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Architecting Affordable Mass

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Architecting Affordable Mass

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Abstract

The U.S. guided munitions enterprise faces critical production and surge limitations, a significant vulnerability in the context of industrial-scale warfare and strategic competition. While current efforts to ramp production through larger budgets and supply chain investments are underway, these solutions are often slow and capital-intensive. They are further hampered by a consolidated industrial base, high barriers to entry, and boom-and-bust demand cycles that discourage investment.

This paper examines how the synergy between two key initiatives—affordable mass programs and Modular Open System Approaches (MOSA)—can address these challenges by fostering production adaptability. Affordable mass programs leverage flexible requirements and commercial technologies to boost producibility and lower unit costs. In parallel, MOSA uses government-defined open architectures to lower barriers to entry, sustain competition, and speed innovation. This paper draws from interviews regarding pathfinding munitions and adjacent systems to draw lessons on achieving production capacity and surge capability. The paper identifies seven categories of enablers: (1) enhance module competition, (2) promote reuse, (3) modularize in-service, (4) commoditize modules, (5) sustain markets, (6) sustain system competition, and (7) acquire mobilization options. The paper explores how these enablers interact and suggests options to scale the approaches of pathfinder programs.

Executive Summary

The global proliferation of munitions, advances in unmanned systems and their use in conflict, China's emergence as a manufacturing superpower, and the return of industrial scale warfare are all pressing problems for the U.S. guided munitions enterprise. The Department and the defense industrial base (DIB) are limited in their ability to produce and surge guided munitions, especially those with exquisite performance. Executive orders, legislative actions, and departmental decisions have sought to address this problem.

In a panel discussion on this topic, Maj Gen Kunkel drew from his own experience as a fighter pilot to outline what limitations look like to an operator in wartime. In the initial weeks of the war in Kosovo, the Air Force had top-of-the-line missiles that could hit a target the size of the projector in the room, but after a few weeks those were expended, and the targeting accuracy was decreased to a target the size of the tall and wide screen. A few weeks later they were reliant on stockpiles of dumb bombs that may hit a target the size of the room. This challenge is even more dangerous in a great power conflict such as the war in Ukraine, where defending vital targets is increasingly difficult, let alone to deterring a war with China.

Elected leaders and the Department are already pursuing the munition production growth via one primary and one supporting avenue, respectively:

- **Increasing the demand signal** through budgets, block buys, and the use of multiyear procurement (MYP).

- **Investigating in supply chains and intervening** to address limiting factors and bolster the munitions industrial base (IB), including both private and government-owned facilities.

These steps are already boosting production capacity. However, that process is capital-intensive and time-consuming. This inherent difficulty is magnified by three additional problems:

- **High barriers to entry exist** due to inherent technical and qualification difficulty, magnified by incomplete data and a consolidated munitions IB segregated from commercial industry.
- **Production capacity is fragmented by program**, leading to notable nonrecurring engineering, time, and financial costs to crossover, especially for the qualification process.
- **Boom-and-bust cycles and uncertainty** impede investment. The demand for munitions regularly changes, and the industrial economics only reward addressing enduring demand.

Fortunately, the Department is already pursuing two initiatives that, along with supply chain efforts, enable production adaptability. These efforts provide combat capability by accelerating the rate at which the acquisitions system and IB orients and acts on operator needs.

- **Developing affordable mass programs** that leverage flexible requirements, commercial technology, and new manufacturing processes to boost producibility and lower unit costs.
- **Architecting openness and commonality** to lower barriers to entry, sustain competition, and speed innovation through a modular open system approach (MOSA), government reference architectures (GRAs), or government reference designs (GRDs).

This project examines how synergies between how affordable mass and MOSA can address the warfighting imperative of production adaptability. The results are summarized in Table 1.

Table 1. Theorized Affordable Mass and MOSA Pathfinder Enablers of Production Capacity and Surge Capability

