2022 Additive Manufacturing Workshop

Executive Summary

Additive manufacturing (AM) is a versatile technology that provides manufacturing, supply chain, and economic advantages across a wide range of defense applications in order to build a more lethal and ready force. AM supports rapid design and prototype cycles that can significantly reduce production timelines, improve repair part availability, and increase speed to the warfighter for new systems. In order to maximize this potential, the Additive Manufacturing for Maintenance Operations Working Group (AMMO WG) and America Makes have been hosting annual AM wargames or workshops as an opportunity for government, industry, and academia to assemble and collaborate on the most challenging AM focus areas.

This year, the AMMO WG and America Makes worked closely with the DoD's Joint Additive Manufacturing Working Group to identify five workshop topics that address foundational aspects of additive manufacturing necessary for DOD-wide adoption of this capability. The topics were: DoD standardization prioritization; cybersecurity (wargame) "hack-a-thon" and improving AM in small and medium manufacturers; assessing additive manufacturing crisis response; Additive Manufacturing Portal for Education (AMPED); and agile inspection and testing. A working group was developed for each of the five workshop topics. The workshop was conducted from 28-29 June 2022, at the MxD (Manufacturing x Digital) Digital Factory of the Future in Chicago, IL.

The results of the 2022 AM Workshop are the progressive steps achieved by the working groups in addressing these critical AM areas in a collaborative manner to developing solutions that will enable the successful adoption and implementation of AM within the DoD.

Below is a Summary of the Key Findings and Accomplishments of the 2022 AM Workshop Organized by Workshop Topic Area:

DOD Standardization Prioritization

- Identified the top 5 defense industry standards gaps in the ANSI and America Makes AMSC Standardization Roadmap for Additive Manufacturing:
  - Machine Qualification
  - AM Part Classification System for Consistent Qualification Standards
  - Contents of an AM Technical data Package (TDP)
  - Recycle & Re-use of Materials

- Material Properties / Design Allowables
- Identified recommendations on how needs could possibly be filled in the future.
- Surveyed existing standards (currently focused on powder bed fusion) and create standards for Directed Energy Deposition, Material Extrusion, Binder Jetting, etc.
- Recommend that DoD should prioritize further opportunities to support future material/process qualifications.
- Recommend a review where certain TDP requirements can be transitioned to a standard.

Cybersecurity (wargame) Hack-a-thon and Improving AM in Small and Medium Manufacturers

- Played a Cyber Hackathon Game and identified and reinforced key security threats and our cyber controls for manufacturing environments.
- Created cyber awareness and identified key activities to improve cybersecurity posture for manufacturing environments.
- Began (and completed) two Cybersecurity Maturity Model Certification (CMMC) 2.0 Level 1 assessments in the MxD Cyber Marketplace.
- Need to expand the awareness campaign to assure there is a multi-prong approach, include all the elements/tools, scaling considerations, and messaging.
- Recommend expanding visibility through additional partnerships, use current institutional partnerships for teaming with lateral partners.

Assessing Additive Manufacturing Crisis Response

- Created a list of Lessons Learned from COVID-19 response and a list of needs for crises response
- Assessed crisis landscape: Regulations / Governance needs imbedded in each criterium.
- DoD needs new business models for contracting and acquisition of AM digital technical data.
- DoD needs a logistics model for production of AM parts at forward operating locations.
- Recommend identifying and testing concepts during “wargames”.

Additive Manufacturing Portal for Education (AMPED)

- Ranked job roles from 2020 AMMO workshop to AM criticality.
- Documented 11 job role categories required to advance adoption of AM.

- AMPED tracking metrics can be used to identify gaps in training based on data from searches with no results.
- America Makes/OSD are working to identify Project Steering Committee members to contribute to portal requirements, designs, and demo sessions.

Agile Inspection and Testing

- Identified short-term and long-term benefits of implementation.
- Identified roadblocks and challenges with AM part inspection and testing.
- Initiated development of roadmap to enable the capability.

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Additive Manufacturing Workshop 2022

Purpose

This additive manufacturing workshop is a follow up to the AM Workshop held virtually on, 14-21 June 2021. The purpose of this workshop is to address five foundational aspects of additive manufacturing necessary for the DOD's wide adoption of this game-changing capability. Interested parties from government, industry, and academia/non-profits were all actively invited to participate in the workshop. Past workshops have had strong interest from hundreds of AM leaders, in both industry and government. This event presents a unique opportunity for AM leaders and functional stakeholders to collaborate on key issues that pertain to leveraging additive manufacturing capabilities.

The workshop was sponsored by DoD's Joint Additive Manufacturing Working Group (JAMWG), America Makes Additive Manufacturing for Maintenance and Sustainment Advisory Group and the Additive Manufacturing for Maintenance Operations (AMMO) Working Group. Participants included members from the government, industry, and academia.

Background

DoD has completed two AM business model simulations, known as the 2016 and 2017 Business Model Wargames, a 2018 Business Model Workshop, to address the aspects of employing AM technology and techniques to sustain DoD equipment in multiple scenarios, a 2019 AM Workshop to collaborate on five critical AM topics, a 2020 AM Workshop to work seven foundational AM topic areas, and a 2021 AM Workshop to work seven key AM topic areas, and four additional topics break-out sessions.

In May 2016, the AMMO WG and America Makes conducted the first AM Business Model Wargame, a simulation that focused on the business transactions involved when DoD requires that repair parts be additively manufactured at a DoD depot or third-party location to support immediate readiness goals. In response to the 2016 wargame, the AM Business Model Wargame II took place in May 2017 at the Lockheed Martin Global Vision Center in Arlington, Virginia. The results of the simulation revealed common issues among all teams and unique opportunities and business model considerations particular to each team. The issues included the need to negotiate a value for access to intellectual property (IP), warranty impacts, liability shifts, brand risk concerns, and an increased reliance on data and the security of that data.

In 2018 the organizers switched to a workshop format to address five business model aspects of AM for sustainment and production in parallel with ongoing AM technology community efforts. The five aspects were: develop an AM contracting guide for Navy / DoD, information assurance on 3D technical data packages (TDPs) and blockchain, pathfinder scenario study of AM repair parts, 3D model exchange, and AM intellectual property management. Similarly, the 2019 AM Workshop divided into five workgroups that focused on data standards and data / model sharing, qualification and certification, AM business practices, workforce development, and DoD AM policy development.

For 2020, the AMMO WG and America Makes decided to build upon previous AM workshop results and actively pursue solutions in seven foundational topic areas critical to our ability to scale additive manufacturing adoption and execution across DoD. The 2020 AM Workshop had 275 registrants divided into the following work groups: addressing AM cyber challenges, AM data management, workforce development for AM, AM metrics, AM part risk categorization and relation to part criticality, AM TDP for procurement in sustainment, and framing the DoD-level AM guidebook.

