validated to ensure they are fit for the intended purpose and ready to be scaled up and can be used for broader industrial applications. These changes need to consider qualification and data acceptance standards. When starting up a production line using traditional or advanced approaches, the entire line, including both the process and the outcomes, must be certified. The process of qualifying limited rate and then full

¹ Commercial and defense standards include model based system engineering (MBSE), digital twins specifications, technological readiness levels (TRL), and manufacturing readiness levels (MRL), prototype development, and specific standards such as ISO/ASTM 52900, ASTM F2792. See the subsequent section on Qualification and Testing Challenges. For a discussion of one particular additive manufacturing approach, see the [DoD additive manufacturing strategy](#) for additional details.



rate production can be even harder for advanced manufacturing because there is less historical data to rely on, as discussed in the next sub-section. Moreover, legacy munitions already have production lines and processes that have undergone qualification. Industry finds the qualification process daunting because the process takes time and is expensive. OEMs also contribute to variation between programs due to their differing approaches. Each munition often requires an individual qualification, approval, and sign-off from a chief engineer.

Remaking legacy parts and components often will require requalification, which can be prohibitively expensive. Some components, such as energetics and fuzes, face particularly high burdens because new processes can introduce energy or change the chemical properties of the result. An end-product that matches one produced by a traditional method may not be accepted because there could be potential impurities or chemical changes not found in traditional methods. On the other hand, delaying qualification of a product may mean that a new entrant's investments in design, testing, and iterating to enhance producibility goes to waste because the item or subcomponent lacks key attributes to allow it to meet requirements. These burdens are greatest the first time an approach goes through development. Piloting for future adoption and cost reduction initiatives can ease adaptation in future programs, though adoption by legacy programs will still face higher burdens.

This process is lengthy due to extensive safety, performance, and reliability testing prior to delivering platforms to the public or military personnel. Because the qualification process is lengthy, manufacturers need to be prepared to outlay substantial funds for a potential benefit that will not be realized in the near term. Often, the expense does not yield a sufficient return on investment. Qualifiers may reject a technology, which makes it risky to invest in. Program offices for sustainment systems may pay to support company qualification and certification efforts, but only if they have sufficient O&M dollars. Proposals for qualification process reforms have been raised, which focus on allowing the use of prototyping, digital threads, artificial intelligence, or incremental assurance of capabilities.

Data Challenges

Qualification requires supporting data. Developers of new technology often lack experience and data supporting the viability of their newly developed technology. Commercially proven technologies already have some data on hand, but that data may not address military specific concerns or the specific demands of government processes. As a result, vendors need to produce a statistically significant number of pieces or parts that can be tested to prove the validity of any process. This delays vendors' opportunity to earn a return on investment because the DoD requires this data when deciding whether to integrate or scale production of new technology, which amplifies these challenges. As part of the qualification process, validation often requires access to a controlled and intrinsically safe environments. Many existing facilities do not allow on-site testing and prototyping on their production lines. Thus, many vendors need to pay an upfront cost to contract with a government organization to make use of a testing range so their technology can undergo safety inspections. Small vendors and new entrants often do not have the funds to build a testing range, or it would not make sense for them to build one without confidence in a good return on investment or guaranteed purchase orders.

Vendors that manage to test their new process or end-item internally or generate testing data for the certification process, are often only rewarded with payment for all up rounds (AUR). If process controls are not in place, the DoD is unlikely to accept their data as allowable or to provide certification or qualification based on industry-provided data. This lack of acceptance of data disincentivizes vendors from investing in creating data or sharing data with the government.



Safety Concerns

Vendors are also reluctant to move away from traditional manufacturing processes toward advanced manufacturing techniques due to safety concerns, particularly in energetics. Many munitions manufacturing steps are carefully controlled because they involve manual, labor-intensive, and dangerous work that can lead to injuries. Working with energetic materials is inherently risky, leading to stringent safety requirements for explosives, propellants, and related components such as motor cases. Vendors may be reluctant to change processes out of fear of undermining current safety measures.

Changes to processes implemented through automation are often met with resistance because they can create electromagnetic fields (EMF) and explosive dust, which contributes to the lengthy qualification process for new technologies involving energetics, as discussed above. Progress requires more knowledge about testing new technologies for use with energetics and using manufacturing equipment, convincing the engineering community to accept new and changing requirements, and then changing those requirements or processes. Quality control for a new process must validate the advanced manufacturing processes in a way that addresses safety concerns.

Contract, Requirement, and Design Inertia

The Department primarily structures contracts to ensure stringent adherence to national security standards. The DoD offers some flexibility in contract requirements when warranted by offering waiver requests when suppliers do not meet certain contractual requirements.² The DoD is undertaking a modernization and commercial innovation adoption push and has contract approaches and acquisition policies to encourage new processes. However, this still means that the government and the IB often must do considerable work together to update contracts or requirements to allow for new processes, techniques, or surveillance approaches. For example, contracts often require an Authorization to Operate (ATO) before software can be deployed. This process can take months to years, depending on what stage of development the software is in, which may result in the software becoming obsolete by the time it is installed.

