Accuracy Before Tempo: Designing Industrial Scale, Resilience, and Adaptability for Wartime Production

A White Paper

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Recent efforts to revitalize the United States defense industrial base emphasize the need to produce weapons systems "at speed and scale." While intuitively compelling, this framing misidentifies the primary constraint on wartime production. Drawing on engineering principles, historical analysis of World War II industrial mobilization, and contemporary challenges in defense manufacturing, this paper argues that speed is a lagging indicator rather than a controllable variable. Sustainable industrial scale emerges from upstream design choices—particularly accuracy, tooling maturity, process stability, and yield—rather than from direct pressure on output metrics. The paper introduces the concept of the Output Control Fallacy to describe the systemic failure that occurs when leaders attempt to command outcomes instead of engineering inputs. It further argues that resilience and adaptability are not in tension with scale, but co-emergent properties of well-designed production systems. The paper concludes with design-level principles for building a defense industrial base capable of endurance, learning, and regeneration under wartime conditions.

I. Introduction: The Speed Illusion in Wartime Production

Across recent defense policy discussions, a consistent refrain has emerged: the United States must learn to produce weapons systems faster. Concerns about munitions stockpiles, shipbuilding delays, and the demands of potential high-intensity conflict have driven calls for accelerated schedules and compressed production timelines. In this context, "speed and scale" have become shorthand for industrial readiness (U.S. Department of Defense [DoD], 2023a).

While these concerns are well founded, the prevailing framing risks obscuring the nature of the problem it seeks to solve. Production shortfalls are frequently attributed to insufficient urgency or excessive process discipline, leading to proposals that emphasize schedule acceleration, concurrency, and output targets. Such approaches may increase visible activity in the near term, but they often fail to produce durable increases in usable output.

This paper argues that the emphasis on speed reflects a category error. In complex industrial systems, output rates are not directly controllable through urgency or exhortation. They are emergent outcomes that reflect upstream conditions, including design stability, tooling maturity, process capability, workforce readiness, and supply-chain reliability. Attempts to increase output without addressing these inputs frequently degrade system performance by increasing defects, rework, congestion, and fragility.

Importantly, this analysis does not treat stability and adaptability as competing objectives. Rather, it argues that meaningful adaptability and learning emerge only after production systems achieve sufficient accuracy and process discipline. This distinction is central to understanding how industrial systems scale, endure, and evolve under wartime pressure.

II. Theoretical Foundations

This analysis builds on established principles from operations management and systems engineering. The concept that outputs are determined by system inputs rather than managerial pressure reflects core insights from Theory of Constraints (Goldratt & Cox, 1984) and quality management systems (Deming, 1986). The emphasis on process capability and first-pass yield draws from lean manufacturing principles documented in studies of Japanese automotive production (Womack, Jones, & Roos, 1990) and the Toyota Production System (Spear & Bowen, 1999).

While these frameworks originated in commercial manufacturing contexts, this paper applies them specifically to the unique requirements of wartime production and defense industrial base design. The Output Control Fallacy, as defined here, represents an original synthesis of these principles applied to contemporary defense manufacturing challenges.

III. The Output Control Fallacy

In engineered systems, outputs cannot be controlled directly. They are lagging indicators of upstream inputs and processes. Engineers do not command desired results into existence; they design the conditions under which those results reliably emerge (Deming, 1986). Output metrics—such as production rates, delivery schedules, or throughput targets—serve as diagnostic signals that reveal whether a system is functioning as intended.

This paper refers to the failure to respect this principle as the Output Control Fallacy. The Output Control Fallacy occurs when leaders attempt to increase production by applying pressure to outcomes rather than by redesigning the inputs that generate those outcomes. In complex manufacturing environments, this approach predictably degrades performance.

Output pressure typically manifests as accelerated schedules, higher production targets, expanded labor hours, or overlapping development and production phases. When applied to systems already operating near their process limits, such pressure increases variability, overwhelms quality controls, and drives rework. The appearance of acceleration is often followed by delay as downstream congestion accumulates (Goldratt & Cox, 1984).

From a systems perspective, this behavior is expected. Stable performance emerges when inputs—design maturity, tooling accuracy, process capability, and constraint management—are aligned. When these inputs are unstable, forcing higher output merely propagates defects more rapidly through the system. The result is not speed, but fragility.

