SYSTEMS ENGINEERING RESEARCH CENTER

Digital Engineering Transformation at JPEO

WRT-1052

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ANNUAL RESEARCH REVIEW 2022

Agenda

- Recap of SERC Research at JPEO
- Agent Based Modeling & Lessons Learned
- Additive Manufacturing Background & Policy
- SERC Research Process & Findings
- Additive Manufacturing (AM) Recommendations & Way Forward

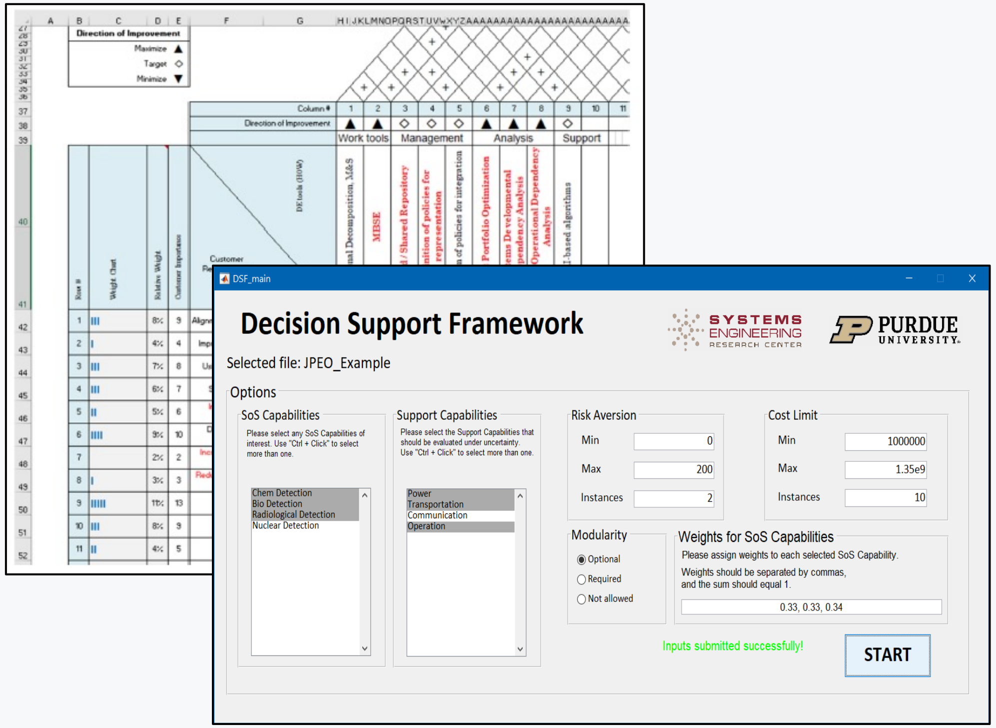
Recap – WRT-1014 SERC Research

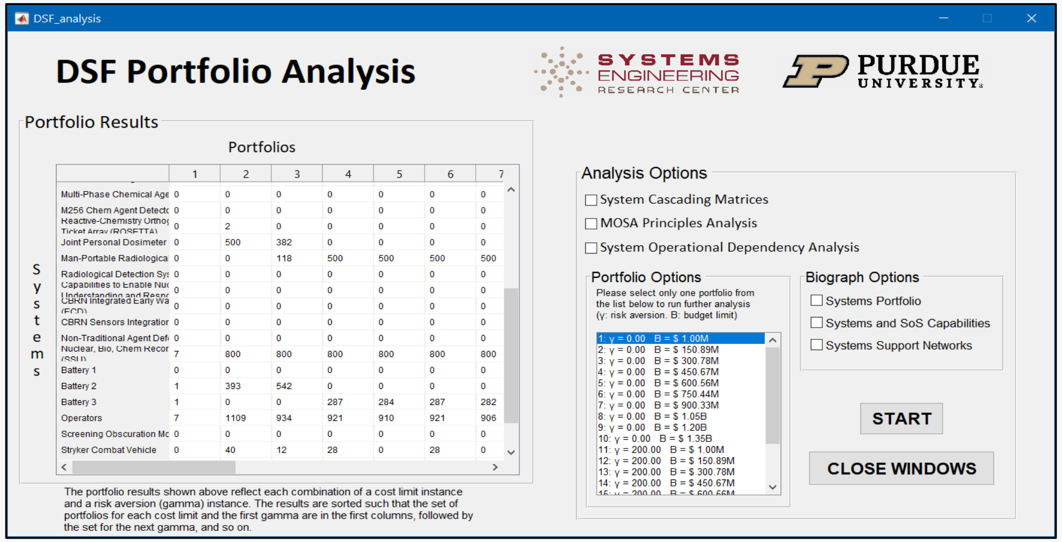
- In FY20, SERC conducted a portfolio-oriented system of systems study
- Research focused on utilizing the tools within SERC & Purdue's Analytic Workbench (AWB) to produce CBRND portfolio insights and results that could influence decision making

