Department of Defense Joint Additive Manufacturing Roadmap

Defense Manufacturing Conference

30 Nov 2016

Dr. Jennifer Fielding – Technical Advisor, Structures, Propulsion, and Manufacturing Enterprise Branch, Air Force Research Laboratory, founding Government Program Manager, America Makes
Mr. Rob Gorham – Director of Operations, America Makes
Mr. Andy Davis – Program Manager, Manufacturing Technology, U.S. Army
Mr. Ben Bouffard – AM Lead, RDT&E, Department of the Navy
Ms. Kelly Morris – Chief, Logistics R&D, Defense Logistics Agency

www.AmericaMakes.us/dod-amroadmap

Outline

- Motivation and Strategic Alignment
- Methodology/Approach
- Joint Workshop Participants and Facilitators
- Results
  - Applications
  - Enablers
  - Roadmap
    - Design
    - Materials
    - Process
    - Value Chain
- Key Takeaways
- Recommendations
- Acknowledgments
- Points of Contact
- Q&A / Discussion

Motivation and Strategic Alignment

- AM has incredible opportunity for impact to the DoD
- Significant investments have been made by DoD
- Need for a shared vision
  - ID common areas of interest
  - Have a framework to guide coordination and collaboration
  - Track progress towards goals
  - Inform industry of DoD needs
- Build upon America Makes roadmap framework and methodology

DoD Strategic Goals	Benefits of AM
Defeat our Adversaries, Deter War, and Defend the Nation	Facilitate adaptive responses and new capabilities to counter increasingly agile adversaries
Sustain a Ready Force to Meet Mission Needs	Use AM to create a more resilient supply chain and enable in-theatre manufacturing
Strengthen & Enhance the Health & Effectiveness of the Total Workforce	Use AM to create a more resilient supply chain and enable in-theatre manufacturing
Strengthen & Enhance the Health & Effectiveness of the Total Workforce	Increase system availability (readiness), and produce novel, high performance parts
Reform & Reshape the Defense Institution	Incorporate supply chain and production benefits of AM into DoD operations

Methodology / Approach

Separate workshops for each Service/DLA

Joint DoD workshop

1. Visioning

Captured the current state of AM within the DoD services/DLA, the future state vision, and outlined how the Services will get there

Output:
- Aligned current state within the Service
- Defined future vision of AM within the Service

2. Functional Requirements

Rationalized requirements against desired capabilities of the DoD services/DLA to develop a detailed sequence of activities for the DoD Services/DLA to realize their AM visions

Output:
- Provisional AM technology roadmaps for each Service

3. Synthesis

Developed a joint vision of AM across the DoD and identified areas of commonality between the Services and DLA

Output:
- Integrated DoD-wide AM roadmap
- Identification of potential collaboration points

March – April 2016

11 May 2016

Joint Workshop Participants and Facilitators

Andy Davis – Chief, Manufacturing Technology
Rick Foley – Tobyhanna Army Depot
CAPT Jeremey Pinson - CASCOM
Vince Matrisciano – PEO Ammunition
Robert Carter - ARL

Ben Bouffard – AM Lead, DASN, RDT&E
James Pluta – OPNAV N41
Jenn Wolk – Program Officer, ONR
William Frazier – Chief Scientist, NAVAIR
LtCol Howie Marotto – HQ, Installations & Logistics

Mary Kinsella – Manufacturing Technology, AFRL
Joe Carignan – Tinker AFB
Kristian Olivero – Tinker AFB
Jamie Gilbert – Tinker AFB
Mark Benedict – Manufacturing Technology, AFRL

Kelly Morris – Chief, Logistics R&D
Edilia Correa – Chief, Tech & Qual
Phillip Radliff – Value Engineering
Michael Ball – Chief, Technology Office
Kyle Hedrick – Exec Sponsor for AM

America Makes

Rob Gorham
John Wilczynski
Kevin Creehan
Ed Morris
Jennifer Fielding (AFRL)

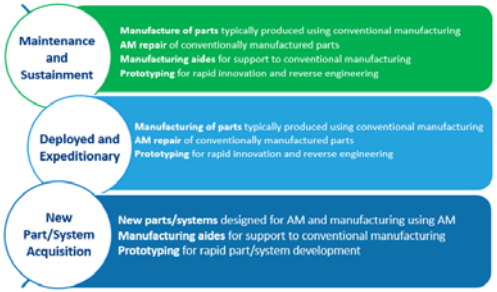
Deloitte.

