Department of Defense Joint Additive Manufacturing Roadmap

Defense Manufacturing Conference 30 Nov 2016

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**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](http://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


doplay strategic goals
- Defeat our Adversaries, Deter War, and Defend the Nation
- Sustain a Ready Force to Meet Mission Needs
- Strengthen & Enhance the Health & Effectiveness of the Total Workforce
- Reform & Reshape the Defense Institution

Benefits of AM
- Facilitate adaptive responses and new capabilities to counter increasingly agile adversaries
- Use AM to create a more resilient supply chain and enable in-theatre manufacturing
- Use AM to create a more resilient supply chain and enable in-theatre manufacturing
- Increase system availability (readiness), and produce novel, high performance parts
- Incorporate supply chain and production benefits of AM into DoD operations
Methodology / Approach

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

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

Ian Wing
Mark Cotteleeer
Mark Vitale
Jim Joyce

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Visioning Exercise
Results: Major Sections of the DoD AM Roadmap

Objectives and Sequenced Technology Elements (visual form)

Detailed Objectives Technology Elements, Application Spaces, Technology Enablers (written form)
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
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Maintenance and Sustainment: Manufacturing Aides to Support Conventional Manufacturing

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

Motivation: Cost and Lead Time improvements
Application Spaces / Categorization

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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

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
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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

**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.
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
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

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## Design

### Objective and Impact

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<thead>
<tr>
<th>DoD.D.1 – Enable Robust, Integrated, and Intelligent Design Tools</th>
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<td><em>Streamline design process, reduced cycle time, and higher performance products</em></td>
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<tr>
<th>DoD.D.2 – Enable Design for AM</th>
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<tr>
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### Sequenced Technology Elements

<table>
<thead>
<tr>
<th>DoD.D.1.1 Implement AM Design Tools and Software</th>
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<tbody>
<tr>
<td>DoD.D.1.2 Integrate Materials, Process, and Property data into Design Tools</td>
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<td>DoD.D.1.3 Ensure Intelligent Process Design Tools</td>
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<tr>
<td>DoD.D.2.1 Establish AM Designs/Parts Libraries</td>
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<td>DoD.D.2.2 Establish Digital Design Standards</td>
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<td>DoD.D.2.3 Ensure Cyber-Physical Security and Anti-tampering</td>
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</tbody>
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## Design

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<tr>
<th>Objective and Impact</th>
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<tbody>
<tr>
<td><strong>DoD.D.3 – Improve Reverse Engineering Capabilities</strong></td>
<td><strong>DoD.D.3.1 Standardize Reverse Engineering Procedures</strong></td>
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<tr>
<td>Push AM forward, enabling increased self-sufficiency of units and innovation by users in the field</td>
<td><strong>DoD.D.3.2 Develop Design Tools for Reverse Engineering</strong></td>
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<td><strong>DoD.D.3.3 Mature 3D Scanning Technologies</strong></td>
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<tr>
<td>Apply AM to meet specific weapons systems requirements</td>
<td><strong>DoD.D.4.2 Establish AM Materials and Process Selection Guidelines</strong></td>
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<tr>
<td><strong>DoD.M.1 – Define Standard AM Materials Requirements</strong></td>
<td><strong>DoD.M.1.1 Establish acceptable AM feedstock material properties</strong></td>
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<tr>
<td><em>Enhance predictability of resulting part performance using an interoperable framework for AM</em></td>
<td><strong>DoD.M.1.2 Characterize Impact of Material Properties and Process on Performance</strong></td>
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<td><strong>M.1.3 – Accelerate the material qualification process</strong></td>
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<td><strong>DoD.M.1.3 Develop Feedstock Materials Specifications and Standards</strong></td>
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<tr>
<td><strong>DoD.M.2 – Establish Vendor Qualification and Encourage Expansion of Material Sources</strong></td>
<td><strong>DoD.M.2.1 Establish Vendor Qualification Procedure</strong></td>
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<tr>
<td><em>Increase the range of materials available to designers, enhancing part performance</em></td>
<td><strong>DoD.M.2.2 Identify Potential AM Materials Sources</strong></td>
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<tr>
<td><strong>DoD.M.3 – Develop AM Materials</strong></td>
<td><strong>DoD.M.3.1 Assess Current Materials Capabilities and Identify Gaps</strong></td>
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<tr>
<td><em>Establish priorities for AM material development activities necessary to meet DoD requirements</em></td>
<td><strong>DoD.M.3.2 Develop AM Materials to Meet DoD Needs</strong></td>
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<tr>
<td>DoD.M.4 – Create Defined and Accessible Pedigreed Datasets and Schemas</td>
<td><strong>DoD.M.4.1</strong> Develop Comprehensive and Standardized Material and Process Data Schemas</td>
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<tr>
<td>Establish authoritative data sets for simulation and reference</td>
<td><strong>DoD.M.4.3</strong> Develop Procedures for Pedigreed Datasets</td>
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<tr>
<td>DoD.M.4.3 Increase the Availability of Pedigreed Datasets</td>
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<tr>
<td>DoD.M.5 – Establish a DoD-wide Materials and Process AM Data Repository</td>
<td><strong>DoD.M.5.1</strong> Establish Secure, Standardized, Data Repository</td>
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<tr>
<td>Establish a single repository of material, process, and performance data. Speed up research, enables quality</td>
<td><strong>DoD.M.5.2</strong> Develop Procedures to Populate and Use Data Repository</td>
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<tr>
<td>DoD.M.5.3 Populate Repository with Available Data</td>
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<tr>
<td>DoD.M.6 – Develop Model-based Approaches to Accelerate Materials Qualification and Certification</td>
<td><strong>DoD.M.6.1</strong> Develop Empirical and Physics-Based Models</td>
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<tr>
<td>Guarantee quality of AM parts</td>
<td><strong>DoD.M.6.2</strong> Develop Approaches to Reduce Computation Time</td>
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## Process