IV. Accuracy as the Foundation of Scale

At the core of scalable production lies accuracy—not simply in the sense of precision machining, but in the broader sense of producing outputs that meet requirements without rework. In manufacturing terms, this condition is reflected in first-pass yield and process capability (Deming, 1986). High first-pass yield indicates that a system is producing correctly on the first attempt, without consuming additional time, labor, or capacity for correction.

Rework is the hidden enemy of scale. It consumes capacity that could otherwise be used for new production, obscures true bottlenecks, and creates the illusion of activity without corresponding progress. Systems with low first-pass yield often appear busy while delivering little usable output.

Historical experience demonstrates that sustained increases in production volume follow improvements in accuracy and yield, not the reverse. Herman's (2012) account of wartime industrial mobilization describes how production chief William Knudsen insisted that manufacturers first perfect their processes before attempting to scale output. Knudsen's experience at General Motors had taught him that "accuracy comes before speed"—rushing production before achieving process stability merely multiplied defects faster (Herman, 2012, pp. 134-138). This lesson applies equally to modern defense manufacturing, where system complexity magnifies the cost of defects and late-stage corrections.

V. Embedding Accuracy: From Human Skill to Engineered Systems

A central challenge in modern defense production is determining where accuracy resides within the system. In many contemporary programs, accuracy remains disproportionately concentrated in expert labor, bespoke processes, and late-stage inspection. While such arrangements can produce high-quality outputs at low volumes, they scale poorly and are fragile under disruption.

Early twentieth-century manufacturing faced a similar constraint. Production depended heavily on skilled craftsmen whose judgment compensated for unstable processes and inconsistent components. Scaling output under this model required more experts, longer training pipelines, and increasingly complex coordination—limitations that became untenable during industrial war (Hounshell, 1984).

U.S. wartime mobilization addressed this challenge by deliberately relocating accuracy from individuals into systems. Standardized designs, hardened tooling, gauges, fixtures, and interchangeable parts embedded correctness upstream, allowing production to scale without relying on scarce artisanal skill (Herman, 2012, pp. 89-112). The significance of this shift lies not in the specific machines used, but in the design principle they embodied: accuracy had to be engineered into the process itself.

Modern manufacturing operates under the same logic, even though the technologies have changed. Contemporary equivalents include computer numerical control machining, automated inspection, standardized digital interfaces, software-defined manufacturing, and modular production cells (Womack et al., 1990). These systems serve the same function as historical tooling: they reduce reliance on individual judgment, constrain variation, and enable replication.

VI. Why Mass Production Wins Wars

Wars are contests of endurance as much as innovation. While technological breakthroughs shape the character of conflict, victory ultimately depends on the ability to replace losses, repair damaged systems, and sustain operations over time. Industrial capacity therefore constitutes a form of latent combat power (Kennedy, 1987).

Attrition scales faster than innovation. Systems that take years to design and months to produce can be destroyed in minutes. In such environments, replaceability often matters more than initial performance. Mass production—understood as the ability to produce reliable, interchangeable outputs at volume—enables this replacement capacity.

Interchangeability is particularly consequential. Systems designed with standardized interfaces and components can be repaired quickly, maintained by a broader workforce, and kept in the fight longer. Conversely, bespoke or highly customized systems impose maintenance burdens that erode readiness over time (Hounshell, 1984).

VII. Resilience Under Attack: Standardization Without Fragility

A common concern about mass production is that standardization creates vulnerability. If production depends on identical tooling or centralized facilities, adversaries may target these nodes through sabotage or attack. This concern is valid—but it reflects a misunderstanding of how resilient production systems are designed.

The vulnerability is not standardization itself, but over-centralization. World War II industrial planners distinguished clearly between these concepts. Designs and tooling standards were shared widely, while production was distributed across multiple facilities and regions. Tooling knowledge was replicated, not concentrated (Herman, 2012, pp. 201-224).

Resilient production systems combine standardized designs with distributed execution. Redundant tooling sets, modular production cells, and geographically dispersed facilities reduce the impact of disruption. When designed correctly, tooling-based systems are often more resilient than craft-based systems because they can be copied, stored, and redeployed.