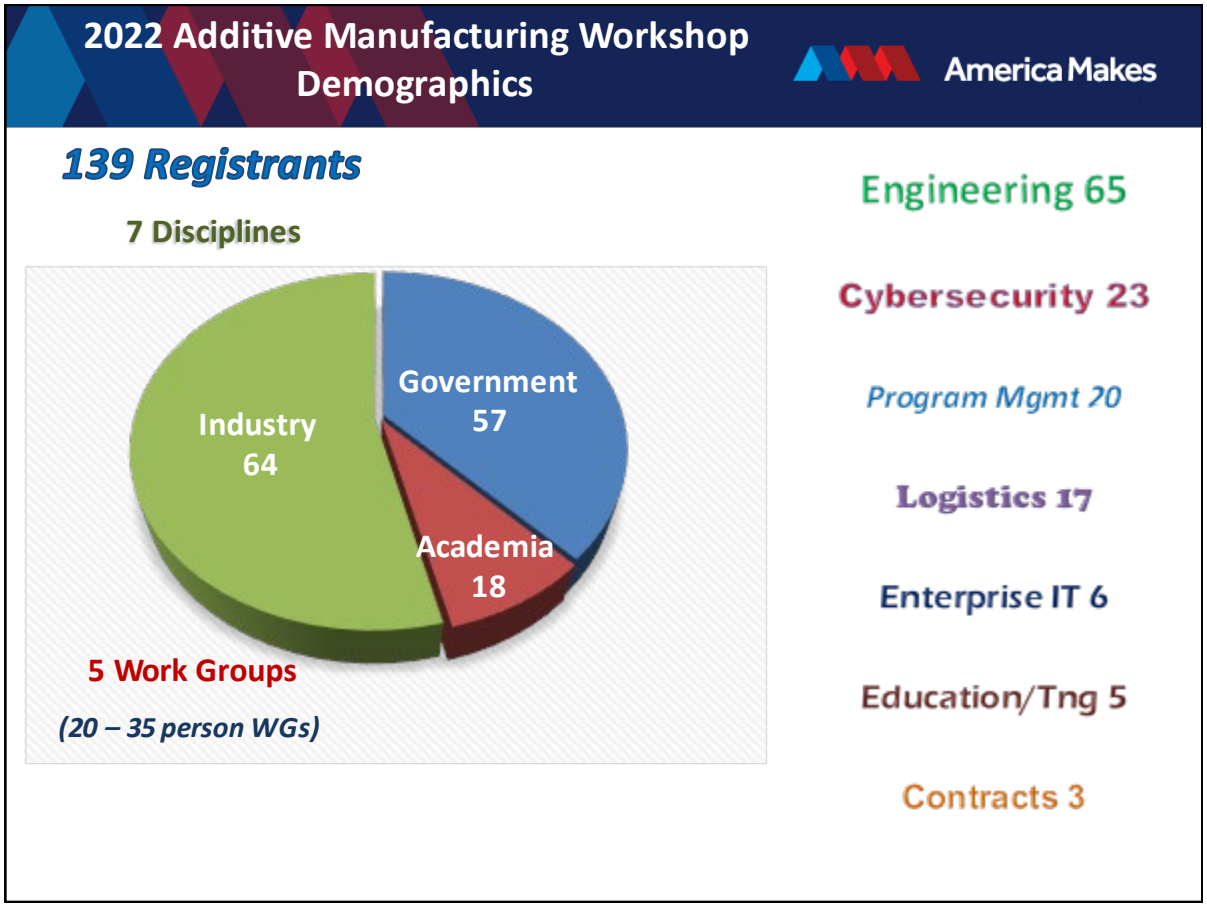
In 2021, the AMMO WG and America Makes worked closely with the DoD's Joint Additive Manufacturing Working Group (JAMWG) to identify seven workshop topics that address key aspects of additive manufacturing necessary for DOD-wide adoption of this capability. The topics were: research and development to advance AM qualification and certification; cybersecurity; common AM data package approach; education and AM workforce development; AM standards – defense industry priorities and addressing the research and development gaps; integrated AM network response – how industry and government can work together to respond to urgent and important needs; and AM decision making business case analysis for AM in the defense industry. A working group was developed for each of the seven workshop topics, and four additional topics were added as optional informational break-out sessions. These four topics were: the role for technology in meeting the multiple workforce challenges in manufacturing; training: Joint Additive Manufacturing Model Exchange (JAMMEX) introduction; DoD additive manufacturing draft guidebook review; and cybersecurity in the manufacturing workforce. The virtual workshop had 280 people register and was spread over five days consisting of afternoon sessions only, two each for the working groups and one for the optional break-out sessions.

Appendix A provides more detailed information on the previous AM wargames and workshops and contains links to the final reports.

Participant Demographics

The 2022 AM Workshop had 139 people register amongst the five workgroups. Participants were composed of representatives from government, the military services, academia, and industry, with disciplines in engineering, cybersecurity, program management, logistics, enterprise IT, education/training, and contracts administration. Figure 1 shows the demographics of the AM Workshop 2022 registrants.

Figure 1. AM Workshop 2022 Registration Demographics



AM Workshop 2022 Concept Development

The concept of this workshop was to assemble five working groups of subject matter experts (SMEs) composed of key disciplines, and then focus their efforts on key integral areas of additive manufacturing necessary for DoD's wide adoption of this game-changing capability. The working groups were selected from a combination of last year's AM workshop and ongoing efforts at the JAMWG and America Makes.

Five Workgroups

The 2022 AM Workshop Workgroups and co-leaders are listed in Table 1.

Table 1. 2022 AM Workshop Workgroups

No.	Work Group Name	Co-Leaders / Facilitators
1	DOD Standardization Prioritization	• Jesse Chambers (DLA), Jesse Boyer (Pratt & Whitney)
2	Cybersecurity (wargame) Hack-a-thon and Improving AM in Small and Medium Manufacturers	• Larry Lynch (USACE), Laura Elan (MxD)
3	Assessing Additive Manufacturing Crisis Response	• Josh Heller (ASNRDA), John Wilcynski (America Makes)
4	Additive Manufacturing Portal for Education (AMPED)	• Jeremy Chang (OSD ManTech), Courtney Puhl (America Makes)
5	Agile Inspection and Testing	• Vincent Paquit (ORNL), Derrick Lamm (Lockheed)

AM Workshop 2022 Workgroup Descriptions

Following are the five AM Workgroup abstracts.

DoD Standardization Prioritization

The 2021 DoD AM workshop resulted in a prioritized list of standards gaps identified by participants. These include the following:

- AM Part Classification System for Consistent Qualification Standards
- Machine Qualification
- Contents of a TDP
- Harmonization of AM Q&C Terminology
- Design Allowables
- Terminology for the Identification of AM Flaws Detectable by non-destructive examination (NDE) Methods
- Standard Guide for the Application of NDE to Objects Produced by AM Processes

The standardization prioritization breakout group will revisit this list, amend, and update the list based upon a structured feedback session. Participants will be led through exercises which identify standardization opportunities which can benefit from applied research. Participants will engage in brainstorming which identifies and prioritizes gaps in methods, tools, and technologies pertinent to various standardization priorities.

Cybersecurity (Red Team / Blue Team Hack-a-thon) & Improving AM in Small and Medium Manufacturers

The two-day Cybersecurity Workshop activities do not require technical know-how to participate. Both events will include detailed introduction and will be facilitated and are suitable for cyber beginners as well as seasoned cyber professionals.

Day 1 - Participants will engage in a Red Team / Blue Team hack-a-thon relevant to a manufacturing environment. Each participant will have the opportunity to work with both

a Red Team and Blue Team to actively attack or defend a manufacturing environment. The activity includes the opportunity to execute several DoD relevant hack-a-thon exercises to identify, prioritize, and document cybersecurity vulnerabilities for AM digital workflows considering multiple equipment makes/models, support software types (design, build file generation, etc.), and AM modalities. These vulnerabilities under different manufacturing operating scenarios will serve to assess vulnerabilities which arise not only to hardware or software design features, but how individuals execute AM operations under different use-cases or operating scenarios. It is expected that these scenarios will identify future R&D investment, product development, and education and workforce development efforts for the AM supply chain.

