Additive Manufacturing Opportunities in Aerospace & Defense Acquisition

John F. Rice
Professor of Digital Engineering
Defense Acquisition University

Defense Acquisition University

AM INTRODUCTION

According to Joint Technology Exchange Group (JTEG) Technology Definitions "*additive manufacturing (AM), also referred to as 3D printing, is a layer-by-layer technique of producing three-dimensional (3D) objects directly from a digital model*.”

TED TALKS:
https://www.youtube.com/watch?v=IbIdztMOomI

AM PROCESSES

Table 2. AM Major Manufacturing Processes

Vat photopolymerization
A liquid photopolymer (i.e., plastic) in a vat is selectively cured by light-activated polymerization. The process is also referred to as light polymerization.
Related AM technologies: Stereolithography (SLA), digital light processing (DLP)

Material jetting
A print head selectively deposits material on the build area. These droplets most often are comprised of photopolymers with secondary materials (e.g., wax) used to create support structures during the build process. An ultraviolet light solidifies the photopolymer material to form cured parts. Support material is removed during post-build processing.
Related AM technologies: Multi-jet modeling (MJM)

Material extrusion
Thermoplastic material is fed through a heated nozzle and deposited on a build platform. The nozzle melts the material and extrudes it to form each object layer. This process continues until the part is completed.
Related AM technologies: Fused deposition modeling (FDM)

Powder bed fusion
Particles of material (e.g., plastic, metal) are selectively fused together using a thermal energy source such as a laser. Once a layer is fused, a new one is created by spreading powder over the top of the object and repeating the process. Unfused material is used to support the object being produced, thus reducing the need for support systems.
Related AM technologies: Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)

Binder jetting
Particles of material are selectively joined together using a liquid binding agent (e.g., glue). Inks also may be deposited to impart color. Once a layer is formed, a new one is created by spreading powder over the top of the object and repeating the process until the object is formed. Unbound material is used to support the object being produced, thus reducing the need for support systems.
Related AM technologies: Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)

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

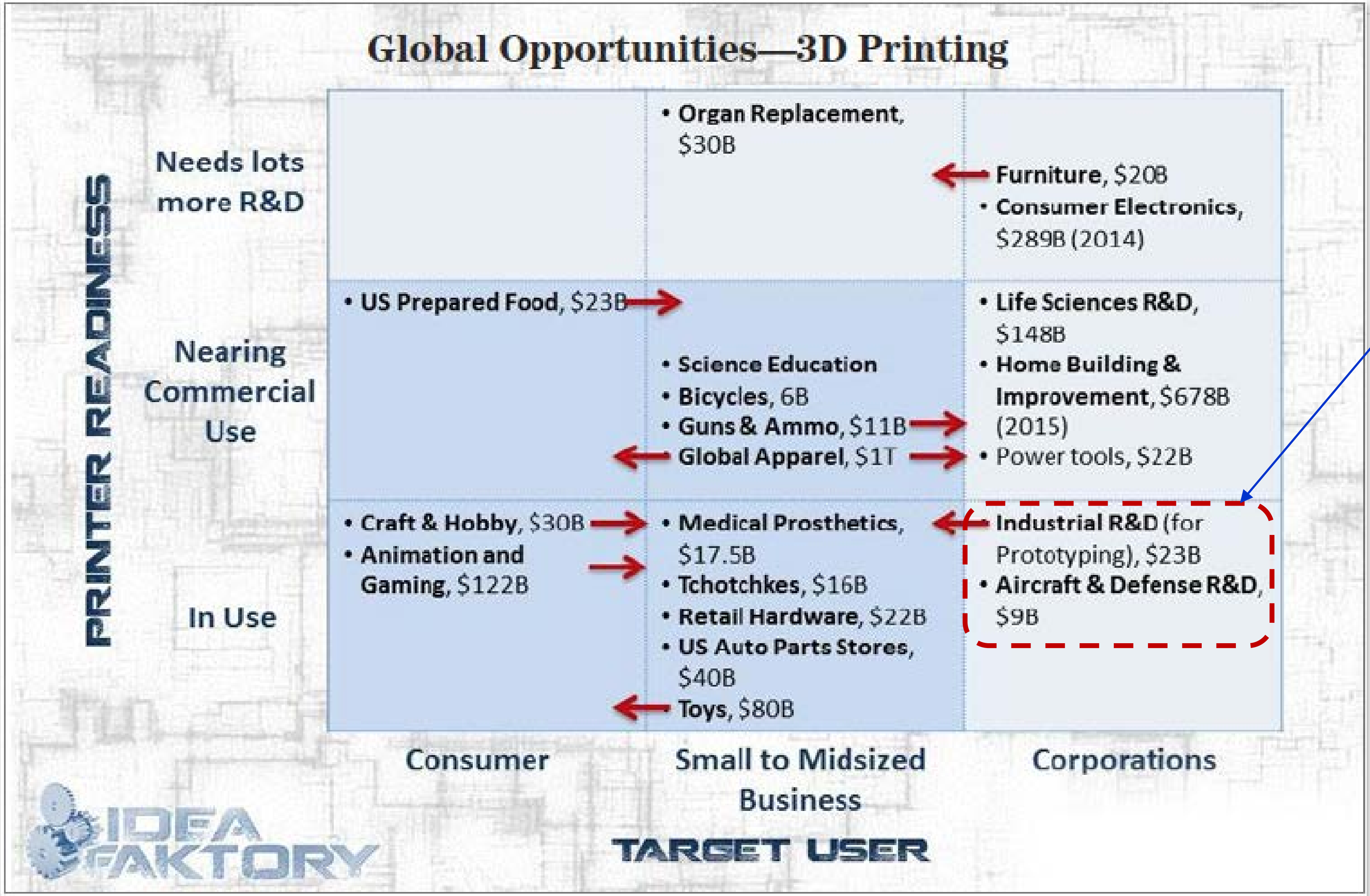
Directed energy deposition
Focused thermal energy is used to fuse (typically metal) material as it is being deposited. Directed energy deposition systems may employ either wire-based or powder-based approaches.
Related AM technologies: Laser metal deposition (LMD)