- **Study 1:** Needs of JPEO-CBRND were then mapped to these DE elements, via "House of Quality – style" product
  - ➢ Needs associated with appropriate tools and methodologies

- **Study 2:** Focused Case Study - System-of-Systems methods aligned with "Portfolio Optimization" Goals of JPEO-CBRND
  - ➢ Decision Support Framework
  - ➢ Pareto frontier analysis

- **Study 3:** Theoretical study with JPM CBRN sensor's portfolio and representative data
  - ➢ Optimize portfolio based on capability requirements and risk vs. cost analysis
  - ➢ Analysis of operational risk associated with disruptions in elements of the selected portfolio





FY22 Research Objectives

FY22 SERC research efforts were broken up into two main parts:

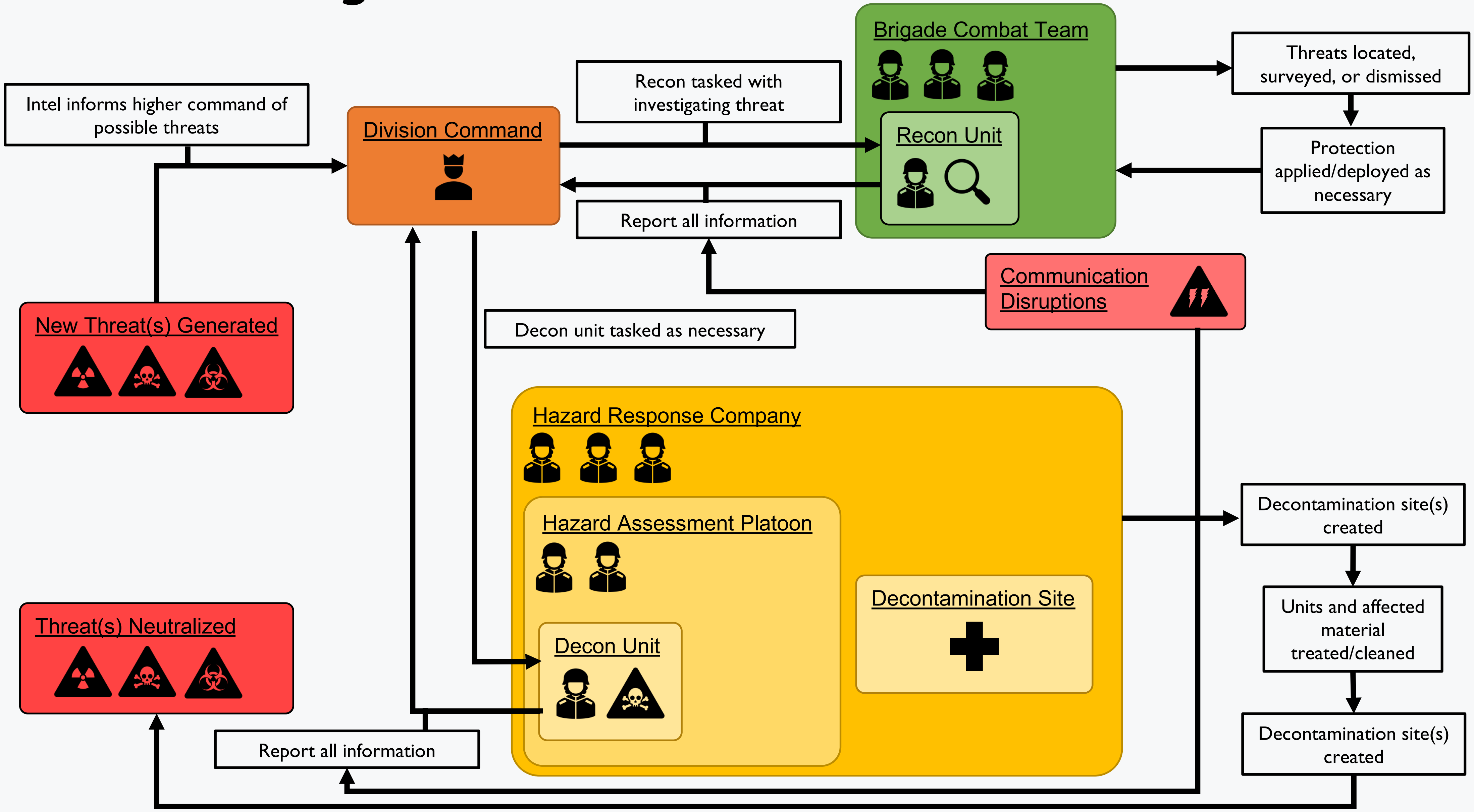
Part 1: Apply Agent-Based Modeling (ABM) techniques to model non-CBRN threats (e.g., electronic warfare) and apply them to CBRN defense operations