Day 2 - Improving AM in Small and Medium Manufacturers (SMM): There is a critical need to improve cybersecurity in SMMs that are part of the DoD supply chain. In the second day of the workshop, cybersecurity capabilities will be explained in an easy-to-understand assessment format. The Cyber Marketplace, developed by MxD, describes the cybersecurity assessment process, and helps an organization conduct a self-assessment against the types of vulnerabilities and attack scenarios exposed during the Day 1 hack-a-thon. The assessment outcomes are used in the tools available from the Cyber Marketplace to gain prioritized tools, services, and policies should be implemented to close security gaps.

Assessing Additive Manufacturing Crisis Response

The DoD wants to assess the ability of the department to respond to crises such as natural disaster, pandemic, or hostile events. This session seeks to review the lessons learned from the advanced manufacturing crisis production response (AMCPR) and Covid-19. Participants will be asked to help define scenarios and use cases. The workshop will determine the questions that should be asked for an assessment. From this information, assessment formats can be proposed (i.e., wargame, tabletop exercise, chalk talk, demonstration, exercise, or other).

Additive Manufacturing Portal for Education (AMPED)

America Makes, in collaboration with a number of partners (including OSD ManTech EWD and JAMWG EWD), will be hosting a series of three workshops during the AM Workshop.

Workshop 1 (Day 1 – AM) will be a continuation and culmination to validate the previous additive manufacturing roles identification and definition across the DoD and organic defense base. Building from the work in the last workshop the team will validate and confirm the identified and defined roles, and through continuous improvement, qualify this data set to move forward in the AMPED project.

Workshop 2 (Day 1 – PM) will be a continuation and culmination of the previous work both in the JAMWG EWD team and AMMO workshops in the identification and analysis of DoD training assets. The team will explore the listing and categorization of training offerings by broad classification to explore gaps, missing assets and assist in the prioritization of future needed assets.

Workshop 3 (Day 2 – AM) will allow the team to work through existing requirements of the AMPED portal to highlight areas of focus important to the group as well as key features that would be value in a full-scale launch of the new tool hosted by America Makes in collaboration with OSD ManTech EWD.

Agile Inspection and Testing

Required testing timelines for additive manufacturing first article efficacy does not meet demand requirements. There is a need to improve inspection throughput and techniques. In addition, resources for witnessing acceptance testing at the vendor site are limited and remote inspection methods need to be considered. Cybersecurity and IT procedures can pose challenges to remote inspection or portability of digital inspection data to the engineering authority. The output of this session should be a multi-year plan with phased approach to incrementally improve the ability to create the framework for agile inspection and testing of AM parts.

AM Workshop 2022 Workgroup Objectives and Deliverables

The five AM Working Groups briefed their objectives and deliverables during the opening plenary on 14 June. Though these are generally stated within the abstracts above, you can view them in bullet form on the attached slides briefed during the opening plenary. (Appendix B)

AM Workshop 2022 Workgroup Key Takeaways and Recommendations

On the final day of the workshop, the workgroups presented their out-briefs of findings. Each team's entire brief can be found in Appendix C. The subsections that follow detail the key takeaways and next steps that each team presented.

DoD Standardization Prioritization Working Group

Key Takeaways / Accomplishments:

- Identified the top 5 defense industry standards gaps in the ANSI and America Makes AMSC Standardization Roadmap for Additive Manufacturing:
  - Machine Qualification
  - AM Part Classification System for Consistent Qualification Standards
  - Contents of an AM TDP
  - Recycle & Re-use of Materials
  - Material Properties / Design Allowables
- Reviewed each of the top 5 gaps and determined the rationale behind why a need still remains.
- Identified recommendations on how needs could possibly be filled in the future.
- Although AMSC is a useful tool for gaps, there is still a need for a good reference (centralized search) for all Additive Manufacturing Standards.
- For some instances, there needs to be clarification of the intended meaning for particular AMSC listed gaps such Machine Qualification, Material Properties, Design Allowables, etc.

- Powder Bed Fusion tends to dominate the conversation, but other methods still need to be considered.
- Conducted a significant discussion regarding Design Allowables and the financial impact related to follow-on applications.

Recommendations / Next Steps:

- Possibly use a reference material and better define standards/artifacts for process/material qualification.
- Survey existing standards (currently focused on powder bed fusion) and create standards for Directed Energy Deposition (DED), Material Extrusion (MEX), Binder Jetting (BJT), etc.
- DoD should prioritize further opportunities to support future material/process qualifications.
- Currently working laser beam powder bed fusion /Ti. What is next? We should be working it soon.
- Once ASTM WK70164 is officially published, the standard should be considered for DoD adoption and used as a baseline to create additional standards in other areas (subs, nuclear, etc.).
- Separate Material properties in other specifications and include in TDP witness coupons for verification (material specific and part classification) and show process is in control.
- Review where certain TDP requirements can be transitioned to a standard.

Cybersecurity (Red Team / Blue Team Hack-a-thon) & Improving AM in Small and Medium Manufacturers Working Group

Key Takeaways / Accomplishments:

- Played a Cyber Hackathon Game and identified and reinforced key security threats and our cyber controls for manufacturing environments.
- Created cyber awareness and identified key activities to improve cybersecurity posture for manufacturing environments.
- Reviewed cybersecurity frameworks and guidance, focusing on CMMC 2.0.
- Began (and completed) (2) CMMC 2.0 Level 1 assessment the MxD Cyber Marketplace.
- People are (still) the weakness link in cybersecurity. Do not forget to include security training and awareness as part of your security controls.
- Leadership awareness is imperative for a successful cyber program.

Recommendations / Next Steps:

- Cyber awareness with gamification element appears to increase engagement, interest, learning, add this component to awareness for SMMs

- Need to expand the awareness campaign to assure there is a multi-prong approach, include all the elements/tools, scaling considerations, and messaging
- Expand visibility through additional partnerships, use current institutional partnerships for teaming with lateral partners

Assessing Additive Manufacturing Crisis Response Working Group

Key Takeaways / Accomplishments:

- Created a list of Lessons Learned from COVID-19 response
- Created a list of Needs for Crises Response
- Evaluated how Point of Need Manufacturing fits into crises/forward deployment Sustainment
- Reviewed Advanced Manufacturing Crisis Production Response (AMCPR) Playbook. Distribute, update, and identify stakeholders
- Assessed crisis landscape: Regulations / Governance needs imbedded in each criterium
- Critical to understand "who is in charge"
- Need: Authority / Knowledge Base / Policy
- Work with OSD to determine applicability to All Partners Access Network (APAN)

Recommendations / Next Steps:

- Align AM activities across the DoD and with external partners
- Need new business models for contracting and acquisition of AM digital technical data
- Need a logistics model for production of AM parts at forward operating locations
- Round out the existing AMCPR Playbook
    - Organic Industrial Base (OIB) Benefit
    - Industrial Base Benefit
    - Capture/Establish "National AM Knowledge"
- Identify and test concepts during "wargames"
- Connect to the digital thread and leverage existing platforms (JAMMEX; 3YourMind). (Become the google maps of the AM Digital Advanced Additive Manufacturing (DAAM) System)

Additive Manufacturing Portal for Education (AMPED) Working Group

Key Takeaways / Accomplishments:

- Ranked job roles from 2020 AMMO workshop to AM criticality

- Documented 11 job role categories required to advance adoption of AM
- Defined list of 25 metadata categories suggested to adequately describe trainings mapped on AMPED
- Brainstormed key features and overall functionality of AMPED portal while maximizing sustainability of the platform
- AMPED tracking metrics can be used to identify gaps in training based on data from searches with no results
- Group members highlighted the need to share “playlist” of successful trainings
- If mapped trainings align to a certification or credential, that will be noted in the AMPED portal
- DoD has a sustained need for AM training, amplifying the need for AMPED long term

Recommendations / Next Steps:

- Work to balance user convenience with sustainability costs
- A second virtual AMPED workshop will be tailored to ensure representation across DoD
- America Makes/OSD are working to identify Project Steering Committee members to contribute to portal requirements, designs, and demo sessions
- Official AMPED project kickoff is 7/1/22, 18-month Proof of Principal

Agile Inspection and Testing Working Group

Key Takeaways / Accomplishments:

- Defined agile inspection and testing.
- Identified short-term and long-term benefits of implementation.
- Identified roadblocks and challenges with AM part inspection and testing.
- Initiated development of roadmap to enable the capability.