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

e

Figure 1. Additive manufacturing (AM) process flow

Graphic: Deloitte University Press | DUPress.com



A&D sector

Source: Unknown -- https://www.ideafaktory.com/

DRIVING PRODUCTIVITY AT EVERY STAGE

CONCEPT DEVELOPMENT

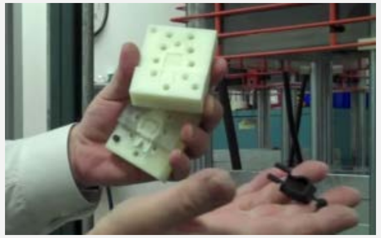
Communicate Design Intent

DESIGN VALIDATION

Functionally Test Designs

PRE-PRODUCTION

Bridge the Gap with Rapid Tooling



DIRECT MANUFACTURING

Production End-Use Parts

Source: 3D Systems briefing

SIGNIFICANT BREAKTHROUGH IN DOD: SAFETY CRITICAL PART

AM Integrated Product Team lead Liz McMichael said: "The flight today is a great first step toward using AM wherever and whenever we need to."

"It will revolutionize how we repair our aircraft and develop and field new capabilities. AM is a game changer."

"In the last 18 months, we have started to crack the code on using AM safely. We will be working with V-22 to go from this first flight demonstration to a formal configuration change to use these parts on any V-22 aircraft."

http://www.naval-technology.com/news/newsus-navair-tests-3-d-printed-safety-critical-parts-on-mv-22b-osprey-aircraft-4965373

DOD OPPORTUNITY MANAGEMENT

Opportunity – potential future benefits to the program's cost, schedule, and/or performance baseline, usually achieved through reallocation of resources.

What trade space from AM "buys" you (i.e. opportunities)

Opportunity Handling *[options]*

- Pursue: Fund and implement a plan to realize the opportunity
- Defer: Pursue/cut-in later
- Reevaluate: Continuously evaluate the opportunity for changes in circumstances
- Reject: Intentionally ignore an opportunity due to cost, technical readiness, resources, schedule burden, and/or low probability of successful capture

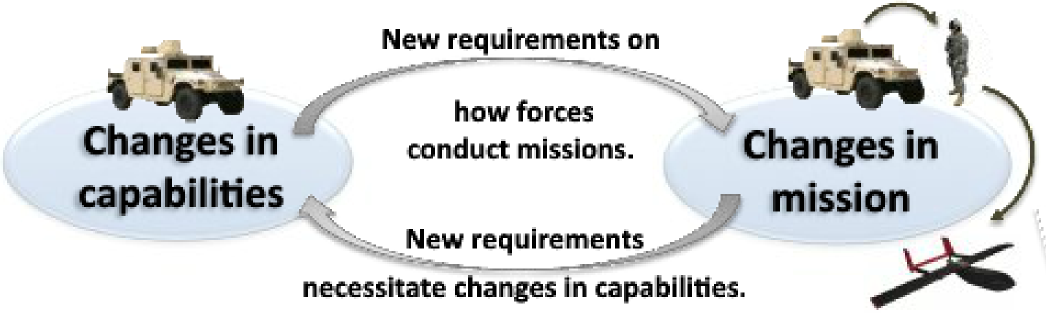
Source: *"DoD Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs"* dated January 2017

UNCLASSIFIED

Motivation: Engineered Resilient Systems

Fiscal reality and differing operational requirements necessitate choices based on what you value most.

The operational reality:



Has led to:

"ERS will empower Pre-materiel analysis with significant impact on:
- *Requirements Generation*
- *Analysis of Alternatives*
- *Lifecycle Intelligence"*

~ Holland, ERS Overview Dec 2013

– **Our goal** –

How can we help system engineers design and analyze more effectively and rationally?

… in support of **Pre-Milestone A** Tradespace Analysis?

Sitterle, Valerie B., Freeman, Dane F., Goerger, Simon R., Ender, Tommer R. *Systems Engineering Resiliency: Guiding Tradespace Exploration within an Engineered Resilient Systems Context.* CSER 2015.

COST, SCHEDULE, PERFORMANCE GAINS

Impact on Technical Reviews

"AM offers companies an array of time efficiencies and cost reductions throughout the product life cycle and supply chain, as well as greater flexibility in design and product customization than traditional manufacturing."