Engineering change proposals are a key mechanism to allow legacy munitions to implement advanced manufacturing. Engineering change requests will require time to get approved and may be rejected if funding is not available or if other changes are necessary, such as a need for new sources for materials. Avoiding delays to production or future contracts requires information to flow quickly and efficiently. Currently, the engineering change request approval process takes more time than implementing the change. Experts provided competing assessments as to whether it would be desirable to make this system more flexible, as it is built on years of learning from mistakes.

Legacy munitions have specific design constraints and performance requirements that are inconsistent with product changes. Changing design or individual performance requirements will have downstream implications, which will require updating guidance software, interface control documents, and performance requirements. Product designs often need to be updated to fully benefit from new manufacturing methods. Returning to the Rock Island 3D printing example raised under infrastructure requirements, additive manufacturing works best when parts are not simply manufactured using a new method but are redesigned to take advantage of 3D printing's versatility.

² Examples of flexibility under traditional contracting include adjusting payment terms, offering small business set-asides, and a willingness to offer economic pricing adjustments and requirements changes when appropriate.



Appropriations Process

Implementing advanced manufacturing in legacy munitions can be an awkward fit for the defense appropriation process. Maturing new approaches is a natural fit for RDT&E, manufacturing of legacy munitions is the domain of procurement funding, upgrading the organic industrial base often involves military construction (MILCON) funding, addressing obsolescence issues is the domain of operations and maintenance (O&M). Funding account regulations, referred to as colors of money, mean that RDT&E, procurement, MILCON, and O&M funding have different rules and are segregated from one another. This can mean that any given funding line is often only relevant to part of the Producer Financial Incentives challenges discussed above. While this project is primarily concerned with the production of munitions, advanced manufacturing is also relevant to the sustaining of present and future stockpiles. Adopting advanced manufacturing can be a collective action problem since there are high upfront costs and the benefits are distributed across multiple communities within the government.

Fortunately, this problem is mitigated by the availability of Defense Production Act Title III and Industrial Base Analysis and Sustainment program funding. However, these mechanisms face multiple competing challenges and for the reasons discussed above and below, implementing advanced manufacturing for legacy munitions must compete with other urgent DIB resilience priorities.

Culture and Workforce Constraints

Resistance to Change

Often, both the government and industry are set in their ways and operating contractors for government owned contractor operator facilities are often negotiated in periods of ten or more years, with mandated requirements. Most of the time, the Department has an objective and vision for a product and contracts with an industrial partner that has a solution aligned with that vision. The Department chooses to contract with this partner based on the company's ability to provide a known solution to a problem. Because the Department has already bought into this solution, purchasers are reluctant to encourage change or tinkering with new ideas unless specific Contract Line-Item Numbers are funding the innovation. Federal Acquisition Regulations and the Defense Federal Acquisition Regulations allow for flexibility but slow the pace of cultural change. Another challenge is that the energetics community is risk-averse and has a low tolerance for newness due to concerns about safety, which are mentioned in the Safety Concerns section. Implementing something new often requires convincing stakeholders to be open to change.

The First Mover Disadvantage for Programs

The first legacy program to adopt a given advanced manufacturing approach faces considerable challenges as discussed above but also creates spill-over benefits for other programs. However, a Program Manager's primary duty is to their own Program. Program Managers are responsible for the execution of approved production budgets within established guidelines. Their mission is to prioritize stability and predictability in established production lines to meet current procurement levels, control costs, maintain schedules, and deliver required performance. With lines often operating at high or near maximum utilization, disrupting these processes to experiment with new technologies introduces significant risks and potential liability from cost overruns, schedule delays, late deliveries, and potential disruptions to existing performance metrics. Consequently, Program Managers often prioritize proven processes and risk mitigation over potentially beneficial, but uncertain, innovations. Program Managers will not make changes if the current process is satisfying production rates. However, if there is a surge or an updated requirement that causes an increase to the required production rate, a Program Manager may be more interested in introducing new production techniques.



Unless the Prime is meeting its obligations, it will be challenging to get support for integrating advanced manufacturing from Program Offices, Program Executive Offices (PEOs), or individual Program Managers. Buy-in from Program Managers involved in production and quality control is necessary to begin implementing a new process. New ideas are most often met with suspicion, especially if they are not fully understood. Education is key, and there also needs to be trust in the latest technologies for innovation to be considered and approved. Conversely, when one legacy program adopts a novel advanced manufacturing approach, they can clear a path through the challenges discussed in the Departmental Process and Regulations section. Cross-program adoption is still costly and time consuming but Program Managers facing critical munition shortfalls today may prove to be the heralds of broader adoption.