Ian Wing
Mark Cotteleer
Mark Vitale
Jim Joyce

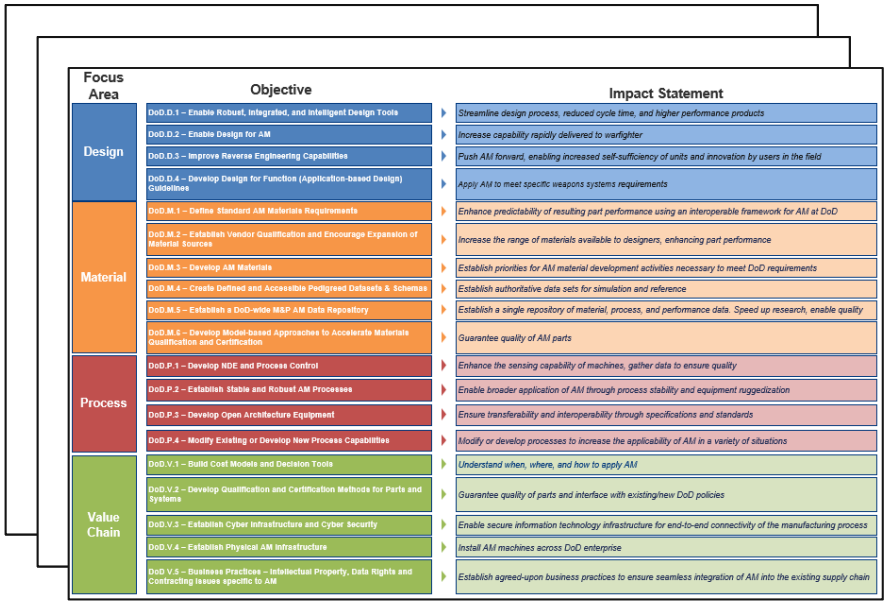
Visioning Exercise

Results: Major Sections of the DoD AM Roadmap

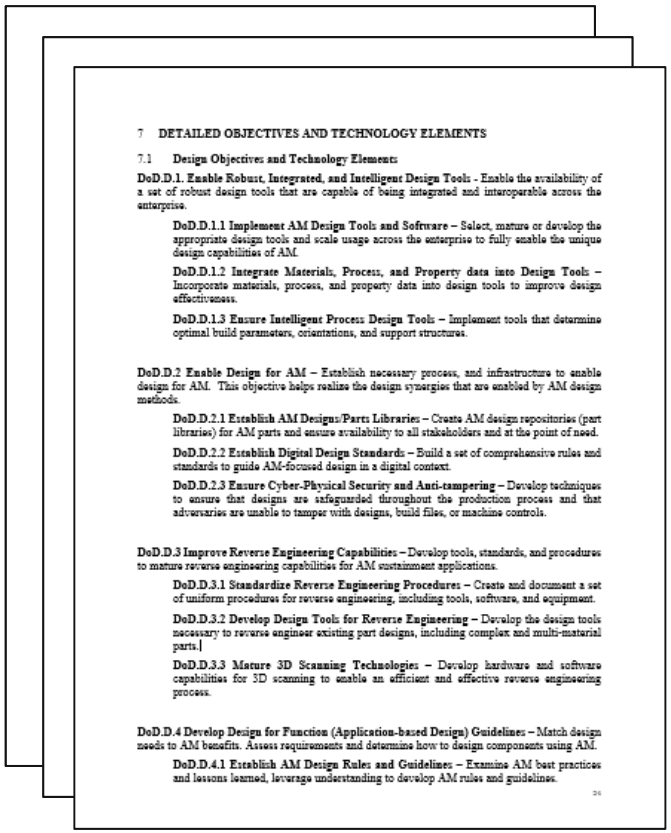
Application Spaces / Categorization



Objectives and Sequenced Technology Elements (visual form)



Detailed Objectives Technology Elements, Application Spaces, Technology Enablers (written form)



7 DETAILED OBJECTIVES AND TECHNOLOGY ELEMENTS

7.1 Design Objectives and Technology Elements

DoD.D.1. Enable Robust, Integrated, and Intelligent Design Tools - Enable the availability of a set of robust design tools that are capable of being integrated and interoperable across the enterprise.