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

Source: Defense AT&L Magazine, Deloitte article, Nov/Dec 2016

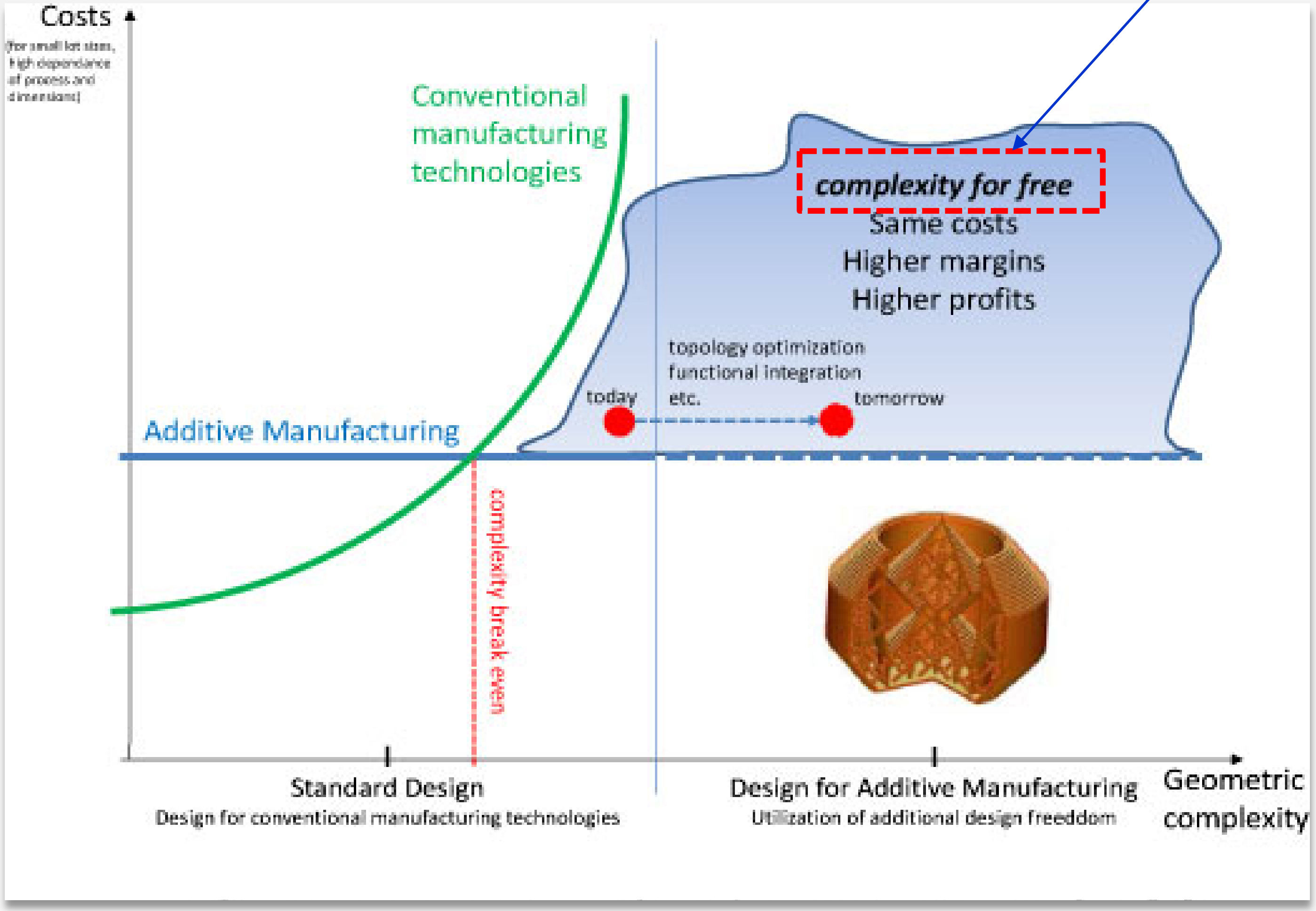
Benefit of design trade space; could streamline reviews

Technological aspects of AM

Opportunities	Limitations
Direct digital manufacturing of 3D product designs without the need for tools or molds	Solution space limited to 'printable' materials (e.g., no combined materials) and by size of build space
Change of product designs without cost penalty in manufacturing	Quality issues of produced parts: limited reproducibility of parts, missing resistance to environmental influences
Increase of design complexity (e.g., lightweight designs or integrated cooling chambers) without cost penalty in manufacturing	Significant efforts are still needed for surface finishing
High manufacturing flexibility: objects can be produced in any random order without cost penalty	Lacking design tools and guidelines to fully exploit possibilities of AM
Production of functionally integrated designs in one-step	Low production throughput speed
Less scrap and fewer raw materials required	Skilled labour and strong experience needed