Enabler	Description	Production Capacity	Surge Capability	Pathfinding Examples
Enhance Module Competition	Allow open competition via open architectures with severable modules	● Adds flexibility to route around bottlenecks and rewards speed of scaling	◑ Incentivizes producibility but optimizing for price risks losing slack capacity	Enterprise adoption of WOSA and AMS GRA
Promote Reuse	Use technology and items from any supplier across programs and life cycle	◑ Reduces development and test requirements but requires conformity	○ Creates commonality which allows for other benefits but has risks	SOSA focus on scale of adoption; GPS modules
Modularize In-Service	Incrementally open a portion of a system's architecture.	◑ Addresses bottlenecks, but requires leverage, e.g. block upgrade or MYP	◑ Enables pursuit of other benefits, as above	Exquisite munition mission systems and propulsion 2nd sourcing
Sustain a Market	Maintain diverse IB by pooling demand and enabling interchangeability	◑ Leverages commercial IB, small business innovation, and allied IB	● Preserves engineering communities and allows for competition for scaling	FACE and SOSA for software and sensors respectively
Commoditize Modules	Prioritize producibility and lower qualification risk	● Sacrifices other priorities for production ramping	◑ Lowers barriers to entry and eases surging	Energetic subsystems experimentation
Sustain System Competition	Use government reference architectures to sustain or expand prime competition	◑ Avoids prime vendor lock, but challenging for exquisite systems	○ Eases bringing in latent or international capacity, but requires development	Affordable mass missiles and UAS; CCA; OMS/UCI inter-system MOSA
Option to Mobilize	Employ contract-producers to address production constraints	◑ Allows for mobilization, if license or government reference design in place	● Mobilizes flexible manufacturing and partner industrial bases.	Development of energetic subsystem technical data packages; franchise model
Legend: ○ Relationship situational or faces high barriers; ◑ General benefit but notable risk(s) or scope limit(s); ● Clearcut benefits				

Source: 18+ interviews with pathfinding programs and guidebooks (Fookes, 2023; Guertin, 2025; Kendall, 2013; OSE&A, 2025). Notes: The table draws from munition and adjacent systems, standards, and architectures with relevant to MOSA. The key standards and architectures include the Weapon Open System Architecture (WOSA) and Weapon GRA, the Open Mission System/Universal Command and Control Interface (OMS/UCI), the Agile Mission System, the Future Airborne Capability Environment (FACE), the Sensor Open Mission System Architecture (SOSA). For the Army, this project focuses on Army Launched Effects (LE) / Long-Range Precision Munition (LRPM). For the Navy, this project examined Conventional Prompt Strike (CPS) and the nascent Coalition Heterogenous Affordable Offensive Strike (CHAOS). For the Air Force, the project considered the Air Force's Collaborative Combat Aircraft (CCA), Family of Affordable Mass Munition (FAMM) and Extended Range Attack Munition (ERAM), and Dragon Cart. Multi-service and Research and Engineering efforts to expand production of energetics subsystems, including the Low-Cost Cruise Missile (LCCM), also provide important examples at the subsystem level.

Introduction

Advances in unmanned systems and their use in conflict, the return of industrial scale warfare, and growing demands on air and missile defense systems are pressing problems for the U.S. guided munitions enterprise. This challenge is reinforced by China's rise as a manufacturing superpower as the U.S. economy shifts to services as part of globalization. Current U.S. guided missiles have exquisite capability but face challenges that limit the defense industrial base's (DIB's) production capacity and surge capability. Executive orders, legislative action, and departmental decisions have invested time and money in pursuit of addressing this problem.

In a panel discussion on this topic, Maj Gen Kunkel drew from his own experience as a fighter pilot to outline an operator's wartime perspective on these limitations. In the initial weeks of the war in Kosovo, the U.S. Air Force had top-of-the-line missiles that could hit a target the size of the room's digital projector. After a few weeks those were expended, and the available munitions could instead hit a target the size of the tall and wide screen. A few weeks later, operators were reliant on stockpiles of dumb bombs that may hit a target the size of the room. This challenge is even more dangerous in recent industrial-scale conflicts, let alone to deterring a war with China.

Elected leaders and the Department are already pursuing the production aspects of the munition production challenge via one primary and one supporting avenue, respectively:

- **Boosting the demand signal** via budgets, handshake deals, and multiyear contracting.
- **Investigating supply chains and intervening** to address limiting factors and bolster the munitions industrial base (IB), including both private and government-owned facilities.

These steps are already boosting production capacity. However, that process is capital-intensive, requires time-consuming facilitation efforts, and faces difficult workforce constraints. This inherent difficulty is magnified by three additional problems:

- **High barriers to entry exist** due to inherent technical and qualification difficulty, incomplete technical data packages, and a consolidated DIB segregated from commercial industry.
- **Production capacity is fragmented by program**, leading to notable nonrecurring engineering, time, and financial costs to crossover, especially for the qualification process.
- **Boom-and-bust cycles** impede investments. The demand for munitions regularly changes, and the industrial economics only reward addressing enduring demand.

This paper explores the production acceleration and returns on investment that could be achieved by a Modular Open System Approach (MOSA). MOSA's established benefits have the potential to address these challenges. However, policy-makers lack good metrics and models to weigh the relevance of MOSA to their production problems.

This paper further explores how developing affordable mass programs that leverage flexible requirements, commercial technologies, and new manufacturing processes boost producibility and lower unit costs. Affordable pathfinders used two more approaches of interest:

- **Sustaining System Competition** by employing government reference architectures (GRAs) to retain multiple primes through production to allow for future competitive on-ramps.