Workforce Requirements and Concerns

Implementing new manufacturing approaches can require finding new workers or retraining existing staff. Munitions manufacturing often involves low pay and poor or dangerous working conditions. The OIB and private sector already have difficulty finding workers willing to work on the factory floor. People with a 2-year college degree, a trade school degree, and/or specialized manufacturing knowledge are increasingly hard to find in today's world. The workforce may also need clearance to participate in classified manufacturing.

Advanced manufacturing raises productivity, but in the near term, it can compound labor shortages by requiring manufacturers to look for workers with specialized knowledge. Personnel operating these technologies need to be trained on new manufacturing systems before adoption. This training can include teaching workers how to program robots and operate machines employing advanced manufacturing, which can be a time-consuming and complex task. Shop floor personnel be prepared and empowered to make purchase decisions. Finally, post-processing work to iterate manufacturing approaches is an essential skill set for the manufacturing workforce.

Advanced manufacturing's specialized workforce requirements make it less appealing for established manufacturers to invest in technology. Also, it is difficult to spread technologies when specialized knowledge is limited to certain people in some geographic regions, which may not align with the location of existing facilities. It takes time to train more individuals to have the

Manufacturing Innovation Institutes

To help mature manufacturing process that show promise, Office of the Secretary of Defense Manufacturing Technology Office (OSD ManTech) sponsors Manufacturing Innovation Institutes (MIIs), which are public-private partnerships that help to mature manufacturing processes and support required infrastructure. The MIIs connect technology, industry, and market sectors to enable the rapid transition of new defense technologies to the warfighter. More specifically, they advance research and technology through partnering with industry, establishing manufacturing ecosystems and regional hubs, and providing education and workforce development to the workforce.

There are nine MIIs in total including MxD, LIFT, and ARM Institute, which were the most relevant to this paper. These three MIIs aided in identifying examples of advanced manufacturing techniques being utilized to produce legacy munitions. In addition, to identifying examples, the MIIs were often involved in implementing many of the examples discussed below. MxD is a digital manufacturing and cybersecurity institute that works to accelerate the adoption of digital solutions and secure supply chains. LIFT is focused on supporting advanced manufacturing through technology, advanced materials, talent development, manufacturing processes, and systems engineering. ARM is focused on deploying robots and artificial intelligence to support implementing advanced manufacturing and developing the next generation workforce.



required skill sets if new workers not from the local area are needed.

For successful adoption of advanced manufacturing, a shared investment in workforce development is essential. Manufacturers need assurance that their workforce possesses the skills and knowledge to effectively support advanced processes, a significant challenge given the current skills gap. Reskilling initiatives are crucial but require time, resources, and a proactive approach to address potential worker concerns about job security and evolving roles. For example, those individuals who take on dangerous tasks are well compensated compared to laborers who are insulated from hazards by new production approaches. Emphasizing the opportunities for career advancement and skills enhancement can foster a more receptive environment for change.

Mature Advanced Manufacturing Processes Showing Promise

Advanced manufacturing is already being applied to legacy munitions in a cases discussed below and summarized in Table 2. These existing examples are followed by a discussion of other promising manufacturing approaches.

Automation Technologies

Automation is the use of technology in manufacturing processes to reduce the need for human intervention to perform in repetitive, complex, or dangerous tasks. Many of these tasks pose safety risks to the humans conducting them or can be completed by machines with greater consistency. Automation uses robotics, information technology, and computer-controlled machinery. By applying automation to existing processes, organizations can achieve enhanced efficiency, productivity, and flexibility. Automation achieves these benefits through mechanisms such as reducing waste through greater reliability, reducing touch labor, and leading to rapid reconfiguration of production lines. These mechanisms are particularly valuable for modernizing legacy systems, especially where precision and safety are paramount. Mature automation technologies show promise for enhancing the producibility of legacy munitions.

Implementing robotics is ideal when the technology can replace labor-intensive, tedious, or dangerous processes. The ARM Institute, Lockheed Martin Corporation, the University of Southern California, and Texas A&M University have collaborated to develop a robotic sanding and finishing solution to address manual sanding in the production of the Joint Air-to-Surface Standoff Missile. In Troy, AL, Lockheed Martin currently sands 2,000 blades per year and each individual blade takes eight hours. The robotic sanding and finishing approach reduced the time required to sand each blade and increased production rates. Additionally, this new approach saved \$813,000 in the first year of implementation. The ARM Institute assessed that widespread adoption of this technology is expected to yield significant savings and growth over time.

In most circumstances, energetics manufacturing is a labor-intensive, time-consuming process that involves exposure to hazardous chemicals and multiple nonlinear, non-concurrent steps. This long process extends production cycles and makes it logistically challenging to process and finish pieces. Despite the current challenges in energy manufacturing, there has historically been reluctance to change processes and procedures because of concern that new external stimuli could cause energy to be released quickly, disrupting manufacturing and endangering workers and facilities.