Recommendations / Next Steps:

- Develop draft guidance: “Attritable Parts on Exquisite Vehicle Guidance Document”.
- Develop draft “Flexible Distributed Manufacturing and Operation Framework”.
- Draft the contents of a “Technical Data Package for Certificate of Conformance”.

AM Workshop 2022 Hotwash

The AM Workshop 2022 planning team conducted a hotwash on July 22, 2022, to discuss lessons learned during the 78-29 June 2022 Virtual AM Workshop. The following are some of the key discussion points.

Planning Timeline:

- Due to delays, the group felt the timeline became too aggressive.
- Lesson learned/best practice: Start planning earlier. A follow up with the working groups could be a starting point
- Recommend implementing a timeline that includes follow-up of the 2022 work group (WG) post-workshop actions throughout the year, and early identification of WG topic candidates, possibly wargame related, that the planning group can select from.
- Recommend integrating timeline with JAMWG actions.

Topic Selection:

- Topics were selected by the JAMWG and America Makes and vetted through the planning group.
- Topics could have been more detailed.
- May not want to merge topics from two different sources.
- Topics should bring value to both DoD and America Makes.
- WG Co-leads should have ownership in the topic
- Lesson learned/best practice: Successful working groups are often those that have clearly defined (or focused) outcomes. Examples: Groups that work on a policy document, shaping JAMMEX requirements, or AMPED.
- Lesson learned/best practice: People want to come to the AM Workshop to shape outcomes, but they do not come to test hardware or software.
- Lots of interest in aligning WGs in a scenario-based approach, perhaps another business case/wargame to use/test what we have learned/developed the past few years.
- Lesson learned/best practice: Simulation/wargame engages the participants and drives outcomes. We do have to be aware simulations/wargames are resource intensive.

Roles and Responsibilities

- All agreed the framework was successful and information flow was excellent.
- America Makes volunteered to have their graphic arts section work to improve the existing templates to widescreen, etc.

Facilities

- Comments about MxD facilities and tours were very positive.
- Government participation has been better in the National Capitol Region (NCR). It might be easier to get SESs/FOGOs from R&E, A&S and other organizations if the workshop is conducted in the NCR.

Next Steps / Follow-on

- All thought the workshop was a valuable tool and should be continued in some form.

- Posed the possibility of continuing as separate work groups, but no annual combined workshop.
- Strong interest in having a simulation/wargame type event in the future.

Survey Results

A survey was distributed to all the participants after the wargame, with a variety of questions to solicit feedback and help shape future wargames. The vast majority of respondents stated that they would very likely attend an AM Workshop in the future, that the workshop met or exceeded expectations, the event was engaging and about the right duration, and that their time spent dedicated to the workshop was informative and valuable. The survey results also include numerous responses on what participants liked, suggested changes, potential future topics, and other general comments. To view these responses, go to Appendix D.

Conclusion

The 2022 AM Workshop provided a venue where members from government, industry, and academia were able to collaborate and work on five foundational aspects of additive manufacturing necessary for DOD-wide adoption of this capability. The progress achieved by the working groups in addressing these AM critical areas, whether collectively developing solutions, or better defining the problems, will support the continuous efforts that members of the DoD's Joint Additive Manufacturing Working Group, the America Makes Additive Manufacturing for Maintenance and Sustainment Advisory Group, and the Additive Manufacturing for Maintenance Operations Working Group perform throughout the year with the goal of enabling the successful adoption and implementation of AM within the DoD and its' industry partners.

Appendix A. Previous AM Workshops

AM Business Model Wargame I

In May 2016, the DoD AMMO WG, in collaboration with the America Makes AM for Maintenance and Sustainment Advisory Group, co-sponsored AM Business Model Wargame I in Suffolk, Virginia. The purpose was to bring together participants from DoD and industry and illuminate the required business transactions when DoD needs repair parts to be additively manufactured at a DoD depot or third-party location in support of an immediate readiness goal. The wargame also assessed gaps and challenges discovered during the simulation to begin developing the necessary environment to support the continued adoption of AM capabilities.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2016

AM Business Model Wargame II

In 2017 the first wargame scenario was expanded to include life cycle platform considerations relevant to the business environment required to support the continued adoption of AM capabilities. Four teams, representing four different business models, dealt with the same scenario involving a need to manufacture repair parts using AM capabilities at the point of use. The four teams were:

- #1 Team “Buy-out”: Traditional government acquisition
- #2 Team “Loaner”: Government leases the end items
- #3 Team “CLS”: Contractor provides commercial logistics support (CLS)
- #4 Team “Net-Flix”: Government and original equipment manufacturer (OEM) set-up a “pay as you go” IP arrangement to allow AM part production in the field

The 2017 AM Wargame participants concluded that future focus areas should align with gaps identified in developing the business models during the AM wargames. These gaps include AM contracting guidelines, security, technology certification, workforce training, IP protections, and establishing secure data transmissions for AM and the digital thread. The AM planning group will organize future AM workshops to develop solutions to these gaps that create improved sustainment opportunities for the warfighter.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2017

AM Workshop 2018

The purpose of this workshop was to address five business model aspects of AM for sustainment and production in parallel with ongoing AM technology community efforts.

- Develop an AM Contracting Guide for Navy / DoD
- Information Assurance on 3D TDPs and Blockchain
- Pathfinder Scenario Study of AM Repair Part
- 3D Model Exchange
- AM Intellectual Property Management

Key findings from the 2019 AM workshop include:

- Governance needs to be established – a Joint body of Service-level Leadership - subgroup of the JAMWG
- Implement AM-focused policy for AM to begin in acquisition and contract phase
- AM Contracting Strategy should contract for AM as a service…not a supply
- Create a Central Database for AM Tech Data, 3D Model Exchange, and IP rights
- Services are working AM technology with the current processes in place, same engineering processes, similar procurement, similar qualification, and testing
- Blockchain technology itself is not a barrier, but business cases and return on investment in AM are still being defined to determine when blockchain makes sense

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2018

AM Workshop 2019

The purpose of this workshop was to collaborate across government, industry, and academia to actively pursue solutions in five foundational topic areas (and subgroups) critical to our ability to scale additive manufacturing adoption and execution across DoD.

- Data Standards and Data / Model Sharing Work Group
  - JAMMEX Sub-Group
  - TDP Standard Project Sub-Group
  - Cybersecurity Challenges and Solutions (Blockchain) Sub-Group
- Qualification and Certification Work Group
  - Database and Common Language Sub-Group
  - Quality Assurance Sub-Group

    - Standards Sub-Group
- Business Practices Work Group
    - DoD AM Acquisition Guide Sub-Group
    - AM Supply Chain Integration Sub-Group
    - IP Management Sub-Group
- Workforce Development Work Group
- DoD AM Policy Development Working Group
    - Acquisition Sub-Group
    - Engineering Sub-Group
    - Logistics Sub-Group

Key findings from the 2019 AM workshop include:

- Alignment of AM workshop working groups with the JAMWG is important to continue work
- AM-focused policy must include the entire product life cycle
- There is a need for a central database for AM tech data, 3D model exchange, and IP rights
- AM data must be in a “shareable” format across the military services and industry

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2019

AM Workshop 2020

This workshop actively pursued solutions in seven foundational topic areas critical to our ability to scale additive manufacturing adoption and execution across DoD.