DoD.D.1.1 Implement AM Design Tools and Software – Select, mature or develop the appropriate design tools and scale usage across the enterprise to fully enable the unique design capabilities of AM.

DoD.D.1.2 Integrate Materials, Process, and Property data into Design Tools – Incorporate materials, process, and property data into design tools to improve design effectiveness.

DoD.D.1.3 Ensure Intelligent Process Design Tools – Implement tools that determine optimal build parameters, orientations, and support structures.

DoD.D.2 Enable Design for AM – Establish necessary process, and infrastructure to enable design for AM. This objective helps realize the design synergies that are enabled by AM design methods.

DoD.D.2.1 Establish AM Designs/Parts Libraries – Create AM design repositories (part libraries) for AM parts and ensure availability to all stakeholders and at the point of need.

DoD.D.2.2 Establish Digital Design Standards – Build a set of comprehensive rules and standards to guide AM-focused design in a digital context.

DoD.D.2.3 Ensure Cyber-Physical Security and Anti-tampering – Develop techniques to ensure that designs are safeguarded throughout the production process and that adversaries are unable to tamper with designs, build files, or machine controls.

DoD.D.3 Improve Reverse Engineering Capabilities – Develop tools, standards, and procedures to mature reverse engineering capabilities for AM sustainment applications.

DoD.D.3.1 Standardize Reverse Engineering Procedures – Create and document a set of uniform procedures for reverse engineering, including tools, software, and equipment.

DoD.D.3.2 Develop Design Tools for Reverse Engineering – Develop the design tools necessary to reverse engineer existing part designs, including complex and multi-material parts.

DoD.D.3.3 Mature 3D Scanning Technologies – Develop hardware and software capabilities for 3D scanning to enable an efficient and effective reverse engineering process.

DoD.D.4 Develop Design for Function (Application-based Design) Guidelines – Match design needs to AM benefits. Assess requirements and determine how to design components using AM.

DoD.D.4.1 Establish AM Design Rules and Guidelines – Examine AM best practices and lessons learned, leverage understanding to develop AM rules and guidelines.

Application Spaces / Categorization

Maintenance and Sustainment

Manufacture of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid innovation and reverse engineering

Deployed and Expeditionary

Manufacturing of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Prototyping for rapid innovation and reverse engineering

New Part/System Acquisition

New parts/systems designed for AM and manufacturing using AM
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid part/system development

Application Spaces / Categorization

Maintenance and Sustainment

Manufacture of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid innovation and reverse engineering

Deployed and Expeditionary

Manufacturing of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Prototyping for rapid innovation and reverse engineering

New Part/System Acquisition

New parts/systems designed for AM and manufacturing using AM
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid part/system development

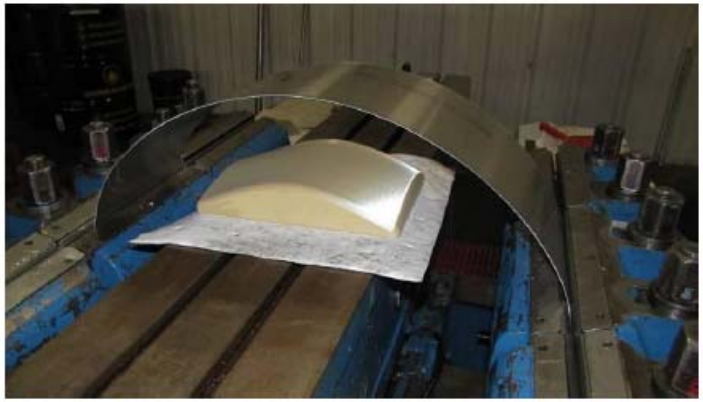
Maintenance and Sustainment: Manufacturing Aides to Support Conventional Manufacturing