COMPLEXITY FOR FREE

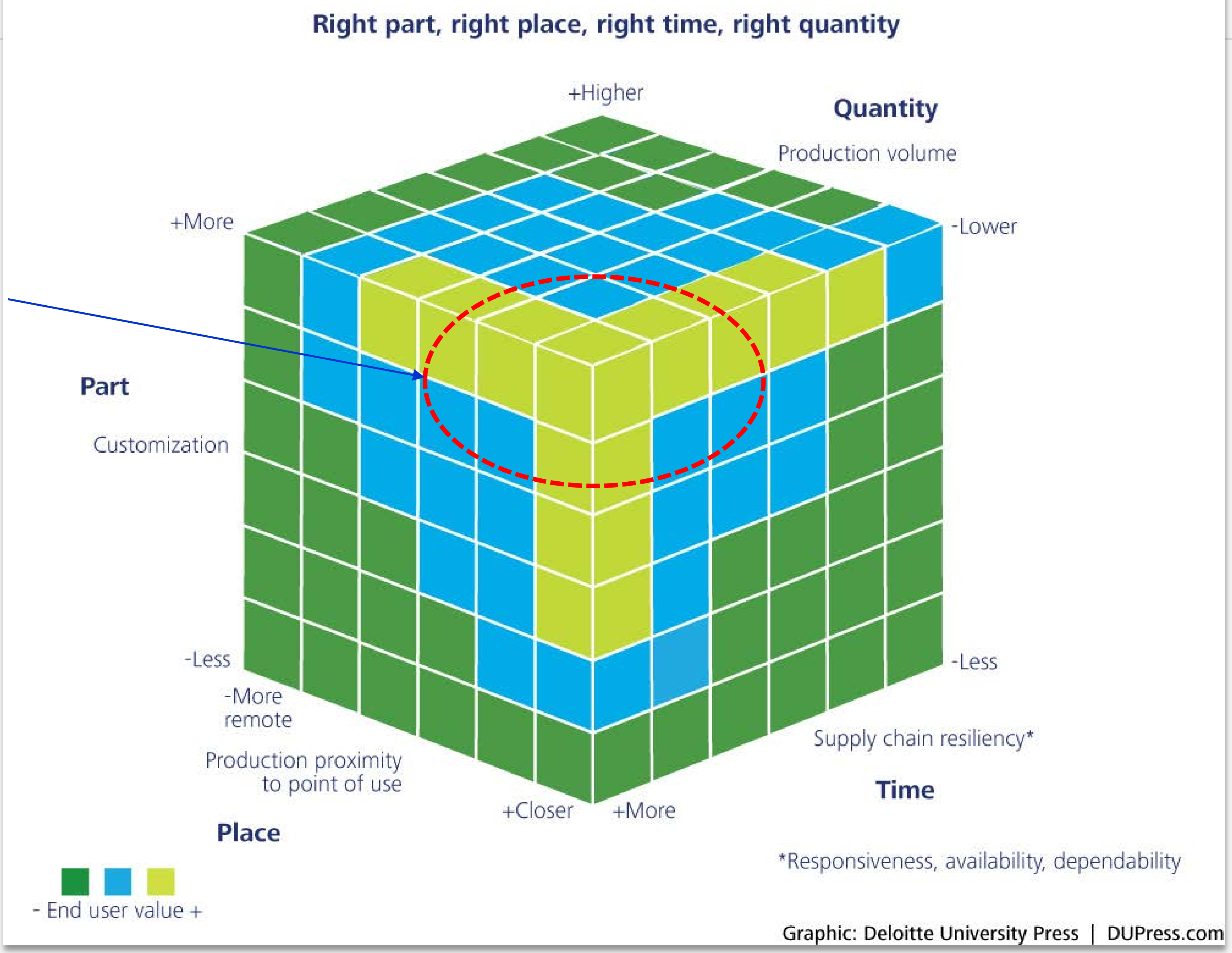
Added benefit of AM in design trades



Source: Deloitte University Press | dupress.com

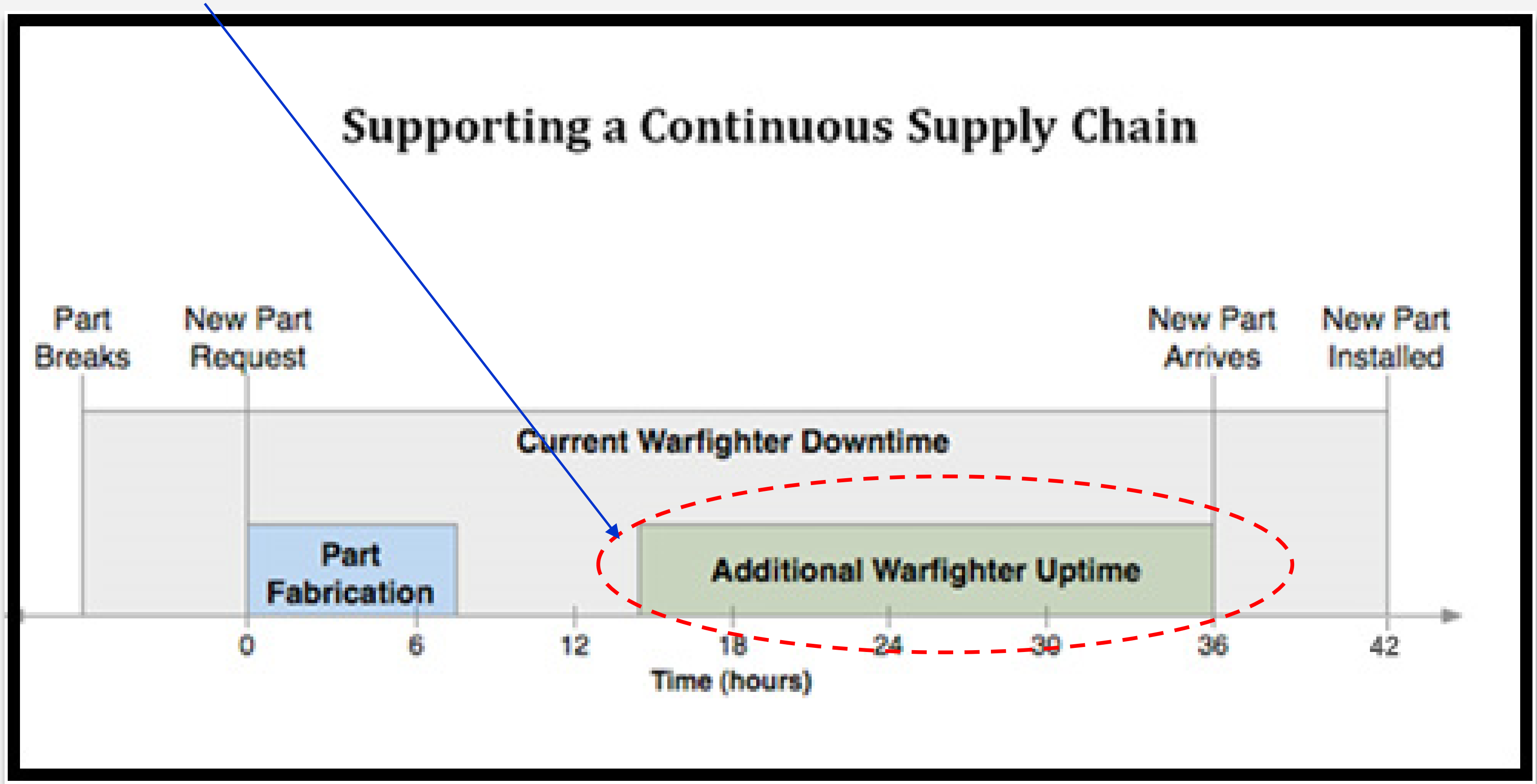
THE SUPPLY CHAIN VALUE ENVELOPE

Trade space sweet spot



BOTTOM LINE OPPORTUNITY IN DOD

Consideration of opportunity from additional trade space



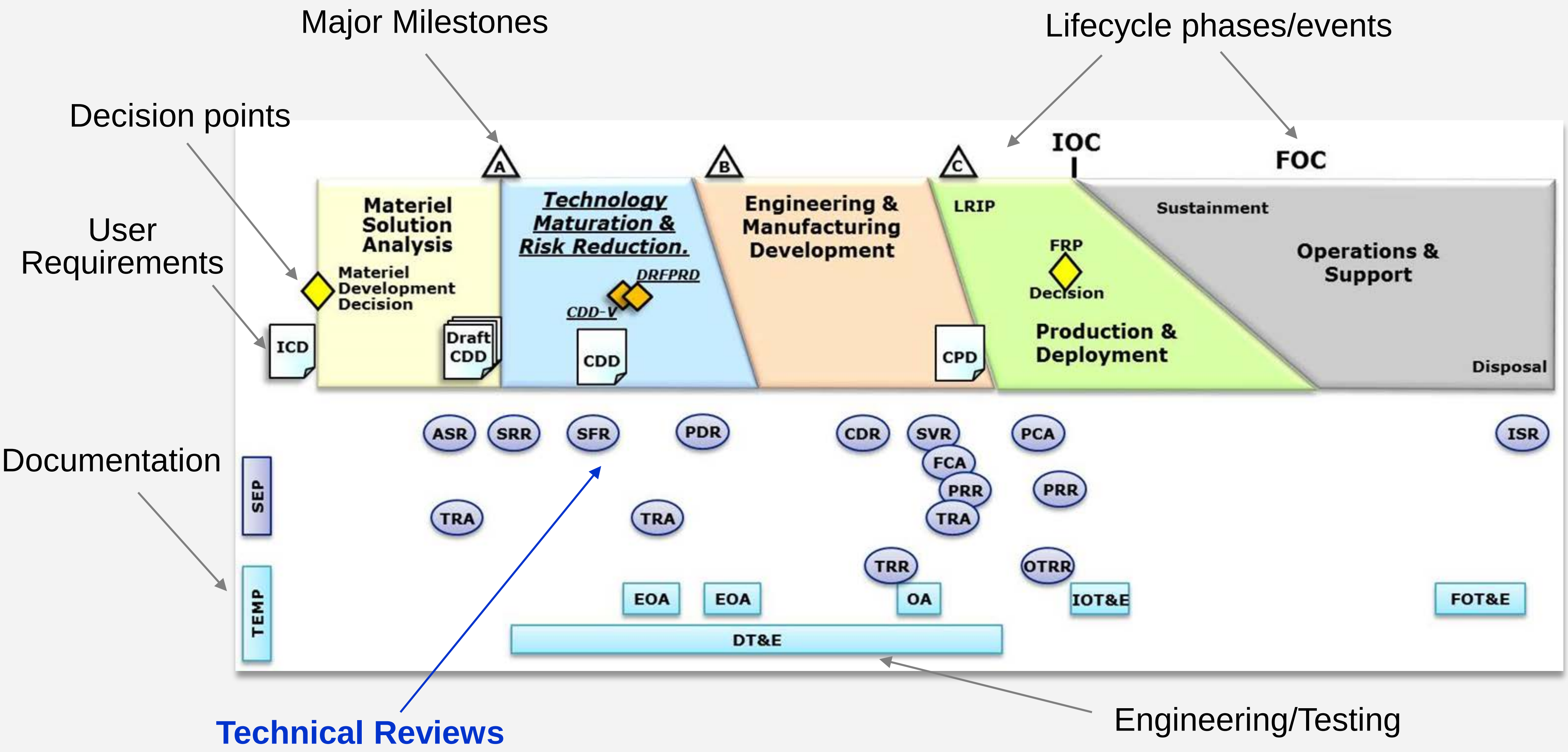
IMPACT ON DOD ACQUISITION LIFECYCLE

"Can AM Revolutionize the Acquisition Process?

Reducing the development cycle through highly streamlined and innovative approaches that ultimately accept risk in exchange for acquisition speed can address the mounting concerns about maintaining technical superiority. In the realm of acquisitions, this form of agility could be called process agility. Attempts at process agility can be found in acquisition reform, where the goal was to merge science and technology and acquisitions and requirements more seamlessly to improve overall capability development."

Source: "Additive Manufacturing From Form to Function", Dr. Amanda M. Schrand, *US Air Force Strategic Studies Quarterly*, Volume 11 Issue 1 - Spring 2017

POSITIVE INFLUENCES ACROSS THE LIFECYCLE



Positive influences can begin with materiel solution analysis and extend to operations & support.