- Addressing AM Cyber Challenges
- AM Data Management
    - Standards and Data Dictionary
    - Common AM Database Experiment (CAMDEN)
- Workforce Development for AM
- AM Metrics – Measures of Effectiveness and Measures of Performance
- AM Part Risk Categorization and Relation to Part Criticality
- AM TDPs for Procurement in Sustainment
- Framing the DoD-Level AM Guidebook

Key findings from the 2020 AM workshop include:

- Cybersecurity assessors and AM leads must have awareness of respective mission requirements (secure infrastructure and produce components, respectively) and select security controls on risk evaluation, not by a checklist
- Need policy emphasis for data management at the start of acquisition
- Standardize workforce roles, language, and definitions as much as possible
- Create a tiered criteria for ensuring AM systems are mature enough to handle a predefined criticality, complexity, and output
- Need to level-set AM methodology across DoD
- Current TDP focus in ensuring accuracy of design data will evolve to ensure accuracy of contracted deliverables
- Government, industry, and academia must collaborate to work these critical focus areas and develop solutions that enable the successful delivery of AM technologies to both the government and its' industry partners.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2020

AM Workshop 2021

This virtual workshop addressed seven foundational aspects of additive manufacturing necessary for DOD-wide adoption of this capability.

- Research & Development to Advance AM Qualification and Certification
- Cybersecurity
- Common AM Data Package Approach / Joint Additive Manufacturing Acceptability (JAMA)
- Education and AM Workforce Development
- AM Standards – Defense industry priorities and addressing the Research and Development gaps
- Integrated AM Network Response – How industry and government can work together to respond to urgent and important needs
- AM Decision Making – Business Case Analysis for AM in the defense industry

Four additional topics were added as optional informational break-out sessions.

- The role for technology in meeting the multiple workforce challenges in manufacturing
- Training: Joint Additive Manufacturing Model Exchange (JAMMEX) introduction
- DoD additive manufacturing draft guidebook review
- Cybersecurity in the manufacturing workforce

Key findings from the 2021 AM workshop include:

- Greatest number of gaps observed were in Inspection and testing (28) and AM processes (29)
- Addressing gaps identified tended to offer weeks of time savings or better (76 out of 95)
- Top cybersecurity needs include:
    - Make security more invisible and unobtrusive
    - Make key security properties or controls “built in”
    - AM machine providers should provide secure machine environments
- The JAMA team determined three module types are needed:
    - TDP Module
    - Manufacturing Module
    - Testing Module
- Deployed a pilot of the “Optimizing for AM” instructor led training
- Developed final list of top 10 defense industry standards gaps in the AMSC roadmap
- An integrated AM Network is important in times of crisis and normalcy, to convene, catalyze, and coordinate AM efforts across the ecosystem. There are critical needs along two primary pathways:
    - Drive Innovation & Collaboration to enable effective response and technology development
    - Be the source of truth to help the AM ecosystem navigate the regulatory complexities of a crisis response
- Developed mathematical frameworks for objective evaluation of business cases for using AM in DoD and identified potential use cases for AM.

Final Report: https://ammo.ncms.org/events/2021-additive-manufacturing-workshop/#agenda (Scroll to bottom page)

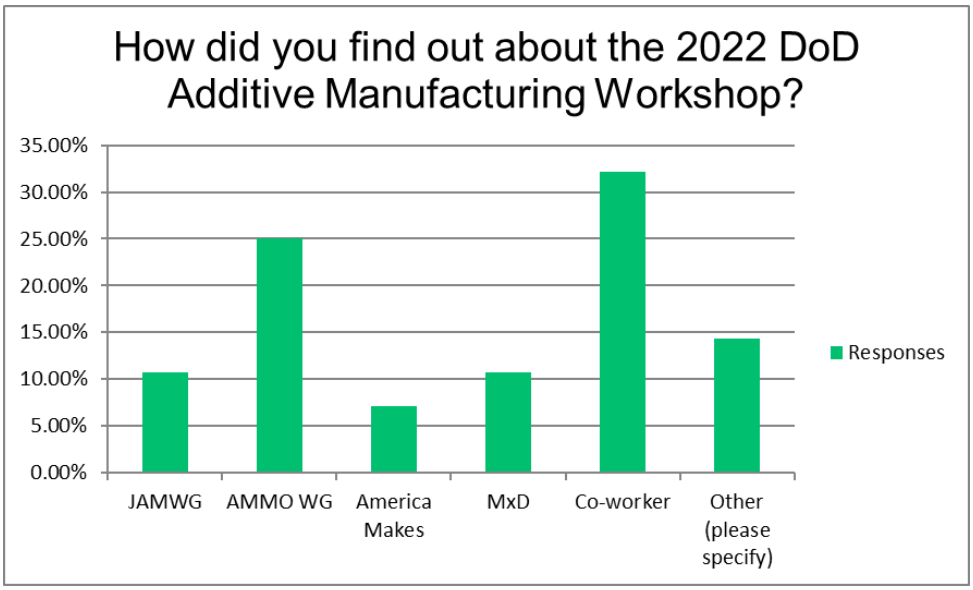
Appendix B. Abbreviations

AM	additive manufacturing
AMCPR	advanced manufacturing crisis production response
AMMO WG	additive manufacturing for maintenance operations working group
AMPED	additive manufacturing portal for education
AMSC	Additive Manufacturing Standardization Collaborative
ANSI	American National Standards Institute
APAN	All Partners Access Network
CAMDEN	common additive manufacturing database experiment
CLS	commercial logistics support
CMMC	Cybersecurity Maturity Model Certification
COVID	Coronavirus Disease
DAAM	Digital Advanced Additive Manufacturing
DLA	Defense Logistics Agency
DoD	Department of Defense
EWD	Education and Workforce Development
ICME	Integrated Computational Materials Engineering
IP	intellectual property
JAMA	joint additive manufacturing acceptability
JAMMEX	joint additive manufacturing model exchange
JAMWG	Joint Additive Manufacturing Working Group
JMADD	Joint Metal Additive Database Definition
MILDEPs	Military Departments
MxD	Digital Manufacturing Institute
NCR	National Capitol Region
NDE	non-destructive examination
NIST	national institute of standards and technology
OEM	original equipment manufacturer
OSD	Office of the Secretary of Defense
Q&C	qualification & certification
SMEs	subject matter experts
SMM	small and medium manufacturers