ARM worked in conjunction with the U.S. Army DEVCOM AC to develop robotics for handling energetic materials. To reduce the number of touchpoints and potential errors, prime contractor Rensselaer Polytechnic Institute partnered with Ensign Bickford Aerospace & Defense at Picatinny Arsenal in Wharton, NJ, to create an off-the-shelf solution for safely pouring granular energetic materials that reduces both human exposure and potential hazardous dust clouds and touchpoints. This led to a design for a container capable of handling



explosive material, a set of robot code, and a supervisory system controller. This solution removed humans from material handling, increased throughput, and improved end-product quality without requiring production line stoppages.

The team at ARM and U.S. Army DEVCOM AC team also worked with Siemens and University of Southern California to utilize imitation learning, using a robot to accurately mimic operators scooping and weighing fine increments of powder. While performed solely with inert materials, this effort demonstrated an initial capability for incorporating robots into hazardous environments, reducing operators' exposure while performing high concentration and labor-intensive tasks. This effort is being incorporated into safe and automated energetic handling research at U.S. Army DEVCOM AC for future transition to the Industrial Base.

Likewise, ARM is working with Indian Head Naval Surface Warfare Center (NSWC), and the U.S. Army DEVCOM AC to apply robotics and automation technologies to explosive pressing operations. The presses form explosive billets that are used in warhead applications. Integrating automation into this process is aimed to reduce operator exposure to hazardous environments and material handling, as well as improving the overall efficiency of the manufacturing process. Both Indian Head NSWC and the U.S. Army DEVCOM AC are planning to develop and evaluate these technologies in prototype systems. Pending a successful prove out, U.S. Army DEVCOM has found interest in further work to transition production lines at manufacturing sites such as American Ordnance, and NSWC Crane.

Also involving some energetics handling, automation is being applied to produce 155mm munitions at three different facilities. At a General Dynamics-Ordnance and Tactical Systems (GD-OTS) facility in Marion, IL, they are producing bag charges for 155mm weapons systems. The assembly process is currently integrating three robotic stations, and the bags are tied using two articulated robots. Additionally, propellant, black powder, and Clean Burning Igniter are delivered to the production line using an Autonomous Mobile Robot. An articulated robot is responsible for stenciling cans and loading pallets. GD-OTS in Hampton, AR, is also using automation in its M795 line for 155mm production. Armtec in Coachella, California, is deploying robots to automate its production line, improving safety and quality. These lines, now automated, have reduced the labor required for 155mm production from 60 to 80 people to 4 to 8 people.

Digital Engineering and Sensing

DoD Instruction 5000.97 defines digital engineering as the use and integration of digital models and underlying data to support the development, testing, evaluation, and sustainment of a system. Digital engineering can be used to modernize how the Department designs, develops, delivers, operates, and sustains systems. Sensors can complement digital engineering by providing real-time data from factory-floor equipment. Even simple sensors can be deployed to effectively monitor machines and items through sensing. Digital tools can analyze data from sensors to monitor quality and drive real-time process improvement. in real-time.

For example, MxD created a sensor kit that is machine-agnostic and requires no coding for implementation. When deployed, the sensing kit can collect data and monitor manufacturing processes, reducing downtime and failures, including on legacy equipment. Data analysis from the sensor kit enables real-time equipment data to inform and improve operations, enhancing efficiency and productivity at the manufacturing site.

Digital tools and sensing have been particularly successful at the U.S. Army DEVCOM AC, which ran a pilot-scale plant where organic material is processed using a melt-pour process. MxD led an effort to implement sensor kits discussed above with the help of sensor integration experts affiliated with the company Concept Reply. They also chose to partner with XMPro to provide the U.S. Army DEVCOM AC with a Digital Twin Framework, as well as the



implementation of a digital twin on the existing melt-pour pilot scale production cell at the U.S. Army DEVCOM AC. Before deploying sensors, the melt-pour process at U.S. Army DEVCOM AC relied on an operator watching the operation and using temperature thresholds to determine whether the slurry mixture was ready to be poured. The implementation of the digital twin enabled the operator to make that decision based on data from industrial sensors rather than relying on and manual recordings, which enhanced precision and consistency across pours. This low-cost digital twin was able to derisk and demonstrate successful implementation, which could be scaled across U.S. Army DEVCOM AC and the DIB. MxD is continuing to work with U.S. Army DEVCOM AC to pilot and prototype this new method for the melt-pour process applies to transform and pour it into shells with uniform quality. The decision on when to pour the mixture will be data-driven and rely on sensors that measure factor such as, sonic velocity, surface tension, viscosity, density, and temperature.

Advanced Materials

Advanced composites combine different materials to produce superior properties that the individual components do not possess. These materials are distinguished from traditional composites by their reliance on cutting-edge materials and manufacturing techniques. These compositions include reinforcement, which strengthens the targeted material, matrix, which holds the components together, and gradients, which replace fragile boundaries with blended materials. For munitions, plasma arc welding is a cutting-edge manufacturing technique that allows for deeper and narrower welds than traditional techniques.