- **Acquire Mobilization Options** via expanding production using franchising / licensing options or government-held technical data packages to address latent industrial capacity.

Key Concepts

MOSA: Programs employing MOSA have several modules that are internally highly cohesive while being loosely coupled with one another through open interfaces. For example, a guided missile may have a solid rocket motor as one module, the warhead as another, and the guidance system as a single subsystem or multiple components. MOSA draws on commercial principles seen in Android phones, universal serial bus (USB) devices, and International Business Machines (IBM) personal computers. The use of a MOSA, mandated for new programs of record to the extent practicable by 10 U.S.C. 4401–4403 and reinforced by tri-service memos, involves technical and business approaches that "enable incrementable development and enhanced competition, innovation, and interoperability" (Del Toro et al., 2024, p. 2).[1] MOSA standards are collected in GRAs developed and shared with partners in industry. MOSA is easiest to apply to a developmental program and has benefits throughout the life cycle but is traditionally not focused on production capacity or surge capability.

Affordable Mass: The concept of affordable mass originates from the idea that the Department should invest in a high–low mix, which is a combination of low-cost systems and exquisite systems that complement each other.[2] Affordable mass systems need flexible requirements that accept niche or lower-level performance to enable greater adoption of commercial technology and advanced manufacturing approaches. Precision-guided munitions and attritable uncrewed systems are well-suited to affordable mass because human pilots are not at direct risk. Finally, affordable mass systems rely on software to allow for fast and scalable adaptation. The name captures two key metrics of success: *affordable* refers to lower unit cost while *mass* implies a mix of production capacity or surge capability. Affordable mass programs must avoid or overcome factors that slow the scaling of exquisite systems.

Production Capacity and Surge Capability: Production capacity refers to the quantity and timeline of goods that the DIB produces under current funding and prioritization. Increasing production capacity involves slow and expensive investments. Surge capability refers to the ability to rapidly increase production. This may be accomplished through employing idle DIB capacity from current producers, including facilities and tools that are set aside ("mothballed") for emergency use. Alternatively, this could involve providing a technical data package (TDP) to a new producer with flexible manufacturing capabilities in private industry or the organic industrial base. This would require a franchising or license agreement or government-owned TDPs or interventions (Cook, 2023).

Research Issue and Method

This paper is concerned with the combat capability provided by DIB production capacity and surge capability. MOSA guidebooks discuss scalability, obsolescence, and diminished manufacturing sources and material shortages (DMSMS) but not production capacity or surge capability directly (Fookes, 2023, p. 15; Guertin, 2025, pp. 14–16; Kendall, 2013; pp. 25, 48;

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[1] The tri-service memo charges acquisition officials with implementing five pillars of MOSA: "(1) employing a modular design, (2) designating modular interfaces, (3) leveraging consensus-based open standards, (4) establishing enabling environments, and (5) certifying conformance" (Del Toro et al., 2024, p. 2).

[2] The concept of a high–low mix, focused on aircraft, dates back to reform proposals in the 1970s and 1980s (Carroll, 2008). Recent discussion of high–low mixes and the newer term *affordable mass* tend to emphasize not just weapon cost but also producibility (Gunzinger, 2001; Pettyjohn, 2025).

OSE&A, 2025, pp. 7, 23–24).[3] While MOSA's benefits are relevant to production capacity and surge capability, the Department's focus on production acceleration demands trade-offs under tight time horizons. This paper studies pathfinding MOSA programs to better understand how and to what extent a MOSA approach allows the production of more guided munitions faster. The author conducted 18+ interviews to answer the following research questions:[4]

- How do munitions and adjacent programs that employ MOSA incorporate producibility into their architectural decisions and investments?
- What traditional munitions producibility challenges are addressable through modularity or adoption of commercial standards, and what are the present plans of affordable mass programs to address or bypass these limitations?
- To what extent could architectural design expand DIB production capacity or surge capability by incorporating nontraditional or international producers or modernizing the existing U.S. DIB?

Results

The interviews with pathfinding programs found that MOSA is being experimented with by a mix of exquisite and affordable mass munitions. Production capacity and surge capability was typically a secondary consideration. Nonetheless, both pathfinders and guidebooks agreed on addressing production constraints using consensus-based open standards that allows cross-vendor interoperability, break-out modules for components of concern, and substitution of components with ones from other suppliers (Fookes, 2023, p. 15; OSE&A, 2025, pp. 23–24). The first three enablers draw from MOSA guidebooks:

1. **Enhance Module Competition:** Using severable modules with open architectures.
2. **Promote Reuse:** Reducing testing and development by reusing items across programs.
3. **Modularize In-Service:** Employing incremental MOSA to allow reuse in exquisite systems.