- Explores how multiple types of threats could impact CBRN defense missions

Part 2: Assess the JPEO-CBRND portfolio for potential applications of Additive Manufacturing (AM) using cutting-edge techniques in both academia and industry

  - ➢ What can we do? Exploration of enterprise-level AM feasibility
  - ➢ What should we do? Given feasible technologies/components, how to evaluate for which of them it is convenient to include AM?

Paper Model of Agent-based Simulation



Agent Based Modeling Lessons Learned

The Agent-Based Modeling effort eventually pivoted to focus on Additive Manufacturing. There were however many lessons learned from the ABM research:

- There's a fundamental lack of digital engineering artifacts to describe system of systems (SoS) capabilities related to CBRN defense operations
  - Products needed to support SoS modeling include mission threads, scenarios, unit/actor definitions, use cases, information exchange requirements
  - JPEO team had to manually create some products with limited subject matter expertise. This created a **massive barrier to progress, as the research had to initially focused on education/training** rather than actual analysis
- **ABM and other SoS modeling techniques are frequently tailored to answer specific questions**
  - SERC researchers developed custom code to perform the modeling behaviors required, as these domains had never been modeled before.
  - JPEO in-house development and sustainment of such models would require significant investment versus alternative means of gathering SoS data (e.g., TTX, OneSAF)