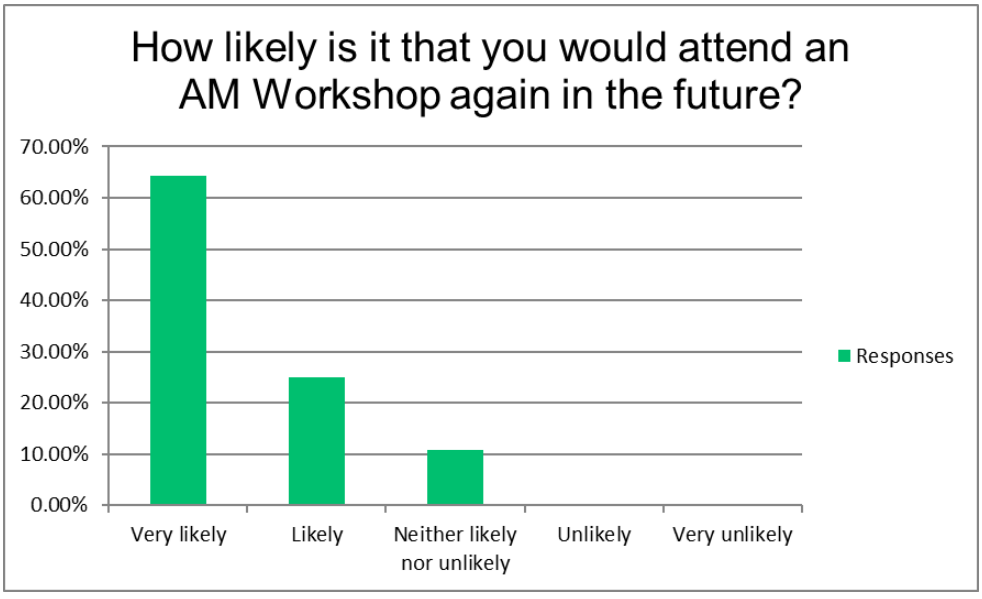
TDP	technical data package
WGs	working groups

Appendix C. Survey Results

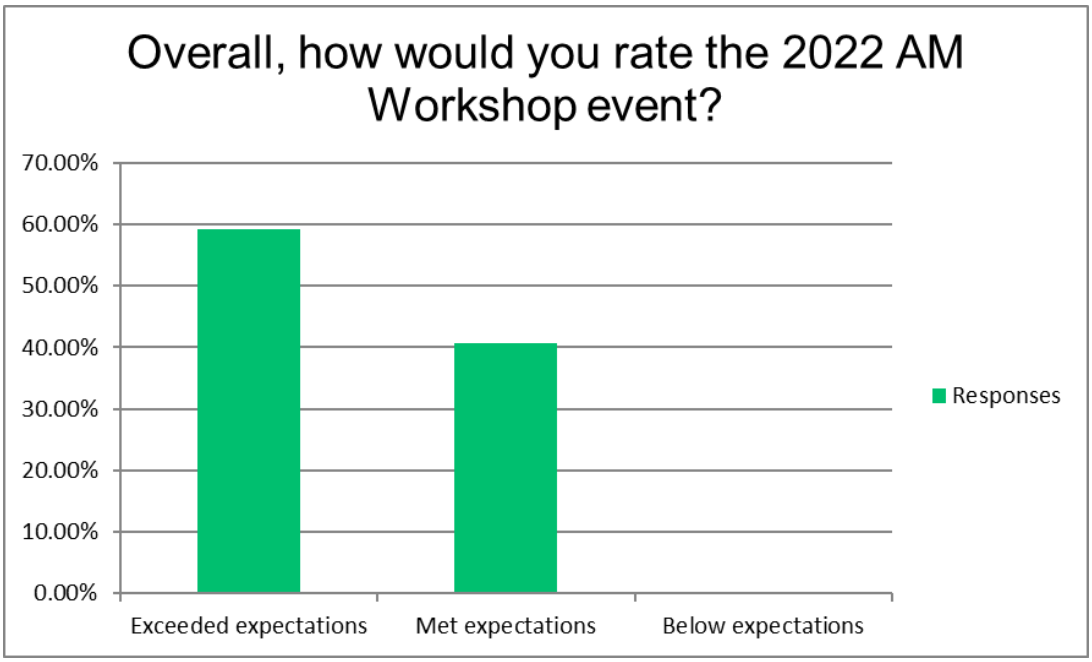
Question One – How did you find out about the 2022 DoD Additive Manufacturing Workshop?



Question Two – How likely is it that you would attend an AM Workshop again in the future?



Question Three – Overall, how would you rate the 2020 AM Workshop virtual event?



Question Four – What did you like about the event?

- The dynamic discussions during the workshops.
- Cyber wargame
- Participation from Government, Industry and Academia with a variety of knowledge/experience.
- Intellectually stimulating discussions. Diverse perspectives. Great lunch.
- The breakout into the 5 sections that enabled focused group thinking.
- Well organized and the venue was convenient.
- The reporting from the groups.
- Collaboration of planning to advance AM across the MILDEPS.
- Getting updated on the DoD challenges regarding the Standards for AM.
- How well organized it was, the 5 WGs having to brief at the end of each day, the SMEs in attendance.
- The MxD facility and MxD host. The opportunity to work in groups vs listening to briefers.
- Meeting new people from different orgs/industry.
- This year focused more directly on topics. Other years topics seemed to be more general.
- The focused work groups consisting of Government and Industry. Also, the key topics that the groups focused on.
- Targeted discussion groups were informative.

- People with diverse background attended the event to develop strategy for real-world problems.
- Well hosted and loved the Red-Blue Game!
- Well organized and attended. Interesting dialogue and workshops - especially Crisis Response. Good food and networking abilities.
- High level of engagement and collaboration
- The opportunity to meet in person to share ideas and priorities for the AM Workforce
- Meeting all the people working in AM with a wide range of organizational roles.
- I learned a tremendous amount which is really why I came -- I needed to better understand where the industry is. Also, meeting great people
- Using the MxD location was a great idea.
- The diversity of the attendees was excellent, and everyone had such rich perspectives, experience, and energy to offer to the discussions.
- Interaction with very knowledgeable working group members and the opportunity to network with professionals in the AM space.
- Good format

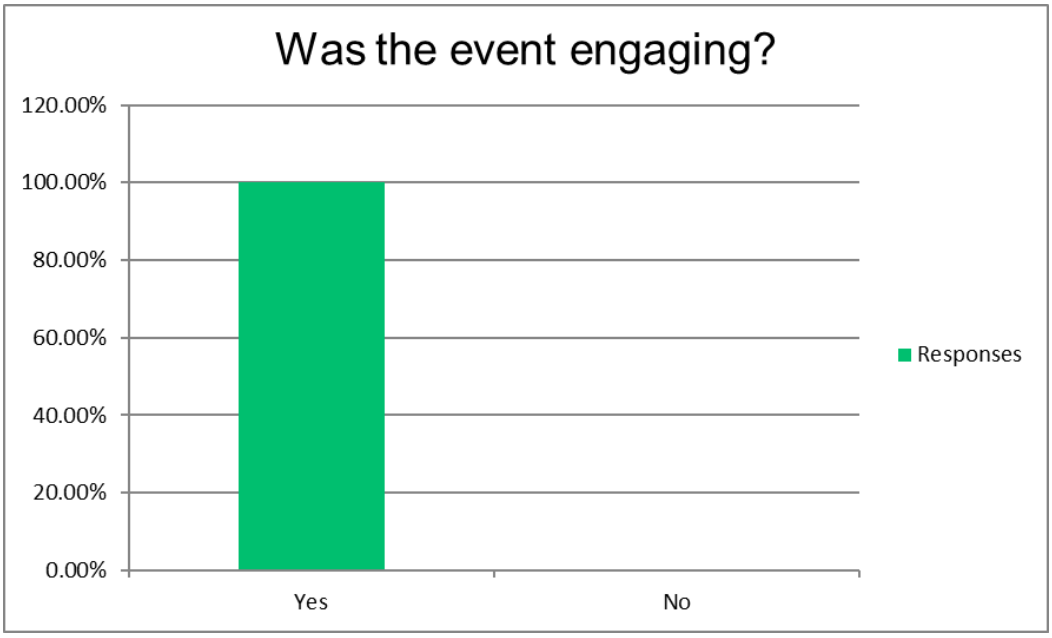
Question Five – What changes would you like to see in future events?