LIFT has opened an Advanced Metallic Production and Processing (AMPP) Center in Detroit, Michigan, which is responsible for development-scale production of custom alloys and feedstocks for metals to support advanced manufacturing. AMPP can produce advanced materials, including metallics, ceramics, high-performance polymer composites, and graded materials. These advanced materials can support parts production and reduce reliance on materials with limited availability by providing substitutes that can be advanced manufactured. This approach integrates physics-based modeling, rapid prototyping, and iterative validation by combining materials design, simulation, and small-batch production. LIFT goal is to employ this approach to dramatically reduce the typical materials development and qualification life cycle—from 5–10 years to just 2–3 years.

Current LIFT brick-and-mortar efforts include finding a more printable alternative to tungsten. LIFT is now working on coupled materials and predicting the performance of materials for hypersonic munitions. For legacy munitions, traditional welding techniques are a source of band failure in 155mm shells, and plasma arc welding could improve band reliability and increase manufacturing productivity fourfold.

Potential Solutions and Reforms and Best Practices

The following reforms, discussed and summarized in Table 3, represent options that would improve production capacity and surge capability for legacy munitions by addressing challenges to the adoption of advanced manufacturing. Some of these options are best practices that already contributed to the pathfinders discussed above. Including advanced manufacturing in new developmental programs is a more straightforward process, but it has limited applicability to producing legacy munitions. Similarly, implementing advanced manufacturing approaches is easier in new facilities than in established production lines, though upgrading established lines is particularly important for legacy munition production. Those forms of advanced manufacturing may prove advantageous for new systems, but the scope of this paper focuses on advanced manufacturing that would providing a positive return on investment for legacy systems.



Producer Financial Incentive Reforms and Best Practices

1.1 *Create steady demand signals to avoid boom-and-bust cycles and encourage investment and consistent funding.*

A repeated problem for the legacy munitions enterprise is a lack of steady demand signals. A history of boom-and-bust-cycles means that the DIB does not see spending increases as indicative of sustained demand. This uncertainty causes both the government and industry to become unsure there will be a return on their investment. Steady demand signals can be communicated through mechanisms such as multi-year contracting for legacy munitions. This approach contractually reinforces the predictability of procurement spending to provide greater confidence in making investments. The downside of this approach is reduced flexibility and less funding available for new systems, but as a result attracts more private capital than the same amount of spending would via shorter term contracts.

1.2 *Invest in research lab efforts to advance understanding of chemicals and materials to the applied level and open new options to address supply chain vulnerabilities.*

A direct path to addressing producer financial incentives is for the Department to further subsidize R&D efforts, derisking, and piloting. The Department has identified advanced manufacturing as a priority by embedding it into its RDT&E budget, as well as by specifically earmarking money to support additive manufacturing. The downside of this approach is that the government bears the cost and strategic choices and oversight are critical for effectiveness. Commercial industry is the proving ground for advanced manufacturing approaches. However, ongoing support for basic research labs like the Office of Naval Research and the Air Force Research Laboratory can aid in addressing challenges specific to legacy munition adoption. This work allows demonstration of the potential of different advanced manufacturing approaches or desired properties for advanced materials. These research labs also are critical in supporting pathfinding for a specific application for the Services. Future opportunities highlighted by experts included research into producing chemicals through biomanufacturing or understanding fundamental properties of materials. Research that can address supply chain vulnerabilities for critical chemicals, materials, or alloys or that could provide the knowledge needed to enable qualification reforms would be especially beneficial for legacy munitions.

1.3 *Invest to derisk and pilot application of relevant advanced manufacturing approaches and expand test and demonstration spaces to encourage advanced manufacturing adoption in the main production lines for legacy munitions.*

Developing and maturing manufacturing approaches that are relevant to legacy munitions is rarely sufficient to incentivize adoption of modernized DIB production lines. Decisionmakers are unlikely to modify established production lines unless the technology is becoming obsolete or there is a demand for higher quantities of the legacy munitions than the technology can support. However, the challenges discussed in the subsection on *Narrow Time Windows for Economical Adoption* mean that prudent investments can expand the menu of options available when the opportunity for modernization arises. This method can also aid Program Managers, System Program Offices, and Program Executive Officers in moving fast while respecting the appropriate grounds for their risk aversion.

The Department invests RDT&E, Defense Procurement & Acquisition Policy, and Industrial Base Analysis and Sustainment program funding enables derisking that helps technology and manufacturing approaches reach higher levels of technological and manufacturing readiness, which may lead to more buy-in. Such funding in combination with DIB investments was the source of most of the pilot case studies discussed above. Further investments in test and demonstration spaces would lower the barriers to entry for small businesses and commercial firms and help address limiting factors for the qualification system.