- Masking
- Tooling
- Fixtures
- Mounts
- Patterns
- Jigs

Masking for Grit Blasting, Triton / Stratasys / AFRL SBIR

Composite Inlet Duct Tooling, Northrop Grumman / DMS&T / AFRL

Motivation: Cost and Lead Time improvements



Metal Sheet Form Tooling, NAVAIR, Cherry Point

Application Spaces / Categorization

Maintenance and Sustainment

Manufacture of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid innovation and reverse engineering

Deployed and Expeditionary

Manufacturing of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Prototyping for rapid innovation and reverse engineering

New Part/System Acquisition

New parts/systems designed for AM and manufacturing using AM
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid part/system development

Deployed and Expeditionary: Manufacturing of Parts Typically Produced using Traditional Manufacturing

- Ruggedization
- Ease of Maintenance
- Mobility and small footprint
- Minimal post processing
- Ease of design and reverse engineering
- Environmental factors
- Materials storage and handling
- Recycled or indigenous material feedstocks

U.S. Army Rapid Equipping Force (REF) ExLabs

Motivation: Complete the mission, shorten logistics tail, produce at point of need

Application Spaces / Categorization

Maintenance and Sustainment

Manufacture of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid innovation and reverse engineering

Deployed and Expeditionary

Manufacturing of parts typically produced using conventional manufacturing
AM repair of conventionally manufactured parts
Prototyping for rapid innovation and reverse engineering

New Part/System Acquisition

New parts/systems designed for AM and manufacturing using AM
Manufacturing aides for support to conventional manufacturing
Prototyping for rapid part/system development

New Part / System Acquisition

- Aerospace, ground and marine vehicle structures and ancillary parts
- Integrated electronics, antennas, structural health monitoring
- Conformal apertures and reconfigurable electronics
- Power, Energy harvesting/storage, Energetics
- Personal protection such as ballistics and sensing
- Medical implants and prosthetics
- Pharmaceuticals
- Shelter
- Food

Heat Exchangers, Within Technologies

Motivation: enhanced performance or capability not able to be affordably produced using conventional manufacturing processes
AND/OR Solving a production lead time issue causing an acquisition schedule slip.

Satellite Propellant Tank, Lockheed Martin

Technology Enablers for Additive Manufacturing

Cultural Change (Mission) - Enabling cultural change will facilitate increased buy-in for and understanding of AM / 3DP

Workforce Development (Talent) - Appropriately educating staff enables increased AM / 3DP understanding and production effectiveness

Data Management and Use of Digital Thread (Insights) - Successful data management facilitates appropriate information exchange to inform key decisions and securing sensitive data

DoD Additive Manufacturing Roadmap

- **Four Focus Areas / Swimlanes**
  - Design
  - Materials
  - Process
  - Value Chain
- **General Observations**
  - Lots of connected relationships between the four Focus Areas
  - This roadmap is a consolidated vision between the services/DLA
    - Service-level roadmaps have more detail
    - Individual organizations within each service may have detailed strategies and programmatic roadmaps for AM
      - Creation of this DoD AM roadmap involved those SMEs to the greatest extent possible
  - Sequenced Technology Elements are shown for each Objective
    - Sequencing is approximate
  - Technology “Enablers” were uncovered