- None.
- Have similar ones for other Industry 4.0 topics
- The breakout discussion was very good. But sometimes, it goes in a different direction from the main theme. I guess it is natural in brainstorming, a bit more guidelines would be helpful.
- Understanding of expectations from the groups to keep the discussions in context. An opportunity to understand the progress of the other groups so that input could be shared for their consideration.
- Location change
- Continuation of the effort year-to-year (i.e., the prior year effort continues)
- May have the event be a day longer, that was a lot to tackle in 2 days.
- I would like to see a Simulation or wargame next year. We could have WGs that simulate different players such as: 1) OSD 2) OEM/Industry 3) FEMA 4) State/Local Govt 5) Cybersecurity 6) DoD Org with AM. We would need some type of simulation software, but I'm sure it exists.
- Bigger event space. Some of the rooms were too small for the amount of people in them. In a time with COVID still going on there wasn't enough room to spread out. I understand wanting to show the demo labs, but a location that is easier to access (parking limitations at facility, commuting through Chicago, etc.) would have made it more enjoyable and less stressful.
- The ability to maybe participate in more than one group.
- Inclusion of AM-PMC and AM-CMC materials would be extremely beneficial. The use case problems are extremely metals centric and the ability to adopt them towards other

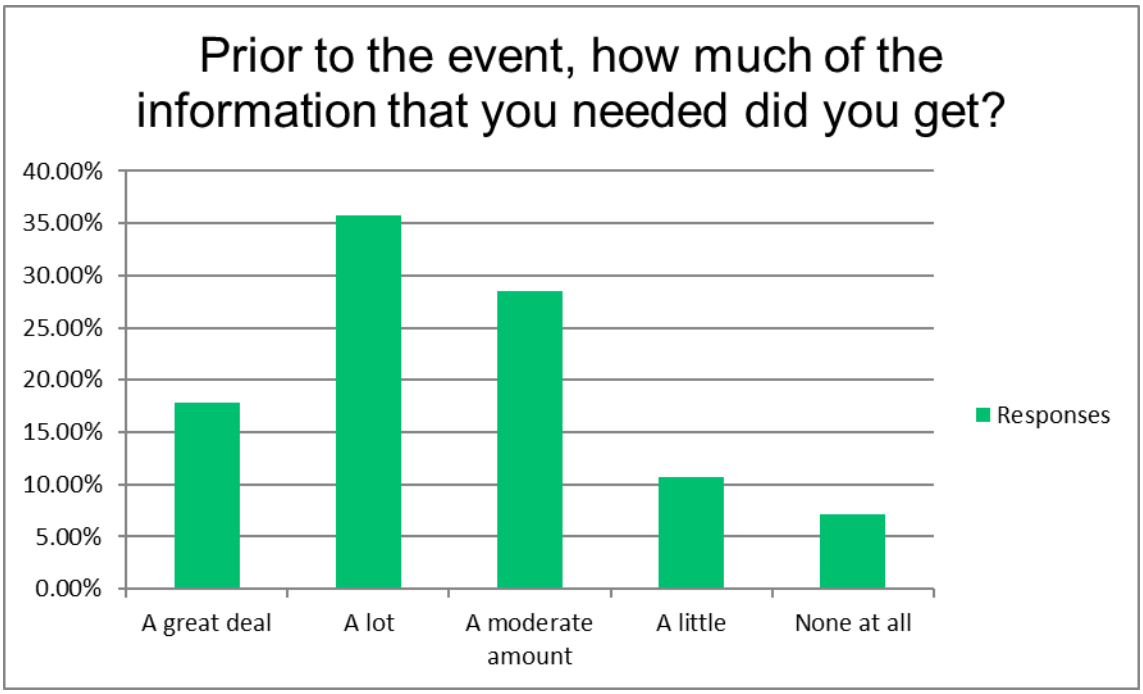
materials would be impractical. 15 minute "TED-like" talks on the state of the art. Can be industrial pitches to research going on.

- Maybe shorten it a bit. It seems like we lost a good chunk of participants on the second day.
- More of the same. Would like to see this keep moving forward. Would like to see more inclusion of IB, not only OIB, in the recommended solutions. Use industry. In times of emergency, the DoD can depend on us. And they SHOULD depend on us. Companies have a responsibility to their government for the protections their government provides them.
- None
- More broken up. Either more activities or swapping people into other groups for partial sessions.
- The only thing I might add is having a "facilitator" or capturer in the workshop sessions to support the leaders. It is very difficult to lead a discussion, and capture everything -- especially to be used in a debrief -- at the same time. Our leaders did GREAT. I just suspect if they had a facilitator to capture the content it might have been helpful for them.
- Better audio in the auditorium.
- This run was great - everyone had so much to offer that we often ran out of time for discussion. I found that breaking out into smaller subgroups of 5-8 (within the sections) helped us go more in depth on the issues and considerations. It would be good if such features could be expanded.
- Could have used some scheduled breaks during the day. Difficult to hear some of the conversation/questions by the remote speakers and audience members in the main room.

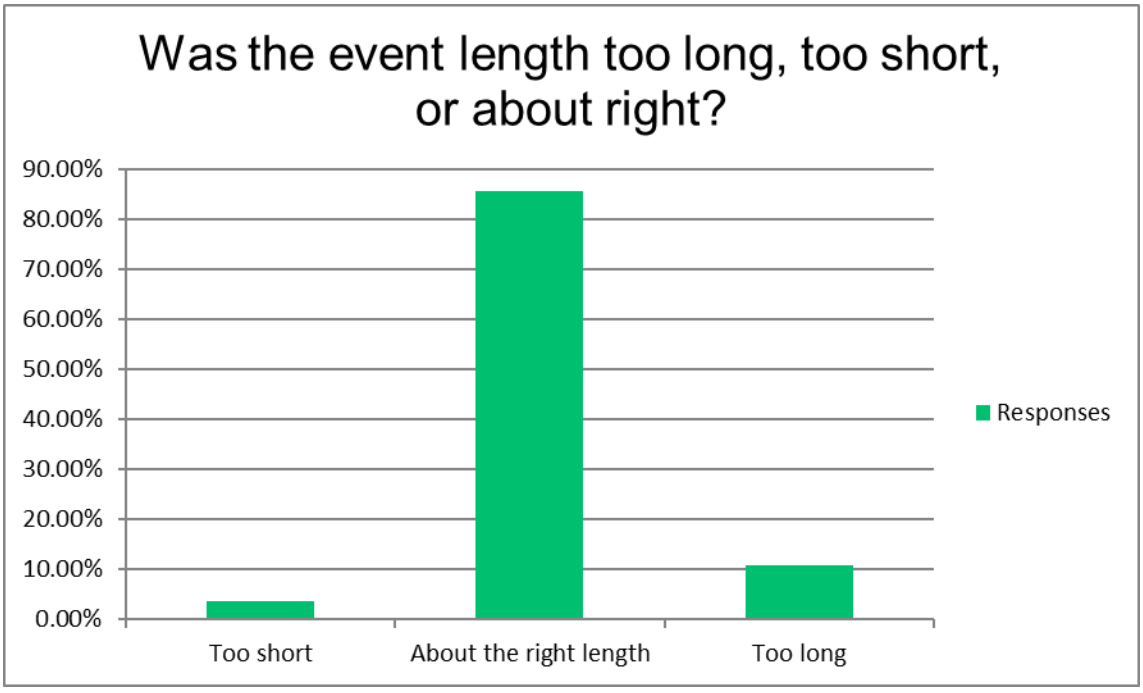
Question Six – Was the event engaging?