The remaining enablers are drawn from MOSA pathfinders:

1. **Commoditize Modules:** Prioritizing producibility and reducing risks that lengthen qualification for items that are capital intensive to manufacture and lack dual-use markets.
2. **Sustain Markets:** Building competitive and pooled markets for modules and resilience by making it easier for multiple suppliers to achieve a minimum sustainable production rate.
3. **Sustain System Competition:** Retaining competitors and the ability to employ and on-ramp primes via GRAs and affordable mass approaches.
4. **Acquire Mobilization Options:** Ensuring means to scale manufacturing in ways not required by MOSA—for example, through a franchising or manufacturing licensing agreement option or by arranging for a distributable government reference design.

The remainder of this paper dives into these enabler categories to draw findings from pathfinder experimentation. Figure 1 presents a theorized relationship between these tools.

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[3] The *DoD Producibility and Manufacturability Engineering Guide* mentions MOSA once, noting that it will be considered as part of the Independent Technical Risk Assessment for Major Defense Acquisition Programs (OEDSE&A, 2024).

[4] See the appendix for the guided conversation questionnaire used in these discussions.

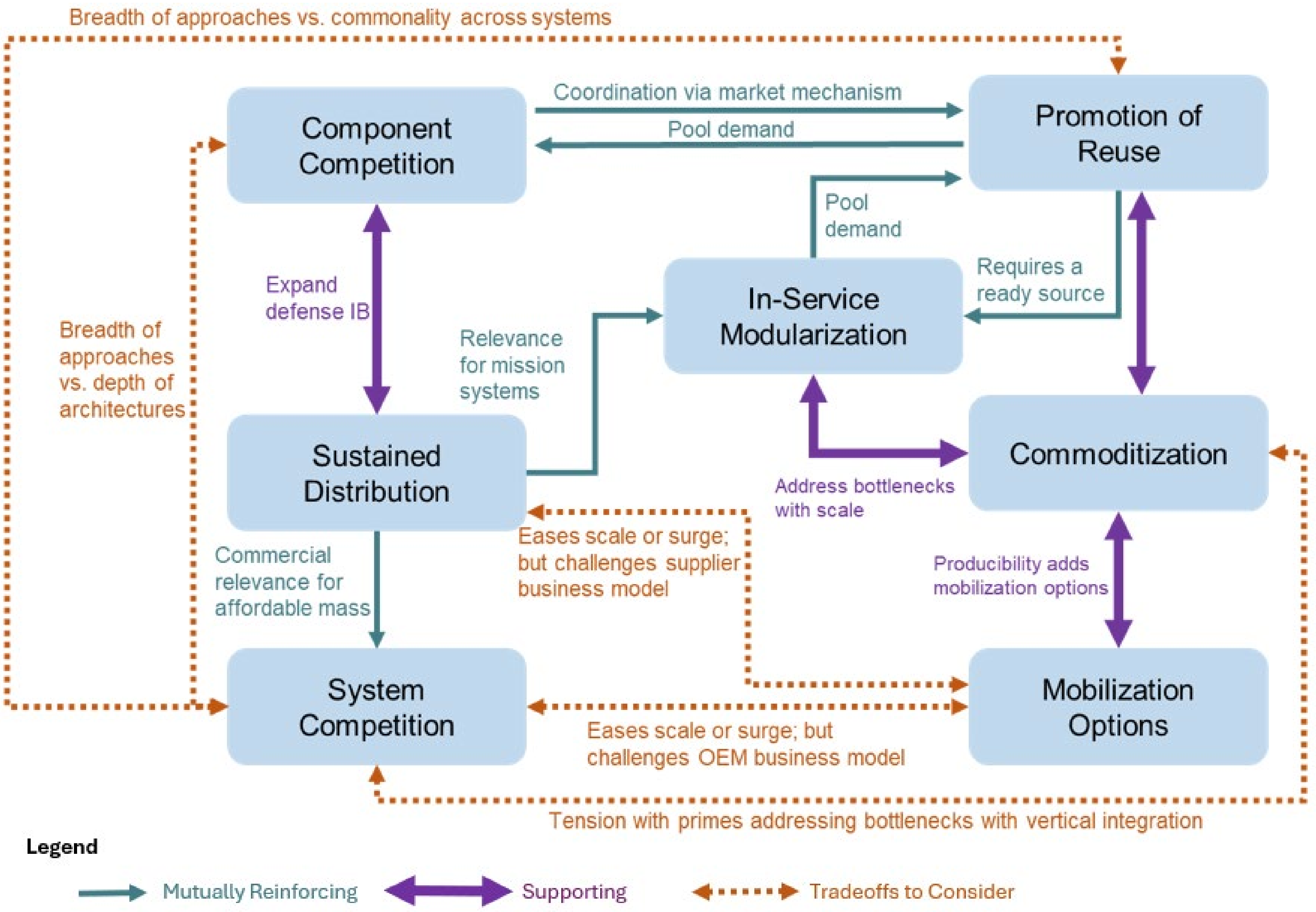

Figure 1. Interaction Between Affordable Mass and MOSA Pathfinder Enablers of Production Capacity and Surge Capability