DoD & Army Additive Manufacturing Policy

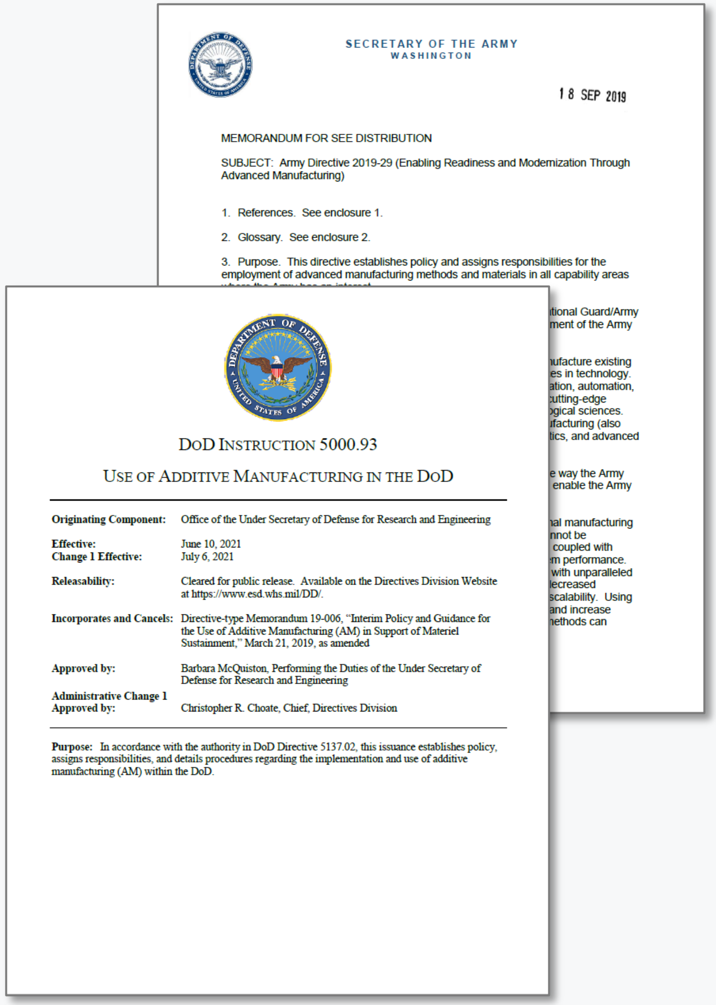
Considerations for Additive Manufacturing (AM) in acquisition are directed by **DoD 5000.93 Use of Additive Manufacturing in the DoD**

3.1.a AM IN ACQUISITION.

The Military Departments, Defense Agencies, and DoD Field Activities with AM requirements will… consider AM as part of the acquisition process, in particular the impact that AM may have on weapons systems design and how contracts or other agreements will address the availability of AM parts and data during maintenance and sustainment.

Additionally, the Army has directed the use of Advanced Manufacturing (AdvM) through **AD 2019-29 (Enabling Readiness and Modernization Through Advanced Manufacturing)** and the associated **Implementation Guidance for 2019-29**

(7.a.7) Materiel developers will address advanced methods and materials required to support design, development, production, fielding, and sustainment in program acquisition and planning documentation.



SECRETARY OF THE ARMY
WASHINGTON

18 SEP 2019

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Army Directive 2019-29 (Enabling Readiness and Modernization Through Advanced Manufacturing)

1. References. See enclosure 1.

2. Glossary. See enclosure 2.

3. Purpose. This directive establishes policy and assigns responsibilities for the employment of advanced manufacturing methods and materials in all capability areas

DoD INSTRUCTION 5000.93

USE OF ADDITIVE MANUFACTURING IN THE DoD

Originating Component:	Office of the Under Secretary of Defense for Research and Engineering
Effective:	June 10, 2021
Change 1 Effective:	July 6, 2021
Releasability:	Cleared for public release. Available on the Directives Division Website at https://www.esd.whs.mil/DD/.
Incorporates and Cancels:	Directive-type Memorandum 19-006, "Interim Policy and Guidance for the Use of Additive Manufacturing (AM) in Support of Materiel Sustainment," March 21, 2019, as amended
Approved by:	Barbara McQuiston, Performing the Duties of the Under Secretary of Defense for Research and Engineering
Administrative Change 1 Approved by:	Christopher R. Choate, Chief, Directives Division

Purpose: In accordance with the authority in DoD Directive 5137.02, this issuance establishes policy, assigns responsibilities, and details procedures regarding the implementation and use of additive manufacturing (AM) within the DoD.

Program Management Offices should consider and plan for manufacturing and sustainment early in the materiel development life cycle.

Teams should consult with subject matter experts throughout the materiel life cycle about emerging advanced manufacturing methods and materials.