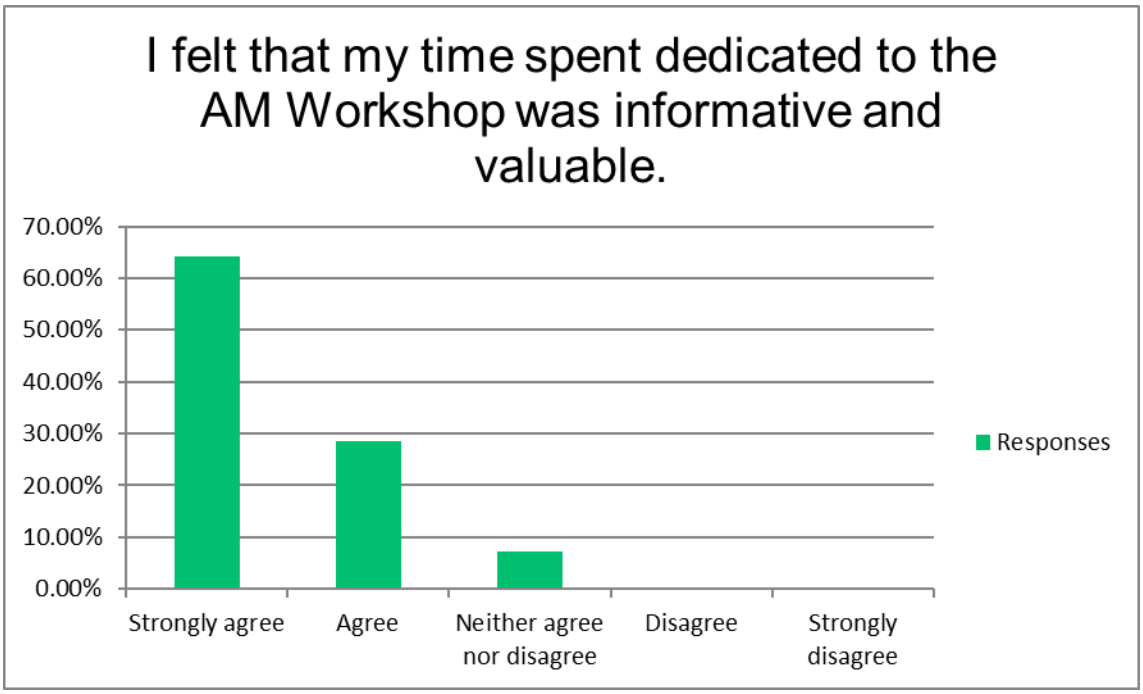
Question Seven – Prior to the event, how much of the information that you needed did you get?



Question Eight – Was the event length too long, too short, or about, right?



Question Nine – I felt that my time spent dedicated to the AM Workshop was informative and valuable.



Question Ten – What topics would you like to have included in the next workshop?

- Further discussion on standards. Discussion on AM Cost and RIO calculation.
- Metal AM - Pros and Cons
- University partnership opportunities.
- Progress updates from this meeting.
- Fundamental AM material and machine qualification process and information sharing.
- From the Standards WG discussion it seems like Machine, Process and Material Qualification is an important topic for the DoD. Possibly, this could be made as a separate topic.
- I think we need to finish up tackling these topics first.
- Simulation Wargame be the "Umbrella Scenario" for role-playing Working Groups. Deliverable would be a "Battle Book" for each WG. Not sure value added from Agile Testing & Inspection. Seems way too generic.
- AM Metrics. The Calculation Cost and Return on Investment and the key metrics associated in those calculations.
- Mishaps of AM parts on Mission critical applications: A mishap is defined by a loss in mission (loss of aircraft to loss of human life). It is not defined by the part failing and you can simply re-print it. Suggest gather experts that investigate crash sites and perform

root cause and analysis. Lessons learned when putting new technologies into aircraft/applications. The DoD is beginning to take risks with AM-PMCs for fracture critical primary structures.

- Cybersecurity never ends so I would continue this session with new topics each time.
- Joint software ecosystems requirements and the architecture and data requirements.
- Additive supply chains -- especially materials -- what is the DOD planning to secure materials sources and plan for long term materials volume increases?
- A Policy update.
- Decision support gaps.
- Process barriers to AM adoption (risk and expectation management)
- Forward-looking topics (e.g., AM in space such as DARPA NOM4D)
- Update/continuation of the Standards WG and Agile Inspection WG topics.
- Presentations on a couple advanced AM applications/use cases.
- Department of energy integration A case, some kind of system, or maybe something requiring support & sustainment that we could all work on? Realize everything is open for everyone to see, so it couldn't be sensitive work, but is this w/in the realm of possibility?
- Same – Cyber
- Anti-counterfeiting for distributed manufacturing: the next cyber-physical security challenge.
- Use Cases for AM applications, AM Material Science, 3D Printing fabrication management, etc.
- As usual I am a strong advocate of reverse engineering and design for additive. In that this was for a high-level manual - I think that more is needed to be addressed concerning these issues.
- NATO AM efforts.
- Cybersecurity requirements will continue to evolve and should probably be repeated; accelerants/precursors for AM to enable supply chain security challenges and remote operations; different industries.
- More enablement topics would be interesting, especially on the part design/validation side of things.
- More context to the survey questions.

Question Eleven – Is there anything else you'd like to share about this event?

- Thanks for the organizers. Good job!
- Expected deliverables that get progress updates in-between meetings.
- A provision to do (availability of) white-boarding or sketching of ideas would be helpful to do brainstorming.
- It would be nice to have a facilitator (who is not an active participant but makes sure everyone in attendance are able to express, would be nice).
- MxD did a phenomenal job hosting this event.
- We had 139 register and only about 103 attendees. That's a lot of no-shows.

- There was a noticeable amount of participants that didn't show on the second day or left early and missed the out brief. Participants should commit to TWO FULL DAYS.
- The MxD tour and guides were fantastic!
- I would not go on to say this is advanced AM when it appears to be a Metals Summit. Therefore, the adoption of many of the endeavors sought by this organization can be negligible on several fronts. Interesting topics can be made by focusing on AM-metals. However, the community significantly lacked the understanding that many of the problems AM-metals has, are not translatable to other material systems. Nor the problems solved for AM-Metals were not even problems for other material systems. These extremely use-case scenarios on metal-based additive were helpful but would suggest bringing experts in AM-PMCs and AM-CMCs. Don't call something material/process/part/application/design agnostic when your focus group is metals.
- Would like for the groups to continue engaging or at least get updates about the work done during the workshop.
- Laura was a fantastic group leader. Her friendly, inviting personality really draws you in.
- Happy to continue to assist
- GREAT facility and location. MxD was a terrific host. Really well-run workshop. Glad I came. Time well spent.
- The hybrid approach of in-person and online can use some fine tuning.
- Wonderful job overall. Thank you for inviting me.
- Venue and location was very convenient. Team did a great job in planning and executing the workshop.

Appendix D. AM Workshop 2022 Opening Plenary and Agenda Slides (Attached)

Appendix E. AM Workshop 2022 Out-Brief Slides (Attached)

Appendix F. Assessing AM Crisis Response WG JAMWG Brief w/ Back-Up Slides (Attached)

Appendix G. Additive Manufacturing Portal for Education (AMPED) WG JAMWG Brief Slides (Attached)