Enhance Module Competition and Promote Reuse

Component competition is core to MOSA and enabled by “open architectures with severable modules” that may be substituted. A diverse and competitive supplier base “fosters innovation and drives down costs” (OSE&A, 2025, p. 6). The possibility of competition gives the government flexibility if another supplier is available and lowers barriers to the entry of new suppliers. However, even competitive markets experience single points of failure, and qualifying new suppliers will be costly and time-consuming, especially where domestic production does not have a comparative advantage.

Reuse of components between programs or variants is also enabled by an open architecture with severable modules. Widespread adoption of a MOSA standard “promot[es] the reuse of technology, modules, and components from any supplier across the acquisition life cycle, reducing the need for redundant development efforts, reducing test requirements, and leveraging existing investments efficiently” (Guertin, 2025, p. 5). Enterprise mandates and mature standards enable pooled and competitive supplier markets (Fookes, 2023, pp. 22–23). That said, enterprise standards do not guarantee reuse because two programs may implement the same standard in different ways that adds friction to commonality.

The most relevant standard for munitions is WOSA, which was developed out of the Air Force Research Lab with help from an industry consortium starting in 2014. This standard and associated weapons GRA has been adopted by multiple U.S. Air Force and U.S. Navy programs, discussed below, each with its own implementation architecture. The Munition Open Architecture Test and Evaluation Laboratory (MOATEL) maintains the standard and provides expertise and modeling capacity to assist in employing and verifying the standard.

WOSA has wrestled with the trade-offs of promoting component reuse versus seeking widespread adoption. After initially taking a more rigid approach, the architects chose to open the standard up to a wide range of projects and focus on standardizing the logical messaging. This left key hardware and transportation protocol decisions to the vendors and mission space. Timing was an important concern when defining the score of domains under WOSA. The architects used research and simulation to ensure that the dividing lines between modules did not result in requirements that industry would not be able to follow. Architecting for affordable mass munitions is less demanding than for more exquisite systems that deal with larger temperature ranges or faster speeds. As a result, an affordable mass system could mandate commercial ethernet standard connections or physically modularize almost every hardware subcomponent. WOSA is now working to extend this logical model into the physical domain.

In addition to WOSA, three other standards highlighted by the tri-service memo’s shortlist were included as pathfinders (Del Toro et al., 2024, p. 1):

- The Agile Mission Suite Government Reference Architecture (AMS GRA) is the U.S. Air Force standard for crewed and autonomous air platforms. AMS GRA deals with large clusters of subsystems. For example, in the Collaborative Combat Aircraft (CCA), there are modules for the air frame, mission systems, and autonomy.
- The Sensor Open System Architecture (SOSA) is a standard for command, control, communication, computers, cyber, intelligence, surveillance, and reconnaissance (C5ISR) payloads. SOSA coordinates U.S. government customers to agree on high volume common form factors and solutions that deliver affordable C5ISR payloads.
- Future Airborne Capability Environment (FACE), like SOSA, emphasizes commonality. FACE decomposes software applications to modules and manages data flows.

The U.S. Army was, at time of interviews, experimenting with their approach to uncrewed systems and missiles. The U.S. Army Launched Effects (LE) is grouping some missile programs within their larger unmanned aerial systems (UAS) family of systems and enterprise architecture approach, including FACE. However, attempts to apply MOSA to small UAS have encountered challenges and may focus on external interfaces (i.e., command and control, and dispenser/launcher) and system competition rather than modules within systems.

Modularize In-Service and Commoditize Long Lead Items

Bringing in a new supplier or manufacturing approach is challenging if that supplier or approach has not already provided equivalent or close components to a different program. The difficulty is magnified for systems that do not have an open interface for the module in question. Most in-service guided munitions have not yet implemented MOSA and tend towards highly intertwined functions. While MOSA is most easily incorporated early in the life cycle, when the government has leverage, this barrier can potentially be overcome by opening a loosely coupled portion of the architecture via incremental MOSA (Fookes, 2023, pp. 13–14; Guertin, 2025, p. 6).