VIII. Systemic Adaptability: Designing for Learning Through Failure

Stability in engineered systems is often mistaken for rigidity. In reality, stability is a prerequisite for meaningful adaptation. Systems that are continuously failing across multiple dimensions generate noise rather than insight. When everything is broken, nothing can be learned (Spear & Bowen, 1999).

Failure in wartime production is inevitable. Equipment breaks, processes drift, suppliers falter, and adversaries adapt. The critical distinction is not whether failure occurs, but whether failure produces learning or chaos. Well-designed production systems fail in bounded, observable, and interpretable ways, allowing corrective actions to be identified, validated, and propagated (Deming, 1986).

Accuracy and tooling do not eliminate failure; they make failure informative. When processes are repeatable and outputs are consistent, deviations stand out clearly. Root causes can be identified because variation is constrained. Improvements introduced at one production cell can be reliably replicated across others because the underlying system is stable (Spear & Bowen, 1999).

In this sense, adaptability emerges from replication rather than improvisation. Agility is not the ability to change everything quickly, but the ability to change one thing deliberately, observe its effects, and propagate that change across a distributed system. Production systems designed for speed without stability often learn the wrong lessons: defects are masked, rework is normalized, and failure signals are suppressed.

Systems designed around engineered accuracy, by contrast, create tight feedback loops between failure and improvement. Scale enables learning, and learning enables adaptation. Far from being in tension, stability and agility are mutually reinforcing properties of well-designed systems.

IX. Applying the Input–Output Framework Across Domains

The Output Control Fallacy and the principles discussed above manifest consistently across contemporary defense production domains.

Shipbuilding: Columbia-Class Submarines

The Columbia-class ballistic missile submarine program illustrates the Output Control Fallacy with particular clarity. The lead boat, USS District of Columbia (SSBN-826), is currently estimated to be 12 to 18 months late, with construction tracking to 96 months instead of the contracted 84-month timeline (GAO, 2024). The Navy's own 2024 delivery review attributes delays not to insufficient urgency, but to upstream input failures: "out-of-sequence work resulted from missing instructions in some design products that detail how to build the submarine" (Congressional Research Service, 2024).

The program attempted to begin construction while the design was still unstable. Areas of the submarine were missing electrical work specifications and holes for pipe installation. Rather than pausing to stabilize design products, the program proceeded with construction, generating massive rework backlogs. Late delivery of major components—including steam turbines from Northrop Grumman and the bow dome from Newport News Shipbuilding—further disrupted the sequential assembly process. The shipbuilder is now consuming resources originally allocated to Virginia-class submarines in an attempt to recover schedule, propagating delays across programs (GAO, 2023).

The result: hundreds of millions of dollars in cost growth, persistent schedule slippage despite heroic efforts, and increased risk to the nation's strategic deterrent posture. The constraint was never insufficient schedule pressure—it was unstable design inputs colliding with premature production commitments.

Munitions: 155mm Artillery Shell Production

Artillery ammunition production demonstrates how output pressure without input stability generates the appearance of progress while masking fundamental constraints. At the start of the Ukraine conflict in February 2022, U.S. monthly production of 155mm shells stood at 14,000 rounds. Ukraine's consumption rate—initially 240,000 shells per month and peaking at over 10,000 rounds per day during intense fighting—immediately exposed the inadequacy of peacetime production capacity (Defense One, 2023).

The Army responded with aggressive output targets: 28,000 rounds per month by September 2023, with goals of reaching 100,000 by late 2025. However, sustained increases have been constrained by upstream inputs: energetic material supply chains, tooling capacity at Scranton Army Ammunition Plant and Iowa Army Ammunition Plant, workforce certification timelines, and inspection capacity (Defense One, 2024). Russia, despite a defense budget one-tenth the size of NATO's combined spending, outproduces the entire Western alliance in artillery shells—not because of greater urgency, but because its production infrastructure remained scaled for sustained output (CSIS, 2023).

Attempts to accelerate production without addressing these input constraints have generated predictable results: inspection backlogs, quality holds, and rework. The Army's planned Texas facility, intended to use "entirely new tech we've never used before" for shell production, represents a belated recognition that sustainable output requires upstream process innovation, not downstream schedule pressure (Defense One, 2024).