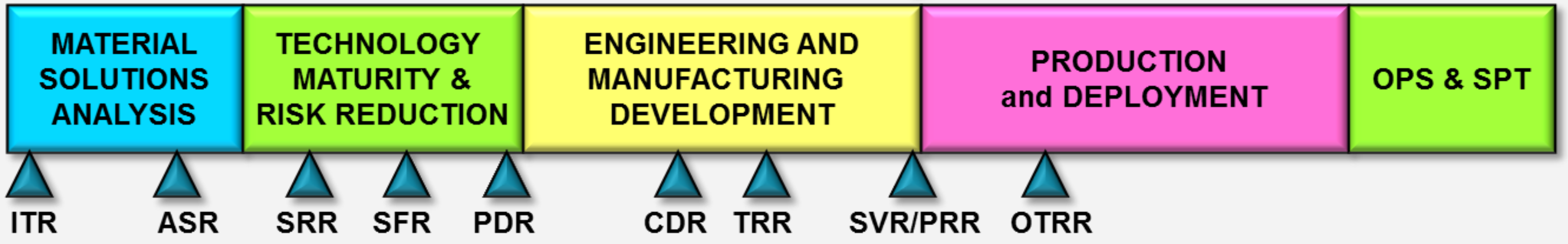
KEY TECHNICAL REVIEWS

- Initial Technical Review
- Alternative Systems Review
- System Requirements Review
- System Functional Review
- Preliminary Design Review
- Critical Design Review
- Test Readiness Review
- Production Readiness Review
- System Verification Review
- Operational Test Readiness Review

Requirements Focus

Design Focus

Verification Focus



DAU

BENEFITS OF TRADE SPACE IN TECHNICAL REVIEWS

Consider traditional technical review checklists/processes as non-value added from a lean or value stream context; i.e. decision points = waste

DECISION POINTS

10.1.1. Types of Decision Points

There are two types of decision points for Major Defense Acquisition Programs and Major Automated Information Systems: **milestone decisions and other decision review points**. Each such point results in a decision to initiate, continue, advance, change direction in, or terminate a project or program work effort or phase. The type and number of decision points may be tailored to program needs. The Milestone Decision Authority approves the program structure, including the type and number of decision points, as part of the program (technology development or acquisition) strategy.

Major decision points (including milestone decisions) authorize entry into the major acquisition process phases:

•Material Development Decision -- entry into Materiel Solution Analysis;
•Milestone (MS) A – entry into Technology Development;
•Pre-EMD Review
•Milestone B – entry into Engineering and Manufacturing Development;
•Milestone C – entry into Production & Deployment (Low Rate Initial Production (LRIP) for Major Defense Acquisition Programs and Major Programs, Production or Procurement for non-major programs that do not require LRIP, or Limited Deployment for operational testing for Major Automated Information Systems or software with no production components); and
•Full Rate Production or Full Deployment.
The statutory and regulatory information requirements specified in DoD Instruction 5000.02 support these major decision points.

10.1.1.2. Decision Reviews

Decision reviews assess progress and authorize (or halt) further program activity. The review process associated with each decision point typically addresses the program affordability and cost effectiveness; program progress, risk, and **trade-offs**; strategy, including maintaining competition and the business arrangement (contract type and incentive structure), program funding, and the development of exit criteria for the next phase or effort.

The regulatory information required to support both milestone decision points and other decision reviews should be tailored to support the review, but must be consistent with the requirements specified in DoD Instruction 5000.02.

Source: Defense Acquisition Guidebook, 2013 (need to update with 2017 DAG content)

Reduction in decision points for leaner process

TECHNICAL REVIEWS

4.2.8. Technical Reviews and Audits Overview

Technical reviews and audits allow the Program Manager and Systems Engineer to jointly define and control the program’s technical effort by establishing the success criteria for each review and audit. A well-defined program facilitates effective monitoring and control through increasingly mature points (see Technical Maturity Point table in DAG section 4.2.1. Life-Cycle Expectations).

Properly structured, technical reviews and audits support the Defense Acquisition System by:
Providing a disciplined sequence of activities to define, assess, and control the maturity of the system’s design and technical baseline, reducing risk over time
Facilitating an accurate technical assessment of the system’s ability to satisfy operational requirements established in capability requirements documents
Providing a **framework for interaction with the Joint Capabilities Integration and Development System (JCIDS)** and Planning, Programming, Budgeting, and Execution (PPBE) processes
Providing a technical assessment and assurance that the **end product fulfills the design and process requirements**.
The technical baseline (including the functional, allocated and product baselines) established at the conclusion of certain technical reviews inform all other program activity. Accurate baselines and disciplined reviews serve to integrate and synchronize the system as it matures, which facilitates more effective milestone decisions and ultimately provides better warfighting capability for less money. The technical baseline provides an accurate and controlled basis for:

•Managing change
•Cost estimates, which inform the PPBE process and ultimately the Acquisition Program Baseline (APB)
•Program technical plans and schedules, which also inform the APB
•Contracting activity
•Test and Evaluation efforts
•Risk analysis and risk balancing
•Reports to acquisition executives and Congress
The Program Manager and the Systems Engineer need to keep in mind that technical reviews and audits provide visibility into the quality and completeness of the developer’s work products. These requirements should be captured in the contract specifications or Statement of Work. The program office should consider delivering the SEP with the Request for Proposal (RFP) and having it captured in the contractor’s SE Management Plan (SEMP); this best practice also should include delineating entrance criteria and associated design data requirements needed to support the reviews. The configuration and technical data management plans should clearly define the audit requirements.

For complex systems, reviews and audits may be conducted for one or more system elements depending on the interdependencies involved. These incremental system element-level reviews lead to an overall system-level review or audit (e.g.,. PDR, CDR, or PRR). After all incremental reviews are complete, an overall summary review is conducted to provide an integrated system analysis and capability assessment that could not be conducted by a single incremental review. Each incremental review should complete a functional or physical area of design. This completed area of design may need to be reopened if other system elements drive additional changes in this area. If the schedule is being preserved through parallel design and build decisions, any system deficiency that leads to reopening design may result in rework and possible material scrap.