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

**Objective and Impact**

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<tr>
<td>DoD.P.3 – Develop Open Architecture Equipment</td>
<td>DoD.P.3.1 Develop Open-Architecture Platforms</td>
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<td>DoD.P.3.2 Ensure Documentation of Open Architecture Standards</td>
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<td>DoD.P.3.3 Develop Open Architecture Equipment Vendors</td>
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<tr>
<td>DoD.P.4 – Modify Existing or Develop New Process Capabilities</td>
<td>DoD.P.4.1 Develop AM Repair Processes</td>
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<td>DoD.P.4.2 Develop Hybrid AM/Traditional Manufacturing Systems</td>
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<td>DoD.P.4.3 Develop Capabilities for Larger Part Processing</td>
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<td>DoD.P.4.4 Develop Capabilities for Multi-Scale Processing</td>
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<td>DoD.P.4.5 Develop Capabilities for Multi-Material Processing</td>
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*Ensure transferability and interoperability through specifications and standards*

*Modify or develop processes to increase the applicability of AM in a variety of situations*
# Value Chain

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<tr>
<td><strong>DoD.V.1 – Build Cost Models and Decision Tools</strong></td>
<td>DoD.V.1.1 Identify and Capture AM Use Cases and Best Practices for Repair, Part Replacement, and New Part Manufacture</td>
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<tr>
<td>Understand when, where, and how to apply AM</td>
<td>DoD.V.1.2 Develop Adequate Cost Models for AM implementation</td>
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<tr>
<td><strong>DoD.V.2 – Develop Qualification and Certification Methods for Parts and Systems</strong></td>
<td>DoD.V.1.3 Develop and Implement AM Decision Tools to Establish the Value Proposition</td>
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<tr>
<td>Guarantee quality of parts and interface with existing/new DoD policies</td>
<td>DoD.V.2.1 Understand Risk of AM Approaches</td>
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<td>DoD.V.2.2 Inform Decision Authorities re: AM Technology</td>
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<td>DoD.V.2.3 Ensure Qualification and Certification Methods Accommodate AM Technologies</td>
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<tr>
<td>Value Chain Objective and Impact</td>
<td>Sequenced Technology Elements</td>
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<tr>
<td><strong>DoD.V.3 – Establish Cyber Infrastructure and Cyber Security</strong></td>
<td>DoD.V.3.1 Establish Configuration Management for Data Collection and Monitoring</td>
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<tr>
<td>Enable secure information technology infrastructure for end-to-end connectivity of the manufacturing process</td>
<td>DoD.V.3.2 Integrate AM Practices into Enterprise-Wide Product Lifecycle Management</td>
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<tr>
<td><strong>DoD.V.4 – Establish Physical AM Infrastructure</strong></td>
<td>DoD.V.3.3 Integrate AM with Efforts that are Developing the Model-Based Enterprise and the Digital Thread Infrastructure</td>
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<td>Install AM machines across DoD enterprise</td>
<td>DoD.V.3.4 Drive toward DOD Usage of 3D data</td>
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<td>DoD.V.1.5 Ensure Cyber Security</td>
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<td>DoD V.5 – Business Practices – IP, Data Rights and Contracting Issues specific to AM</td>
<td>DoD.V.5.1 Issue Guidance on Intellectual Property and Data Rights Considerations</td>
</tr>
<tr>
<td>Establish agreed-upon business practices to ensure seamless integration of AM into the existing supply chain</td>
<td>DoD.V.5.2 Create Streamlined Contracting Approaches for AM Parts</td>
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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](http://www.AmericaMakes.us/dod-amroadmap)
- DoD Points of Contact:
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  - 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
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  - 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