Drone Manufacturing and Space Systems

Drone manufacturing illustrates a boundary condition. Rapid iteration works well in software and prototyping, but physical production still requires stable designs, replicable tooling, and test capacity. Without these inputs, speed produces fragmentation rather than scale (Sayler, 2023).

Space systems are particularly sensitive to the Output Control Fallacy. Low failure tolerance and high rework costs mean that compressing test and qualification timelines often negates any nominal gains in schedule. In this domain, output discipline is inseparable from input discipline (GAO, 2022).

X. Addressing the Wartime Urgency Counterargument

A predictable objection to this analysis is: "But what about urgent wartime needs? In a shooting war, can't we accept lower quality for speed? Isn't some output better than no output?"

This objection misunderstands both the nature of wartime production and the dynamics of complex manufacturing systems. Historical evidence and contemporary experience demonstrate that sacrificing accuracy for nominal speed produces less usable output, not more.

The Paradox of Wartime Acceleration

During World War II, the most successful production programs—Liberty ships, B-24 bombers, M4 Sherman tanks—achieved high output rates by *first* stabilizing designs and production processes, *then* scaling rapidly. Programs that attempted to compress this sequence generated catastrophic failures. Early Liberty ships suffered hull cracks and structural failures because shipyards rushed construction without adequate welding process controls. The solution was not to accelerate further, but to pause, implement process improvements, and only then resume at scale (Herman, 2012).

The Consolidated B-24 bomber program provides an illustrative contrast. Willow Run, Ford's massive bomber plant, struggled for over a year to reach planned output because the company attempted to apply automotive production techniques to an unstable aircraft design. Production rates increased dramatically only after Ford engineers insisted on design stabilization and developed purpose-built tooling. The plant ultimately produced B-24s faster than any other facility—but only after accepting that accuracy had to precede tempo (Herman, 2012).

Defective Output Is Worse Than No Output

In wartime, defective munitions and unreliable systems impose costs beyond mere waste. Troops develop rational distrust of unreliable equipment, reducing combat effectiveness even when systems function correctly. Logistics networks designed for operational equipment become congested with returns, repairs, and replacements. Maintenance personnel spend scarce time troubleshooting preventable failures rather than sustaining operational systems.

Consider the artillery ammunition case: shells that fail quality inspection don't simply represent wasted capacity—they consume inspection resources, generate disposal costs, create safety hazards, and undermine confidence in the supply chain. A 70% first-pass yield delivering 70 usable shells per 100 attempts is vastly preferable to 150 attempts at 40% yield delivering 60 usable shells while generating 90 defects that must be managed.

True Wartime Agility Requires Stable Foundations

Genuine wartime adaptability—the ability to rapidly field improvements, respond to adversary innovations, and pivot production between similar systems—emerges from stable, well-understood processes, not from chaotic urgency. When production systems are stable, engineers can identify which design changes will improve performance and which will introduce new failure modes. When processes are repeatable, improvements validated at one facility can be rapidly propagated across distributed production.

Conversely, systems operating in constant crisis mode cannot distinguish signal from noise. Every problem is treated as unique; no lessons generalize; improvements cannot be confidently replicated. The appearance of flexibility masks an inability to learn.

The Real Choice: Sustainable Versus Illusory Speed

The wartime choice is not between speed and quality, but between sustainable and illusory speed. Sustainable speed emerges from upstream investments in design stability, process capability, tooling maturity, and workforce readiness. Illusory speed comes from schedule pressure on unstable systems—it generates activity, consumes resources, and produces disappointment.

In extended conflicts where industrial endurance determines outcomes, sustainable speed compounds over time while illusory speed degrades. This is not a theoretical claim—it is the lesson of every industrial war, and it remains true today.

XI. Implications for the Defense Industrial Base

The persistence of production challenges across domains suggests that current incentives often misalign inputs and outputs. Peacetime optimization favors centralized efficiency and schedule performance, while wartime readiness demands replicability, tolerance, learning, and endurance.

Industrial revitalization efforts that emphasize speed without addressing upstream design and production inputs risk reproducing these failures at larger scale. Conversely, systems designed around accuracy, yield, replication, and learning can produce scale, resilience, and adaptability simultaneously (DoD, 2023a).