DoD Additive Manufacturing Roadmap

Focus Area	Objective	Impact Statement
Design	DoD.D.1 – Enable Robust, Integrated, and Intelligent Design Tools	*Streamline design process, reduced cycle time, and higher performance products*
	DoD.D.2 – Enable Design for AM	*Increase capability rapidly delivered to warfighter*
	DoD.D.3 – Improve Reverse Engineering Capabilities	*Push AM forward, enabling increased self-sufficiency of units and innovation by users in the field*
	DoD.D.4 – Develop Design for Function (Application-based Design) Guidelines	*Apply AM to meet specific weapons systems requirements*
Material	DoD.M.1 – Define Standard AM Materials Requirements	*Enhance predictability of resulting part performance using an interoperable framework for AM at DoD*
	DoD.M.2 – Establish Vendor Qualification and Encourage Expansion of Material Sources	*Increase the range of materials available to designers, enhancing part performance*
	DoD.M.3 – Develop AM Materials	*Establish priorities for AM material development activities necessary to meet DoD requirements*
	DoD.M.4 – Create Defined and Accessible Pedigreed Datasets & Schemas	*Establish authoritative data sets for simulation and reference*
	DoD.M.5 – Establish a DoD-wide M&P AM Data Repository	*Establish a single repository of material, process, and performance data. Speed up research, enable quality*
	DoD.M.6 – Develop Model-based Approaches to Accelerate Materials Qualification and Certification	*Guarantee quality of AM parts*
Process	DoD.P.1 – Develop NDE and Process Control	*Enhance the sensing capability of machines, gather data to ensure quality*
	DoD.P.2 – Establish Stable and Robust AM Processes	*Enable broader application of AM through process stability and equipment ruggedization*
	DoD.P.3 – Develop Open Architecture Equipment	*Ensure transferability and interoperability through specifications and standards*
	DoD.P.4 – Modify Existing or Develop New Process Capabilities	*Modify or develop processes to increase the applicability of AM in a variety of situations*
Value Chain	DoD.V.1 – Build Cost Models and Decision Tools	*Understand when, where, and how to apply AM*
	DoD.V.2 – Develop Qualification and Certification Methods for Parts and Systems	*Guarantee quality of parts and interface with existing/new DoD policies*
	DoD.V.3 – Establish Cyber Infrastructure and Cyber Security	*Enable secure information technology infrastructure for end-to-end connectivity of the manufacturing process*
	DoD.V.4 – Establish Physical AM Infrastructure	*Install AM machines across DoD enterprise*
	DoD V.5 – Business Practices – Intellectual Property, Data Rights and Contracting Issues specific to AM	*Establish agreed-upon business practices to ensure seamless integration of AM into the existing supply chain*

Design

Objective and Impact	Sequenced Technology Elements
DoD.D.1 – Enable Robust, Integrated, and Intelligent Design Tools *Streamline design process, reduced cycle time, and higher performance products*	**DoD.D.1.1 Implement AM Design Tools and Software** **DoD.D.1.2 Integrate Materials, Process, and Property data into Design Tools** **DoD.D.1.3 Ensure Intelligent Process Design Tools**
DoD.D.2 – Enable Design for AM *Increase capability rapidly delivered to warfighter*	**DoD.D.2.1 Establish AM Designs/Parts Libraries** **DoD.D.2.2 Establish Digital Design Standards** **DoD.D.2.3 Ensure Cyber-Physical Security and Anti-tampering**

Design

Objective and Impact	Sequenced Technology Elements
DoD.D.3 – Improve Reverse Engineering Capabilities *Push AM forward, enabling increased self-sufficiency of units and innovation by users in the field*	**DoD.D.3.1 Standardize Reverse Engineering Procedures** **DoD.D.3.2 Develop Design Tools for Reverse Engineering** **DoD.D.3.3 Mature 3D Scanning Technologies**
DoD.D.4 – Develop Design for Function (Application-based Design) Guidelines *Apply AM to meet specific weapons systems requirements*	**DoD.D.4.1 Establish AM Design Rules and Guidelines** **DoD.D.4.2 Establish AM Materials and Process Selection Guidelines**

Materials

Objective and Impact	Sequenced Technology Elements
DoD.M.1 – Define Standard AM Materials Requirements *Enhance predictability of resulting part performance using an interoperable framework for AM*	**DoD.M.1.1 Establish acceptable AM feedstock material properties** **DoD.M.1.2 Characterize Impact of Material Properties and Process on Performance** **M.1.3 – Accelerate the material qualification process** **DoD.M.1.3 Develop Feedstock Materials Specifications and Standards**
DoD.M.2 – Establish Vendor Qualification and Encourage Expansion of Material Sources *Increase the range of materials available to designers, enhancing part performance*	**DoD.M.2.1 Establish Vendor Qualification Procedure** **DoD.M.2.2 Identify Potential AM Materials Sources**
DoD.M.3 – Develop AM Materials *Establish priorities for AM material development activities necessary to meet DoD requirements*	**DoD.M.3.1 Assess Current Materials Capabilities and Identify Gaps** **DoD.M.3.2 Develop AM Materials to Meet DoD Needs**