Test readiness reviews (TRR) are used to assess a contractor’s readiness for testing configuration items, including hardware and software. They typically involve a review of earlier or lower-level test products and test results from completed tests and a look forward to verify the test resources, test cases, test scenarios, test scripts, environment, and test data have been prepared for the next test activity. TRRs typically occur

Trade space from AM can benefit up-front decision points / reviews

Source: Defense Acquisition Guidebook, 2013
(need to update with 2017 DAG content)

ALTERNATIVE SYSTEMS REVIEW

Perhaps more mini-reviews considering design iterations.

More collaborative reviews using prototype to exhibit/review design characteristics

ASR Products and Criteria

Product	ASR Criteria
Refined Joint Requirements	• Joint context and initial CONOPS updated to reflect current user position about capability gap(s), supported missions, interfacing/enabling systems in the operational architecture; overall system of systems (SoS) context • Required related solutions and supporting references (ICD and CDDs) identified • Joint refined thresholds and objectives initially stated as broad measures of effectiveness and suitability (e.g., KPPs, KSAs, need date)
Initial Architecture for the Preferred Materiel Solution (s)	• High-level description of the preferred materiel solution(s) is available and sufficiently detailed and understood to enable further technical analysis in preparation for Milestone A • SoS interfaces and external dependencies are adequately defined
System Performance Specification	• Clear understanding of the system requirements consistent with the ICD and draft CDD (if available) • System requirements are sufficiently understood to enable system functional definition • Draft system performance specification has sufficiently conservative requirements to allow for design trade space • Relationship between draft system specification and competitive prototyping objectives is established
Preferred Materiel Solution (s) Documentation	• Comprehensive rationale is available for the preferred materiel solution(s), based on the AoA • Key assumptions and constraints associated with preferred materiel solution (s) are identified and support the conclusion that this solution can reasonably be expected to satisfy the ICD (or draft CDD if available) in terms of technical, operational, risk, and schedule/cost (affordability) criteria • Results of trade studies/technical demonstrations for concept risk reduction, if available • Initial producibility assessments of solution concepts
Risk Assessment	• Technical risks are identified, and mitigation plans are in development • Initial hazard analysis/system safety analysis for preferred solution(s) complete

<u>Source</u>: Defense Acquisition Guidebook, 2017

PRELIMINARY DESIGN REVIEW

PDR Products and Criteria

PDR Criteria

Technical Plans

•All entry criteria stated in the contract (e.g., Statement of Work (SOW), SEP, approved SEMP and system specification) have been satisfied

•Integrating activities of any **lower-level PDRs** have occurred; identified issues are documented in action plans

•Plan to CDR is accurately documented in the SEP as well as the IMP and IMS

•Program is properly staffed

•Adequate processes and metrics are in place for the program to succeed

•**Program schedule**, as depicted in the updated IMS (see DAG Section 4.3.2.2. Integrated Master Plan/Integrated Master Schedule) is executable within acceptable technical and cost risks

•Program is executable with the existing budget and the approved product baseline

•**Trade studies and system producibility assessments** are under way

•Majority of **manufacturing processes** have been defined, characterized, and documented

•**Logistics (sustainment) and training systems** planning and documentation are sufficiently complete to support the review

•Life Cycle Sustainment Plan (LCSP) is approved, including updates on program sustainment development efforts and schedules based on current budgets and **firm supportability design features**

•LCSP includes software support requirements

•**Long-lead and key supply chain elements** are identified

•Computer system and software design/development approach have been confirmed through analyses, demonstrations, and prototyping in a relevant environment

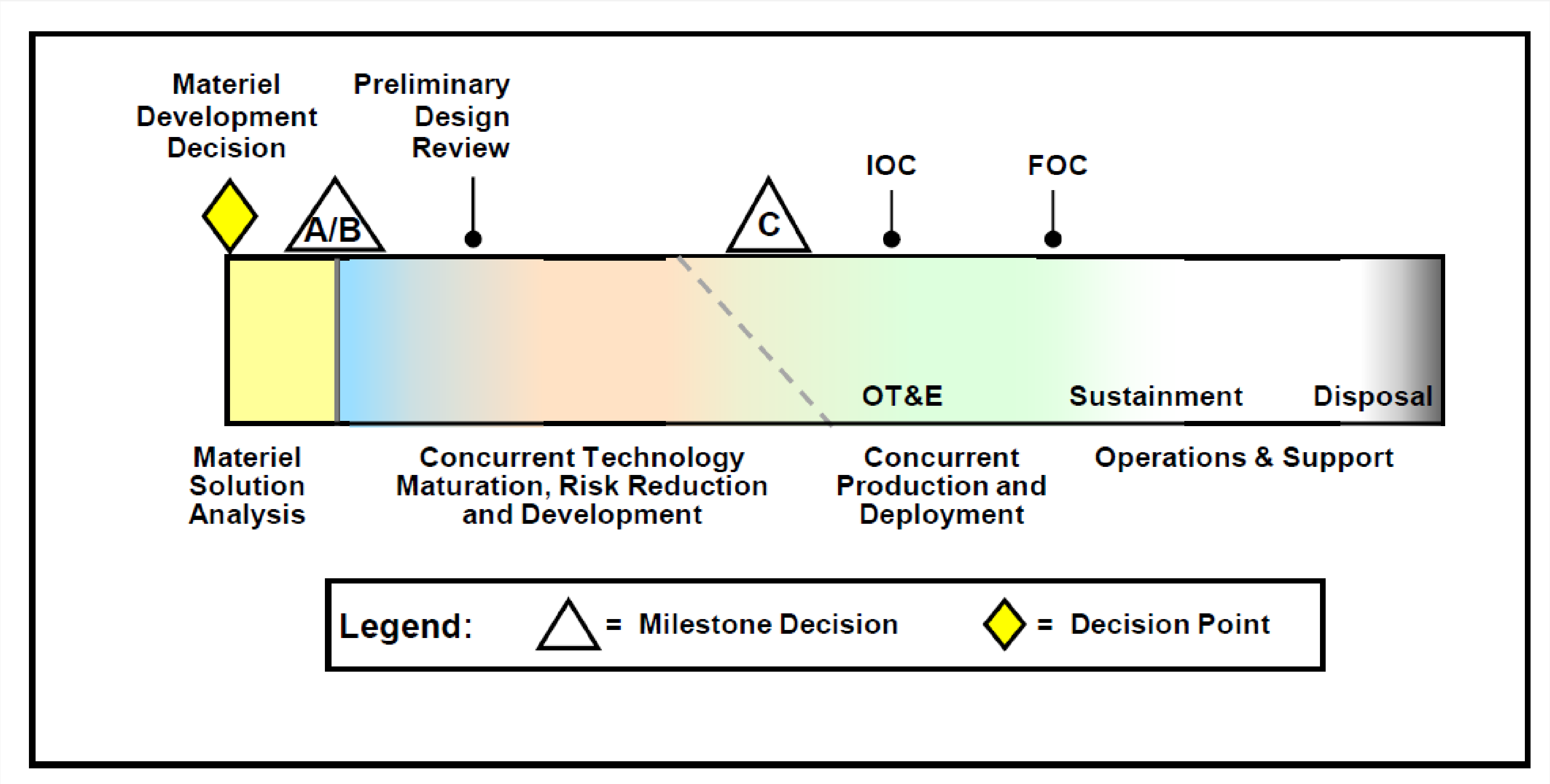
Source: Defense Acquisition Guidebook, 2013
(need to update with 2017 DAG content)