XII. Recommendations: Designing Inputs, Not Chasing Outputs

Based on the analysis above, the following specific policy recommendations are offered:

Acquisition Reform

1. **Establish Design Stability as a Milestone Requirement**: Prohibit Milestone C (production decision) until design achieves demonstrated stability, measured by: (a) completion of 95% of production drawings, (b) release of 90% of tooling specifications, and (c) demonstrated first-article manufacturability at target yield rates. Fund extended Engineering and Manufacturing Development (EMD) phases rather than compressing development to accelerate production.
2. **Restructure Incentive Contracts**: Replace schedule-incentive contracts with yield-incentive contracts for major defense programs. Award fees based on first-pass yield, defect rates, and demonstrated process capability rather than delivery dates. Penalize rework and late-stage design changes more severely than modest schedule extensions.
3. **Mandate Pre-Production Tooling Investment**: Require programs to fund and validate production tooling during EMD rather than deferring tooling investment to production contracts. Establish "tooling readiness levels" analogous to technology readiness levels, with explicit gates for replication, validation, and distributed deployment.

Industrial Base Development

4. **Build Distributed Tooling Sets**: For critical munitions and components, fund development and deployment of at least three geographically distributed, redundant production lines using common tooling standards. Store complete tooling packages —not just designs, but validated fixtures, gauges, and process specifications—in protected depots for rapid reconstitution.
5. **Establish Production Engineering Cadres**: Create dedicated production engineering teams within acquisition program offices, separate from design engineering. Task these teams with manufacturability analysis, process

development, and tooling validation before production commitment. Staff with personnel having manufacturing rather than pure design backgrounds.

6. **Invest in Supplier Process Capability**: Rather than spreading supplier development funding broadly, concentrate investments on developing process capability at critical bottlenecks. Fund statistical process control implementation, automated inspection systems, and workforce training. Make continued contracts contingent on demonstrated yield improvements, not just capacity expansion.

Contracting and Testing

7. **Implement Graduated Production Rates**: For new programs, structure production contracts with initially low rates designed to validate processes and identify failure modes, followed by planned rate increases contingent on demonstrated yield thresholds. Avoid "hockey stick" production profiles that force premature scaling.
8. **Require Process Audits, Not Just Product Inspection**: Shift quality assurance emphasis from end-item inspection to process capability audits. Validate that contractors are using statistical process control, tracking defect modes, and implementing closed-loop corrective action. Treat process instability as a contract deficiency requiring corrective action plans.
9. **Create War Reserve Tooling Accounts**: Establish dedicated budget lines for maintaining warm production tooling for systems no longer in procurement but critical for wartime reconstitution. Fund periodic tooling validation runs and workforce currency training.

Organizational Changes

10. **Establish Industrial Base Resilience Office**: Create a dedicated office within OUSD(A&S) responsible for monitoring production system health across programs. Empower this office to halt production commitments when design stability or tooling readiness is inadequate, with authority independent of program managers.
11. **Revise DoD 5000 Series**: Update acquisition instruction to explicitly recognize design stability, tooling maturity, and process capability as separate milestone requirements. Provide explicit guidance on measuring and validating these inputs before production commitment.

XIII. Conclusion: Endurance Is Engineered

Future conflicts will not be decided by who moves fastest in peacetime, but by who designs systems that continue producing, learning, and adapting under pressure. Speed is not the lever; it is the signal. Accuracy, tooling, process stability, and learning mechanisms are the true determinants of scale.

In engineered systems, leaders cannot command outputs into existence. They can only design the conditions under which those outputs reliably emerge. Wartime industrial readiness, like combat power itself, is engineered.

The choice facing defense industrial policy is not between speed and quality, or between peacetime efficiency and wartime capacity. It is between systems designed for sustainable output and systems designed for the appearance of progress. History demonstrates, and contemporary experience confirms, that sustainable output emerges from upstream discipline in design, tooling, and process—not from downstream pressure on delivery schedules.

Building a defense industrial base capable of prevailing in extended conflict requires accepting that in complex production systems, accuracy must precede tempo. This principle is not a constraint to be overcome through determination or urgency. It is an engineering reality to be designed around—and when designed around effectively, it enables exactly the scale, resilience, and adaptability that wartime demands.

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