Even in the absence of MOSA, primes will seek out second sources, sometimes in response to inducements, pressure, and/or change orders from the U.S. government. Prime vendors do have an incentive to address production constraints and to maintain surge capability, because producing at the pace of demand would earn revenue faster. However, expanding production capacity and maintaining slack capacity are both expensive, and given the history of munition boom-and-bust cycles, a risk averse company may prefer to maintain a backlog, keep costs low, and win sales over a longer time frame.

Sustained ecosystems drawing on the commercial sector offer the most opportunities for innovation. However, when dealing with military-specific technology to address a critical bottleneck, one program at a time may be the fastest option. This might involve an exquisite capacity, for example Military-Code (M-Code) GPS receivers that can overcome jamming but faced significant delays (Ludwigson, 2024). Alternatively, this may involve a widely produced item with difficult-to-source materials, constrained lower-tier suppliers, like solid rocket motors (Shalom, 2026). Multiple factors add time and cost to the qualification process: certify a new vendor or production line, a new production process, or a new design. The standards are even higher for flight-critical components, where any failure could lead to unsafe operations, or energetics, which involve dangerous chemicals and the risk of explosions.

Incremental adoption of MOSA could help scale the benefits of direct-to-supplier efforts to address a critical bottleneck because GRAs and domain implementation packages can be applied to other programs or vendors.

Commoditization is a pragmatic approach for bottlenecks involving difficult-to-qualify items because it focuses innovation on widespread producibility rather than specialized performance. Affordable mass systems have an edge in this case because more of their performance is defined by software, allowing for more reliance on lower-cost mass-produced hardware. However, even for exquisite systems, a subsystem like a solid rocket motor will have components such as inert motor cases where qualification could be eased through greater use of proven items across programs, albeit still needing to allow for differences in diameter or the like.

Sustain Markets

A diverse and distributed manufacturing ecosystem has considerable advantages for resilience and is an opportunity to build up geographic clusters of producers that advance process knowledge that is key to manufacturing success. Competing producers can uncover new production approaches, mitigate risks to any given facility, and offer more choices when it is time to surge.[5]

The number of competitors that can be economically maintained for a system or module depends on the minimum sustainable rate of production. A competitive and pooled market for modules makes it easier for multiple suppliers to achieve that rate and allows primes to take advantage of a shared supply chain. Sustaining distribution is most straightforward when vendors can draw on commercial markets or allies subsidizing sovereign production, or when small businesses can manufacture the item on their own.

The maximum number of sustainable competitors will depend on the extent of demand and the magnitude of barriers to entry and capital expenses—that is, how many vendors could reach a minimum sustainable rate of production. MOSA expands this number by pooling demand to create larger markets, including dual-use technology, increasing the frequency of competition, and offering on-ramps for new vendors. Pathfinders have made decomposition and disclosure choices that allow access to wider commercial or international markets.

Decomposition refers to how a larger system is broken down into smaller modules, which has functional and physical aspects. FACE's and SOSA's granular modules and adoption of commercial standards make them more accessible to small businesses. Incremental MOSA can likewise target modules of less concern to primes with larger potential markets, such as gyroscopes. The greatest benefit for surge capability comes if there is a robust commercial-off-the-shelf (COTS) or near-COTS market for the module in question—for example, for microelectronics or hardware connectors. Affordable mass systems systematically seek to include commercial standards and COTS, though some of the approaches may scale to exquisite systems willing to accept shorter item lifespans.

Disclosure of standards can also ease the participation of international vendors, in line with the National Defense Strategy.[6] U.S. allies and partners have been increasing their defense spending and purchases of U.S. weapon systems, but electoral and sovereignty concerns mean that access to these markets will often depend on partner industrial participation. In addition, MOSA designs for exportability, which enables the substitution of less sensitive items for export, such as seekers, reducing risks of variant-lock and easing the strategic leveraging of partner industrial bases while protecting technology security.

The CCA has been an exemplar of employing MOSA to better leverage international production capacity and investments to ramp production and build surge capability (Decker, 2025; Sanders & Aldisert, 2024). Standard accessibility to allied and commercial industrial bases has been furthered by the U.S. Air Force making an unclassified version of AMS GRA and the release of WOSA to select partners. The FACE standard has been released to the public, incorporated into British standards, and includes Five Eyes industry in their consortium.

Sustain System Competition

This enabler refers to the ability to sustain and on-ramp multiple competing primes for production. This is enabled by shared GRAs and is most common for affordable mass systems.

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[5] Manufacturing ecosystems are an area where China has overtaken the United States in some sectors. For example, Shenzhen is a global electronics manufacturing powerhouse (Wang, 2025, pp. 59–68). That said, economies of scale are a powerful force, and even as China has expanded its ballistic missile facilities and production capacities over the last two decades, their number of companies and facilities has consolidated (Jones & Palmer, 2024, pp. 27–28; Wood & Stone, 2021, pp. 2, 19–20).