Government funders could oversee and promote these efforts by collecting and analyzing data to demonstrate the return on investment of advanced manufacturing approaches, including cost savings, improved quality, and increased production capacity. The vendors are the ones who are ultimately responsible for delivering the product. However, analysis from piloting and derisking efforts could aid Program Managers in judging whether advanced manufacturing could address an urgent challenge.

1.4 Encourage vendors and programs to work with relevant MIIs, Service Research Labs (SRLs), and consortia to facilitate forming partnerships and funding, prototyping, integrating, and certifying advanced manufacturing approaches.

New vendors and programs can leverage a range of government resources to aid innovation. Similarly, SRLs, development centers, MIIs, the larger Departmental ManTech enterprise, and related consortia offer a mix of resources and expertise, which can be helpful for validating new approaches, advising on certification, and helping find or connect to contracts. The MIIs can help new companies connect with or establish partnerships with primes, aiding the integration of new approaches into legacy systems production. The MIIs also support prototyping and pilot plant facilities and robotics manufacturing hubs, and SRLs can offer access to their facilities through testing service agreements, which lower the barriers to the adoption of new manufacturing processes. Finally, these organizations can aid would-be partners in finding contracts or funding sources, or in addressing challenges such as funding gaps.

1.5 Use situationally appropriate mechanisms such as OTA and distributing orders directly or via employing consortia or public-private partnerships to enhance incentives for vendors to prototype and implement advanced manufacturing approaches or to ease engineering changes.

The Department can also enter various contracts and agreements with vendors to incentivize accelerated adoption of advanced manufacturing approaches. When a manufacturing approach offers a positive return on investment, the traditional contracting approach of such as multi-year procurement discussed in recommendation 1.1 can provide companies with sufficient time to profit from adoption. A wider range of incentives could be incorporated through OTAs, which are legally binding agreements that use statutory authorities to allow federal agencies to enter business arrangements that do not have to comply with many of the rules imposed on acquisition contracts. The Department is authorized to employ OTAs for prototyping and production when a vendor has invested their own funds or when there is significant participation by a nontraditional defense contractor that has not adopted the demanding federal acquisition cost accounting standards. These approaches could work indirectly by setting incentives for cheaper, faster performance, or directly by addressing non-recurring engineering costs associated with automation and digitization. These agreements could also include greater flexibility to avoid or mitigate the need for engineering change requests prompted by the adoption of advanced manufacturing approaches.

When the Department is directly contracting for materials, parts, or components in support of legacy munitions, breaking up purchases into smaller order quantities and leveraging consortia could reward new entrants and small businesses that adopt advanced manufacturing. Small order quantities could employ multi-award contracts, although OTAs often work with consortia that are particularly well suited to collaboration and distributed production. Public-private partnerships and consortia can bring multiple vendors together, bid on behalf of multiple vendors, and then distribute the workload. This has the potential to provide a return on investment for various vendors, even if they are not yet able to scale to typical Departmental order quantities.



However, it is worth noting that OTAs do not require inclusion of the Defense Federal Acquisition Regulation Supplement (DFARS) clauses for explosives, and therefore safety standards are potentially at risk. The buying activity or new safety administration/oversight organizations could mitigate that risk by notifying the Defense Contract Management Agency Safety Center, Safety, and Occupational Health Division and making sure the contractor is in compliance with their OTA. This suggestion coincides with the advice in recommendation 3.1 to engage the DoD Explosive Safety Board early in the process. In addition, OTAs and more distributed contracts may require a larger and/or empowered acquisition workforce.

1.6 Create or reinforce policies to address complexities associated with data sharing and IP. Create a shareable IP where appropriate, embrace modular open systems approach (MOSA) or containerized munition models, and encourage vendors to address concerns at the outset.

DFARS rules on IP and data rights ownership can be arcane and, when combined with traditional industrial approaches, can hamper collaboration and licensing. Vendors are often reluctant to share information they view as proprietary. Some MIIIs, development centers, and depots have sought to develop IP, such as government reference designs for inert solid rocket motor components, that can be used by the OIB, relevant vendors, or all consortium members. For existing IP of special interest to advanced manufacturing, the Department could better incentivize industry to license and share data on material properties. For example, the producer of additive manufacturing equipment may be more interested in winning defense production contracts themselves than sharing data that would enable their customers to potentially compete with them. This leads to this data often remaining in the head of the technician, being only available on paper, or lost entirely. Similarly, as mentioned above, partnership agreements would help multiple vendors come together to fulfill large contract solicitation orders and the quantities requested. However, explicit agreement at the outset on who owns the IP and controls the data is necessary to address concerns about data rights, data sharing, and IP. These issues need to be resolved before entering into partnership agreements and submitting joint bids. Under traditional models, managing IP and data rights often involves legal obligations and difficult negotiations. However, innovative approaches such as containerized munitions or a MOSA can provide templates that ease the sharing of interface information while allowing vendors to safeguard their most important IP, enabling distributed production facilities. Public-private partnerships can foster collaboration, encourage the sharing of resources, and enable the leveraging of capabilities for dual-use purposes.