Materials

Objective and Impact	Sequenced Technology Elements
DoD.M.4 – Create Defined and Accessible Pedigreed Datasets and Schemas *Establish authoritative data sets for simulation and reference*	**DoD.M.4.1 Develop Comprehensive and Standardized Material and Process Data Schemas** **DoD.M.4.3 Develop Procedures for Pedigreed Datasets** **DoD.M.4.3 Increase the Availability of Pedigreed Datasets**
DoD.M.5 – Establish a DoD-wide Materials and Process AM Data Repository *Establish a single repository of material, process, and performance data. Speed up research, enables quality*	**DoD.M.5.1 Establish Secure, Standardized, Data Repository** **DoD.M.5.2 Develop Procedures to Populate and Use Data Repository** **DoD.M.5.3 Populate Repository with Available Data**
DoD.M.6 – Develop Model-based Approaches to Accelerate Materials Qualification and Certification *Guarantee quality of AM parts*	**DoD.M.6.1 Develop Empirical and Physics-Based Models** **DoD.M.6.2 Develop Approaches to Reduce Computation Time**

Process

Objective and Impact	Sequenced Technology Elements
DoD.P.1 – Develop NDE and Process Control *Enhance the sensing capability of machines, gather data to ensure quality*	**DoD.P.1.1 Improve In-Situ Process Sensing/Monitoring Capabilities** **DoD.P.1.2 Develop Closed-loop Process Control** **DoD.P.1.3 Advance Data Collection and Analysis** **DoD.P.1.4 Develop and Validate NDE Capabilities**
DoD.P.2 – Establish Stable and Robust AM Processes *Enable broader application of AM through process stability and equipment ruggedization*	**DoD.P.2.1 Reduce Process Variability** **DoD.P.2.2 Ensure Development of Process Standards and Specifications** **DoD.P.2.3 Establish Equipment Certification and Calibration Procedures** **DoD.P.2.4 Improve and Optimize Existing AM Processes**

Process

Objective and Impact	Sequenced Technology Elements
DoD.P.3 – Develop Open Architecture Equipment *Ensure transferability and interoperability through specifications and standards*	**DoD.P.3.1 Develop Open-Architecture Platforms** **DoD.P.3.2 Ensure Documentation of Open Architecture Standards** **DoD.P.3.3 Develop Open Architecture Equipment Vendors**
DoD.P.4 – Modify Existing or Develop New Process Capabilities *Modify or develop processes to increase the applicability of AM in a variety of situations*	**DoD.P.4.1 Develop AM Repair Processes** **DoD.P.4.2 Develop Hybrid AM/Traditional Manufacturing Systems** **DoD.P.4.3 Develop Capabilities for Larger Part Processing** **DoD.P.4.4 Develop Capabilities for Multi-Scale Processing** **DoD.P.4.5 Develop Capabilities for Multi-Material Processing**

Value Chain

Objective and Impact	Sequenced Technology Elements
DoD.V.1 – Build Cost Models and Decision Tools *Understand when, where, and how to apply AM*	**DoD.V.1.1 Identify and Capture AM Use Cases and Best Practices for Repair, Part Replacement, and New Part Manufacture** **DoD.V.1.2 Develop Adequate Cost Models for AM implementation** **DoD.V.1.3 Develop and Implement AM Decision Tools to Establish the Value Proposition**
DoD.V.2 – Develop Qualification and Certification Methods for Parts and Systems *Guarantee quality of parts and interface with existing/new DoD policies*	**DoD.V.2.1 Understand Risk of AM Approaches** **DoD.V.2.2 Inform Decision Authorities re: AM Technology** **DoD.V.2.3 Ensure Qualification and Certification Methods Accommodate AM Technologies**

Value Chain

Objective and Impact	Sequenced Technology Elements
DoD.V.3 – Establish Cyber Infrastructure and Cyber Security *Enable secure information technology infrastructure for end-to-end connectivity of the manufacturing process*	**DoD.V.3.1 Establish Configuration Management for Data Collection and Monitoring** **DoD.V.3.2 Integrate AM Practices into Enterprise-Wide Product Lifecycle Management** **DoD.V.3.3 Integrate AM with Efforts that are Developing the Model-Based Enterprise and the Digital Thread Infrastructure** **DoD.V.3.4 Drive toward DOD Usage of 3D data** **DoD.V.1.5 Ensure Cyber Security**
DoD.V.4 – Establish Physical AM Infrastructure *Install AM machines across DoD enterprise*	**DoD.V.4.1 Assess Current AM Capabilities and Gaps** **DoD.V.4.2 Create DoD AM Enterprise Infrastructure Plan** **DoD.V.4.3 Implement DoD AM Enterprise Infrastructure Plan**