[6] The National Defense Strategy mandates "leverag[ing] allied and partner production not just to meet our own requirements but also to incentivize them to increase defense spending and help them field additional forces as quickly as possible" (Hegseth, 2026, p. 4).

Promoting reuse via commonality allows for shared supply chains, but greater variation may allow for more primes and approaches to producibility.

The traditional departmental approach is to compete primes against one another to win development contracts using a winner-take-all model for production. Vendors are incentivized to bid aggressively to win contracts and then to make their money back in production and, primarily, sustainment. Purchasing from multiple primes and sustaining multiple supply lines is expensive. Modularity can mitigate these challenges, but the largest multi-award crewed system of this century, the Litoral Combat Ship, experienced significant production challenges and met an early end. Other crewed systems like the Future Long-Range Assault Aircraft were able to leverage MOSA and other transaction authority to sustain competition longer than typical but still chose a single prime.

Today, the uncrewed CCA and affordable mass systems are leveraging MOSA and GRAs to sustain competition into production and, in theory, maintaining the ability to on-ramp additional primes in the future. The GRAs make it easier to maintain relationships with multiple vendors and for them to rapidly iterate the products they are experimenting with into compliance with a given program. In its first tranche, the CCA is a notable success story for AMS GRA, going from contract through development in 14 months. Some affordable mass munition and small UAS programs are maintaining a variety of vendors and intend to carry that forward or allow for on-ramps. MOSA allows systems to go beyond interoperability to interchangeability. Maintaining competitors is easier if operators and interconnected systems can operate agnostically of whatever prime provided the system. These can vary in form factors and key design choices, but systems meet the same minimum thresholds.

A key question for program and portfolio officials is to what extent will they allow system competition to substitute for open hardware interfaces (component competition) and commonality (promoting reuse). A vendor may posit that vertical integration and rapid testing is their path to producibility. Alternately, vendors may push for designs with open interfaces that vary, which does not allow for easy reuse of items.

Acquire Mobilization Options

Under the MOSA “gray box” model, the government understands a module’s function, behavior, and interfaces but does not hold the TDP that would allow for organic or contract-producer manufacturing.[7] An option to mobilize goes further, by including a franchising or manufacturing licensing agreement option clause or by arranging for a government reference design that can be directly distributed. This is a challenge to traditional DIB business models and thus may require considerable leverage to arrange.

The option to mobilize has two core advantages: addressing a wider base of manufacturing capacity and employing proven designs to minimize the difficulties of qualifying a new source. This approach draws on multiple concepts: the conversion of factories to wartime production during the Second World War, contract-production common in multinational supply chains, and new concepts such as manufacturing-as-a-service. However, the option to mobilize is more challenging than the disruptive but developed logic of MOSA gray boxes. The Department has rights to IP it fully funds, and MOSA benefits from government-purpose rights (GPR) to open interfaces. However, most development has mixed funding, and detailed manufacturing and process data is well protected absent an invocation of the Defense Production Act. Vendors seeking to ramp manufacturing often want to capture the process

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[7] Taking the example of a lightbulb, the bulb must product light when 120VAC is applied and the interface is the familiar Edison 26 base. The guide notes “the consumer does not need to know the details of the manufacturing process used to extrude a Tungsten filament—nor does it care” (Guertin, 2025, p. 10).

knowledge that comes with doing it themselves. Contract-production is widely used in the commercial sector, but even contract-producers legendary for their protection of partner's IP, like the Tawain Semiconductor Manufacturing Corporation (TSMC), have seen partners become trillion-dollar companies, like NVDIA, or suffer setbacks in their core competencies, like Intel.

In the United States, scaling defense production for a given item typically involves mergers and acquisitions, spin-offs, joint ventures, a vendor expanding facilities, and/or international companies establishing U.S. subsidiaries. Contract-producers and facilities offering manufacturing as a service are standing up, but DIB use of this business model lags commercial use. Interestingly, the DIB does make more use of this model internationally despite higher regulatory barriers. Within the United States, contract-production would require a manufacturing license agreement from the IP holder, a TDP, and appropriate facility permits at the destination factory. For international production, tools, design, and manufacturing know how transfers will be regulated by the munitions list and commerce control list and will need appropriate licenses. These international arrangements often are part of the DIB deals to win foreign market access or U.S. government efforts to achieve foreign policy goals.