Departmental Process and Regulation Reforms and Best Practices

2.1 Share testing data between Services and avoid requiring duplicative testing to achieve qualification to speed innovation and reduce costs.

Reforms that can address the lengthy, time-consuming, and fragmented qualification process are central to advancing the use of advanced manufacturing approaches. Manufacturers are disincentivized from working with the Department because they do not want to allocate significant resources to navigating the qualification and certification process, especially if they are not confident that they will receive a favorable outcome. However, the qualification process plays a vital role not only in ensuring weapon system reliability but also in addressing safety risks for manufacturing workers and weapon system operators. This is especially true for energetic material used in propulsion and warheads, which are rightly subjected to strict safety considerations. Advanced manufacturing offers the potential to improve quality assurance and reduce the role of touch labor in dangerous, dirty, and dull manufacturing processes. However, especially for the newest techniques, the imperative of safety and thoughtful risk-acceptance decisions should be at the forefront of any reforms. Given these difficulties, overcoming fragmentation in the qualification process is necessary to avoid duplicate testing and address data gaps.



2.2 *Where safe and practicable, change the qualification process to allow for end-items that meet well-defined standards to be qualified while reducing or removing importance of assessing the manufacturing process used.*

Because of this difficulty, qualification reforms are easiest to pursue by first focusing on inert components or other situations where an inherently safe environment is more readily achievable. At present, the adoption of advanced manufacturing is slowed by the qualification process that places significant weight on qualifying the manufacturing approach. It would be easier to adopt new and iterate advanced manufacturing approaches if the process increased the focus on ensuring that the end item that meets required specifications and performance requirements.

There are multiple ways to enable a greater focus on the end product rather than the process. In some cases, the commercial industry already employing advanced manufacturing approaches, such as the food and beverage industry, can provide confidence when judging if a manufacturing process meets the criteria for being inherently safe. Inert components, such as motor cases and nozzles used in solid rocket motors, are a good starting point. A related concern is that materials may contain impurities or undergo chemical changes during production using an advanced manufacturing approach. Clearly defining and developing criteria for evaluating potential changes in material properties would reduce qualification uncertainty. Where assessment capacity and safety considerations allow, focusing on the output of the part or component rather than qualifying the process would remove a significant obstacle for the adoption of advanced manufacturing.

2.3 *Encourage and accept more data from manufacturers and tooling suppliers to inform the specification and qualification process.*

A key challenge for the qualification process is that the Department lacks key data on advanced manufacturing production equipment and materials. The Department could invest time and money in generating this data for itself. However, accepting more commercial data to guide qualification and specification decisions would encourage manufacturers to collect and provide more data. Commercial data is especially important for additive manufacturing, where additional data could enable broader standards rather than qualifications specific to a particular machine-feedstock combination. The Department could also relax its standards for the data it accepts, allowing industry testing and certification data to be included in the qualification process. Accepting commercial data would save time and effort, though as trust builds, it may be easiest to use this data as a multiplier for Department-collected data rather than a replacement.

2.4 *Support digital approaches and necessary infrastructure investments by accepting sensor data and digital twins.*

The Department could modernize its policies to reinforce the adoption of digital engineering and model-based system engineering. Shifting inspection regimes to rely on sensors, such as laser phallometers with automated defect detection, can enable the adoption of digital twins. As discussed in the section on *Limits of Incremental Adoption*, manufacturers will typically need to invest in network infrastructure to achieve the benefits. As a result, favorably considering the availability of digital twins and sensor data is an important step to reward the adoption of digital manufacturing approaches. Accepting digital twins and favorably considering sensor-based assessments are important steps toward encouraging the adoption of digital engineering approaches. These benefits may be especially important in supporting the development of advanced materials. Integrated tools and materials enable the simulation of the additive manufacturing and the properties of known alloys, which could allow for digital prototypes.



2.5 Use innovative arrangements to support rapid prototyping, partnerships, and distributed manufacturing, which can lead to faster fulfillment of government needs.

As discussed in recommendation 1.5, OTAs provide a legal mechanism for the government to create and promote new technologies in partnership with nontraditional defense contractors and commercial firms by reducing barriers to entry and burdensome requirements. OTAs are particularly relevant for advanced manufacturing because many vendors creating novel technologies using advanced manufacturing approaches are not typically federal government or defense contractors and have commercial products. OTAs help facilitate rapid government development and the acquisition of novel solutions, including advanced manufacturing approaches. Besides, OTAs, there are also Broad Agency Agreements, Small Business Innovation Research (SBIR) funds, Cooperative Research and Development Agreements, and Indefinite Delivery, Indefinite Quantity contracts that offer opportunities to promote and leverage new technologies. These agreements and authorities help to transition commercial solutions to the defense marketplace.