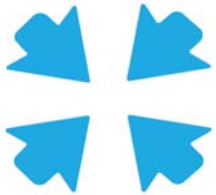
Value Chain

Objective and Impact	Sequenced Technology Elements
DoD V.5 – Business Practices – IP, Data Rights and Contracting Issues specific to AM *Establish agreed-upon business practices to ensure seamless integration of AM into the existing supply chain*	**DoD.V.5.1 Issue Guidance on Intellectual Property and Data Rights Considerations** **DoD.V.5.2 Create Streamlined Contracting Approaches for AM Parts**

Key Takeaways

Opportunity of AM

- Advantages of DoD-wide utilization of AM is greater than risks from unknowns and challenges



Synergistic visions

- Opportunity for coordination and collaboration
- Share information, knowledge

Structured format for action

- Prioritization and allocation of resources

Recommendations

- Create a DoD-wide coordination plan for advancing AM capabilities
  - Appoint lead integrator and council
  - Include relevant stakeholders
- Initial execution
  - Prioritize objectives and coordinate plans between services based on synergy within DoD roadmap
- Continuous improvement
  - Revise and refine implementation plan to reflect changing priorities and more recent developments
  - Measure progress towards key objectives

Acknowledgements

- Funding for this activity is gratefully acknowledged from the Office of the Secretary of Defense, Manufacturing and Industrial Base Policy, Department of the Navy, U.S. Army, U.S. Air Force, and Defense Logistics Agency
- In kind cost share is gratefully acknowledged from America Makes and Deloitte, Inc.

Points of Contact for More Information

- Download Roadmap Here: www.AmericaMakes.us/dod-amroadmap
- DoD Points of Contact:

  U.S. ARMY: Andy Davis, andrew.m.davis1.civ@mail.mil

  U.S. AIR FORCE: Jonathan Miller, jonathan.miller.22@us.af.mil

  DEPT OF THE NAVY: Ben Bouffard, benjamin.bouffard@navy.mil

  DEFENSE LOGISTICS AGENCY: Tony Delgado luis.Delgado@dla.mil

- America Makes Program Points of Contact:
  - Ed Morris, Director, America Makes and VP, NCDMM ed.morris@ncdmm.org
  - Rob Gorham, Director of Operations, rob.gorham@ncdmm.org
  - Dennis Butcher, Government Program Manager, dennis.butcher.1@us.af.mil
  - Mark Benedict, Government Chief Technical Advisor, mark.benedict.2@us.af.mil


DoD AM SYNTHESIS WORKSHOP
service/agency visions
Deloitte.
UNIFY and COLLABORATE
APPLICATION
UNDERSTAND RISKS
NEW TECHNOLOGY
IMPLEMENTATION PROCESS
INVEST IN R&D
AIR FORCE
COMMONALITIES
ARMY
IMPROVE READINESS
INTEGRATION WITH SUMERS
REDUCE LOGISTICS DEMANDS
PARTS ON DEMAND
3-5 days
DIGITAL PARTS DATA
HOW DO WE RESOURCE THE ROADMAPS
INTERNAL COLLABORATION
ACCELERATE ADOPTION
SHAPE INDUSTRY'S DIRECTION
DEVELOP DIGITAL INFRASTRUCTURE
EMPOWERING WARFIGHTERS IN THE FIELD
REDUCE LOGISTICS LEAD TIMES
DEFINING TOPS
Cradle to Cradle
REVOLUTIONIZE SUPPLY CHAIN
DEFENSE LOGISTICS AGENCY
QUALIFIED CONTRACT MANUFACTURING
PARTS YOU CAN TRUST
REPOSITORY
DATA PACKAGES
DEPARTMENT OF THE NAVY
ENHANCED WAR-FIGHTING CAPABILITIES
IMPROVED LOGISTICS
RELATIONSHIPS
CONVERSATIONS
PRIORITIES
NAVY SPECIFIC
ALL DoD
EXIT