Additive vs. Advanced Manufacturing

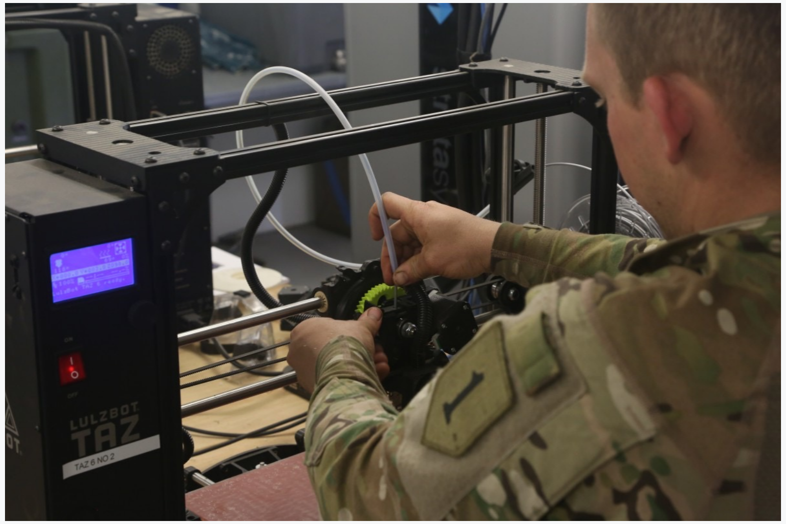
Army Directive 2019-29 describes Advanced Manufacturing (AdvM) as:

> *Advanced manufacturing refers to new ways to manufacture existing products and the manufacture of new products resulting from advances in technology. Advanced manufacturing depends on use and coordination of information, automation, computation, software, sensing, and networking, and making use of cutting-edge materials and emerging capabilities enabled by the physical and biological sciences.* ***Advanced manufacturing includes, but is not limited to, additive manufacturing (also known as three-dimensional (3D) printing)****, artificial intelligence, robotics, and advanced composite materials.*

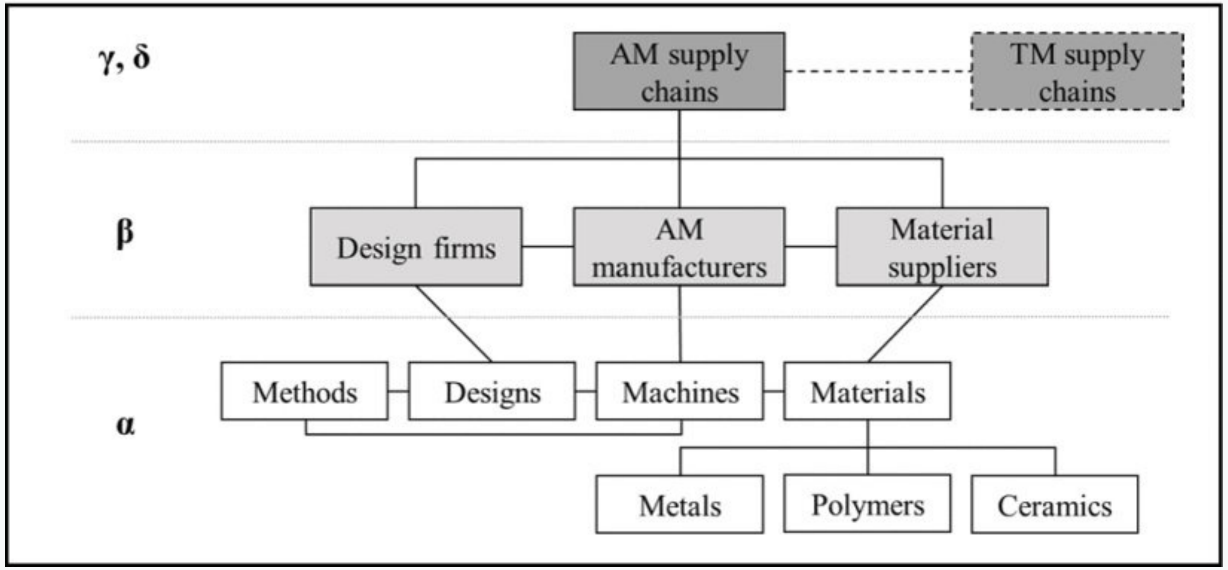
Additive manufacturing (AM) was analyzed for two primary use cases:

Use Case 1: AM as part of the organic industrial base (OIB) for system or parts replacement (i.e., manufacturing closer to the place of usage)

Use Case 2: AM at the original equipment manufacturer (OEM) for the creation of systems or parts for prototype, development, or sustainment (i.e., manufacturing to take advantage of specialized technologies)



AM as a System-of-Systems Problem



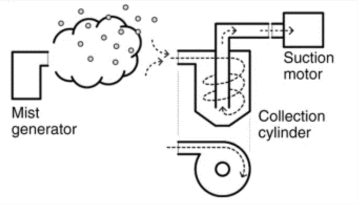
- **Identification of stakeholders and hierarchical levels of AM problem**
  - "What can we do" is more related to lower levels
  - "What should we do" includes all levels

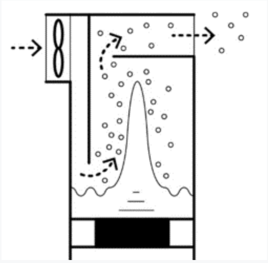
Levels	Resources	Operations	Policies	Economics
α	Machines, materials, design, training materials, software, maintenance equipment	Identification of viable α resources, operations of resources (e.g., machines)	Standards and qualifications of resources (e.g., machines, materials)	Cost comparison with producing, operating, maintaining AM vs. TM resources
β	Facilities and suppliers of resources (e.g., design companies)	Operations of facilities and suppliers, trade studies between different resources	Standards, qualifications, and training of suppliers and operators, consideration of performance parameters	Economics of buying/selling, operating, maintaining facilities and suppliers
γ	AM supply chains, 3D model repositories	Operations and logistics of AM supply chains: contract incentives for suppliers, acquisitions analysis	Standards and policies across supply chains (e.g., IP rights management) (including a request for AM impact in contracts)	Economics of AM supply chains: cost-benefit analysis of AM vs. TM equipment acquisition

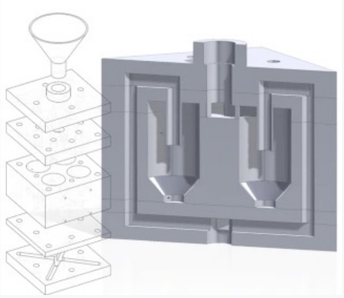
What Can We Do?

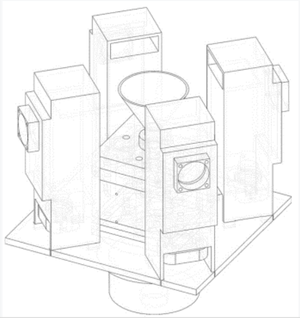
Extensive literature review

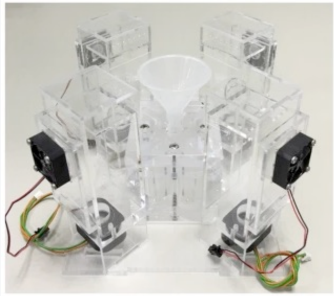
- Comparison of State-of-the-Art in AM **with the whole JPEO portfolio** (enterprise level)
  - ➢ Various opportunities identified:
    - Ergonomic face shield components
    - Lightweight biological surveillance system
    - Carriers for man-portable systems
    - AM for repairs in the field
- Some initial findings:
  - ➢ AM technologies currently allows almost anything
  - ➢ **Additional considerations required at JPEO. For example, how do materials react to chemicals?**
  - ➢ **Some choices heavily depend on scenarios: do we need lightweight? Are repairs in the field feasible?**

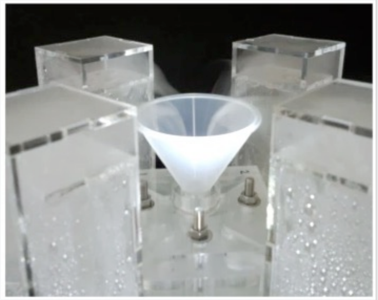












Man-Portable Joint Biological Tactical Detection System (JBTDS)