ACCELERATED ACQUISITION PROGRAM

Is this a model
we can leverage with AM?

Or

Is it an obsolete construct?



Source: DOD Instruction 5000.02
January 7, 2015
Incorporating Change 1, Effective January 26, 2017
Incorporating Change 2, Effective February 2, 2017

KEY QUESTIONS

- What are impacts on decision points and reviews?
- **New process model (acquisition lifecycle framework) with new/different checks and balances?**
- Greater consideration of streamlining opportunities?

DAU

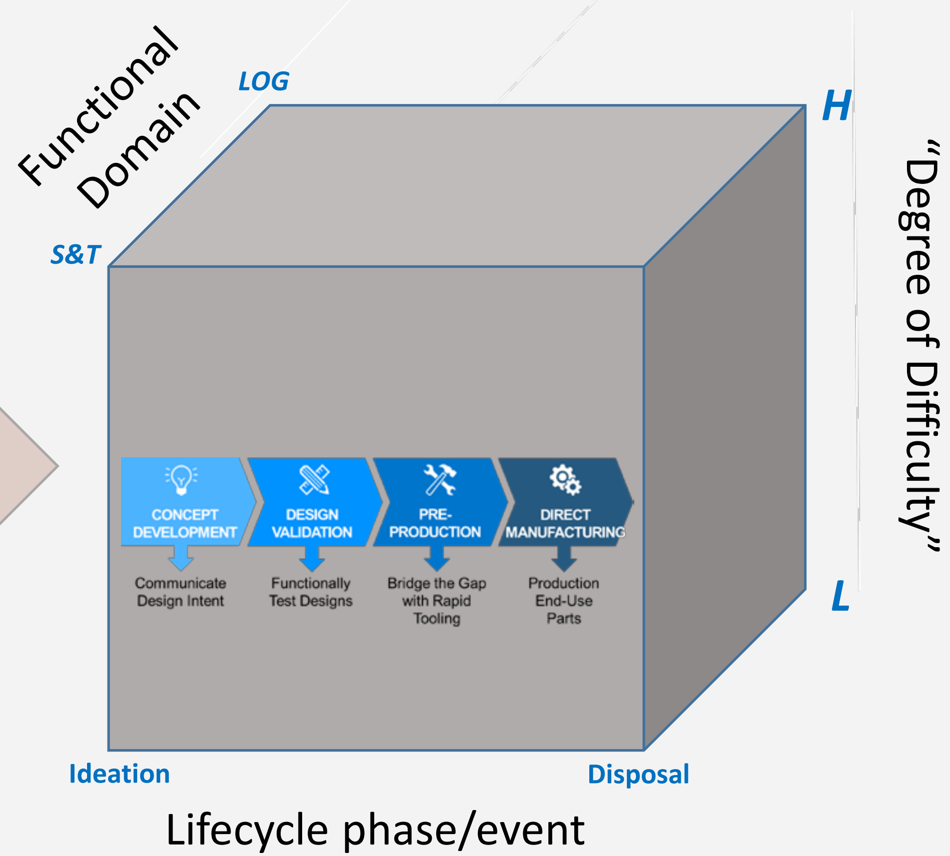
ADDITIVE MANUFACTURING WORKFLOW LEARNING FRAMEWORK

ASSETS

- AM Community of Practice
- Decision aid/tool
- Learning aid: video
- Learning aid: print

Informs AM application

APPLICATION MODEL



Workforce can utilize DAU assets for application of AM in the context of the lifecycle framework

Contact information:

John F. Rice
Defense Acquisition University
7115 Old Madison Pike
Huntsville, AL 35806

256-922-8152
john.rice@dau.mil

Defense Acquisition University