Culture and Workforce Constraint Reforms and Best Practices

3.1 Educate communities, particularly the manufacturing workforce, regarding advances in advanced manufacturing relevant to legacy munitions.

Education about advanced manufacturing can help reduce skepticism about change. User communities that are resistant to change, such as the energetics community, could be introduced to increasingly mature concepts and have their tolerance for newness tested. Bringing program office staff and leadership on board is especially important as they control production dollars. Educating those involved in existing manufacturing processes about the new processes should ease their concerns or identify issues that still need to be addressed. Additional funding for the qualification process to develop safety protocols and risk assessments can reduce reluctance. Advanced manufacturing subject matter experts should evaluate approaches for effectiveness and applicability to specific programs and provide workforce training tailored to each program's context. In addition to education, the Department can pursue this goal by fostering a culture of innovation and experimentation in government and industry, establishing or leveraging Joint Working Groups, supporting for industry conferences and engagements, and work with academia to close skills gaps.

3.2 Employ data driven decision making to target adoption of advanced manufacturing and overcome skepticism where the benefits are greatest.

Decisions about whether to implement a new manufacturing approach should be based on whether there is a return on investment in the approach and on that determination. However, the Department lacks the information needed to make this determination most efficiently. Recommendations 2.2 and 2.3 would help to evaluate whether a proposed or piloted approach would improve quality and production capacity and/or reduce costs. If the Department had relevant data available, it would be easier to persuade Program Managers to implement a particular approach.

3.3 Provide training and workforce development focused on advanced manufacturing to those with manufacturing careers or those interested in manufacturing careers, leveraging MII programs and resources.

Developing and employing next-generation workforce training programs can expand the available workforce and increase comfort with advanced manufacturing. Workforce training programs should be used to train individuals who are interested in advanced manufacturing. Additionally, those in the present workforce who would be involved with implementing new advanced manufacturing approaches should be provided with specific training. Next-generation



training programs allow the current workforce to maintain their jobs and repurpose labor into roles such as robot maintenance, programming, and control room positions that help sustain advanced manufacturing technologies. To assist with these issues, more manufacturers could partner and work with MIIs, which have workforce development programs, including training and certificate programs focused on enhancing proficiency in advanced manufacturing. The MIIs also help grow the workforce by promoting manufacturing jobs, providing opportunities for regional students through partnerships with local community colleges and universities, designing and executing education programs, offering innovative apprenticeships, and providing access to job databases. Additionally, the Office of the Secretary of Defense's Manufacturing Technology Program manages the Manufacturing Workforce Development Program (M-EWD), which advises the MIIs on talent development. By developing talent, the MIIs can help address workforce concerns that their jobs will become obsolete by equipping manufacturing workers with the skills needed to implement advanced manufacturing.

Next Steps

JPAC will apply lessons from this project to foster proactive failure analysis detection and mitigation. JPAC will leverage lessons learned from artificial intelligence to predict and address common production failure modes to better assess failures/defects during processing before they are discovered in the finished product during acceptance testing—saving time and money during production. In addition, this report suggests further opportunities for piloting or scaling the case studies above to better integrate advanced manufacturing into the defense industrial base in hopes of helping to build surge capability and produce legacy munitions faster. These potential pathways focus on automation technologies more broadly, digital engineering and sensing, reforming qualification for additive manufacturing, and flexible manufacturing.

One relevant area for scaling would be the MxD sensor kits, which have been installed at Portsmouth Naval Shipyard. This simple no-code solution could be integrated into legacy munitions production lines. The current focus of the sensor kits is to provide real-time performance tracking and closed-loop real-time data analytics to allow for proactive analysis detection and mitigation. There are many factories, ammunition plants, and systems that would benefit from using sensing to gather data on real-time progress towards an objective. Turning to automation, the paper cites many instances in which advanced manufacturing approaches

Advanced manufacturing has the potential to improve the speed, efficiency, and agility of munitions manufacturing, which could make it easier to surge production. Implementing new approaches may lead to challenges aligning new opportunities with current Departmental processes, paying large upfront costs, and will thus not always be practical for legacy munitions production lines. However, targeted adoption is likely to lead to long-term gains from process improvement, especially when focused on addressing manufacturing challenges and the maturing of defense applications of commercially proven manufacturing approaches. Advanced manufacturing presents a potential solution to an urgent need to surge munitions and strengthen the industrial base, and as such should be viewed as a critical investment in the supply chain. Present efforts to ramp legacy munition production are an opportunity for the Department to leverage partners, MIIs, and innovators to mitigate the challenges with integrating advanced manufacturing and modernizing technology. Success would allow for advanced manufacturing to become a core component of the future munitions industrial base.





ACQUISITION RESEARCH PROGRAM
DEPARTMENT OF ACQUISITION, FINANCE, AND MANPOWER
NAVAL POSTGRADUATE SCHOOL
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CA 93943

WWW.ACQUISITIONRESEARCH.NET