Due to the uncertain models, experimentation in this area is necessary and worthy of close study. One affordable mass model is franchise rights, under which the manufacturer agrees to arrange for new production facilities if surge capacity becomes needed. A variant on this approach would rely on special license arrangement options and the concept of IP as a service to prearrange the ability to surge production to a third party. Two ongoing efforts focus on bottleneck and difficult-to-qualify energetics subsystems. At AvMC, this effort included direct manufacturing at organic depots in parallel with industry. This approach pairs well with targeted commoditization to build up surge capability through more producible designs. Producible designs open the aperture for domestic commercial IB, the domestic organic IB, or in the forward IB of overseas depots and allied and partner production. In these examples, Pathfinders use a mix of direct funding of development and/or competitive pressure to gain rights and options that industry has hesitated to allow under other circumstances.

The speed with which CCA producers established production sites in Europe hints at how existing international co-production models could evolve to more rapidly boost production capacity and arrange for surge capability (Decker, 2025). The franchise model resembles the way producers establish or acquire subsidiaries across international borders. An option to mobilize could involve moving beyond company, program, or variant-specific facilities. Contract production and manufacturing as a service could have a large role in international production. One advantage of the United States in negotiating with international industry is that market access and the imprimatur of being qualified in the U.S. system can enhance the allied industries' ability to compete for international demand. International vendors may be willing to accept greater reliance on third-party production if qualification was part of the deal. Relatedly, there are more international vendors interested in production in the United States than can likely be maintained during a downturn, and each of these international vendors establishing their own facilities makes it harder to plan for economies of scale.

Conclusions

Pathfinding programs in the affordable mass space and beyond are experimenting with employing MOSA to achieve benefits for production capacity. MOSA guidebook recommendations on obsolescence are already relevant to building production agility to address challenges of boosting production capacity. Surge capability is an even greater challenge because demand is often correlated across programs and often across countries. Given the time and capital required to stand up new production lines, this means requiring (1) the U.S. government paying for or incentivizing the preservation of mothballed capacity in government or industry during downturns, (2) dual-use items or sufficiently producible military-spec items with necessary TDPs where military production can displace commercial production, (3) allied and partner production with more capacity than can be met by their domestic needs and that is flexible enough to shift to address bottlenecks and support surge. Pathfinders are most relevant to the second path but have relevant lessons for all three.

This paper offers an initial framework, summarized in Figure 1, to assist in the consideration of tools that could accelerate production, especially with adoption at scale. The Joint Production Accelerator Cell (JPAC) will elevate and echo lessons learned from the challenges faced and successes learned from these efforts. The paper offers the following courses of action as ways of scaling lessons from pathfinder programs to accelerate munition production more broadly.

- Existing guidance on obsolescence on developing a product plan is also helpful for programs seeking to insure against production constraints writ large.
- Existing efforts on energetics subsystems suggest that MOSA can be part of the solution to accelerating the pace of qualification by lowering risk by commoditizing modules and acquiring mobilization options.
- Pathfinders in adjacent systems suggest that MOSA can aid in incorporating COTS and near-COTS to sustain markets that expand the munition IB.
- The Department has important leverage when ramping munition production. Both modularizing in-service munitions and acquiring mobilization options have production benefits, considered as part of negotiating a steady demand signal.
- Testing conformance of intersystem MOSA will aid in achieving and sustaining the benefits of system competition and ensuring the viability of on-ramps.

JPAC will build on this effort through research seeking to understand:

- What makes the affordable mass systems easier and cheaper to produce, besides them being only 80% to 90% effective compared to exquisite systems?
- What lessons can we learn that might be adaptable for those higher-end systems?
- How do we define standards and expectations for families of weapon systems that can enable multiple production lines or production done by different parties? What data rights, processes, and management properties are required to capture all of it in a TDP?

The experimentation by pathfinding systems affirms that MOSA is a combat capability relevant to addressing production constraints that limit the options available to operators even when budget is available. Consideration of MOSA, system competition, and the option to mobilize can play a supporting role in scaling production acceleration today and a vital role for future production agility, surge capability, and sustaining the munitions IB in the face of future budget downturns.

Appendix: Guided Conversation Questions

This ongoing project draws data from six guided conversations with munition and adjacent programs, subject matter experts, supplemented by desk and market research to identify core competencies of industry with assistance from relevant consortiums. The guided conversations asked experts and practitioners six questions:

1) ***Producibility***

    a. What, if any, overarching producibility concerns did you explicitly consider as part of your program or initiative?
    b. Are there any parts, components, or subsystems that are a heightened producibility concern for your program or initiative?

2) ***Architecture:***
    a. What, if any, key commercial standards, open standards, or government reference architectures are you employing or creating in your program or initiative?
    b. Were any of your architectural design or standard adoption decisions made with producibility as a critical factor?

3) ***Outcomes:***
    a. Have you seen any producibility benefits of your architecture choices at your present stage in the life cycle of the program or initiative? Have any expected benefits for this stage not materialized?
    b. Do you see any limits or risks related to affordable mass system adoption of a modular open system approach or government reference architectures?

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