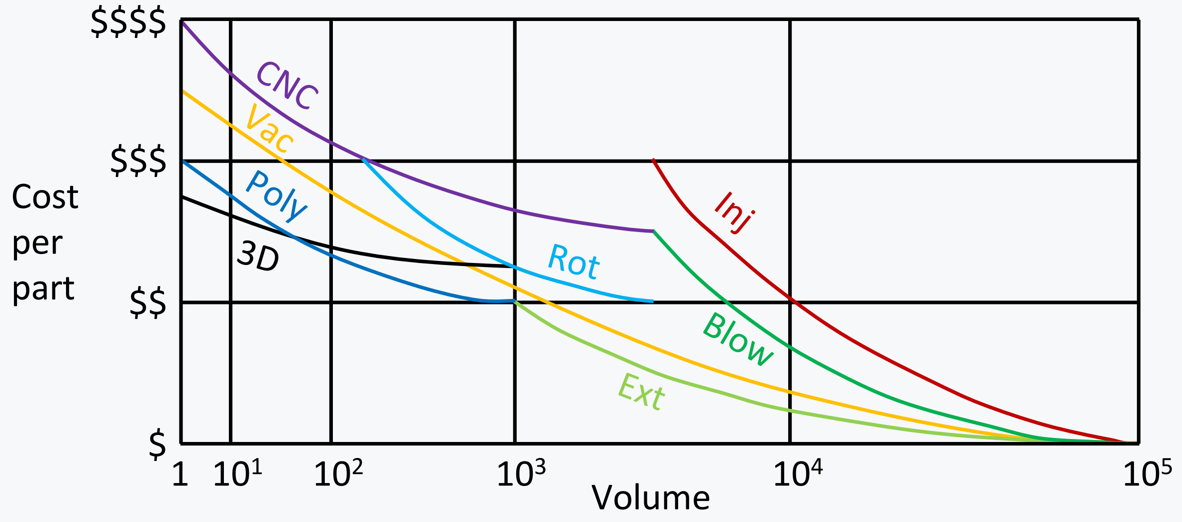
What Should We Do? A Framework for Decision-making

Decisions on what should we do with respect to AM depend on specific scenarios and on many factors

- Questions about models:
  - CAD/physical models → performance, requirements
  - Operational models / mission threads → change in operations, flexibility
  - Supply chain models → cost, time
  - AM models → new requirements before a mission and when deployed
- Questions about specific scenario and technology:
  - Expected production volume
  - Manufacturing details
  - Distribution
  - AM capabilities already existing

AM vs. TM vs. Hybrid – Technology Level

We look at cost, production volume, lead time, complexity of parts that can be produced



AM:
- 3D: 3D printing

TM:
- CNC = CNC machining
- Poly = Polymer casting
- Rot = Rotational molding
- Vac = Vacuum forming
- Inj = Injection molding
- Ext = Extrusion
- Blow = Blow molding

Attributes		AM	TM						
		3D	CNC	Poly	Rot	Vac	Inj	Ext	Blow
Cost per part	Min	$$ - $$$	$$ - $$$	$$	$$	$	$	$	$
	Max	$$ - $$$	$$$$	$$$	$$$	$$$ - $$$$	$$$	$$	$$ - $$$
Production volume	Min	1	1	1	10^2-10^3	1	10^3-10^4	10^3	10^3-10^4
	Max	10^3	10^3-10^4	10^3	10^3-10^4	10^5 or more	10^5 or more	10^5 or more	10^5 or more
Lead time	Min	12-36h	24h-2wk	24h-1wk	4-6wk	4-6wk	8-10wk	2-4wk	4-6wk
Part complexity	Max	5	4	4	2	1	3	1	1

AM vs. TM vs. Hybrid – Enterprise-level Considerations

- Data management. Models available in common software, but need data protection
- Product lifecycle management tools
- Personal data (some might be considered health information)
- Intellectual property: who owns the source of truth?
- Decision might be different based on product stage. Introduction and growth will be initially expensive
- Different branches might be open to more or less use of innovative technology
- Visit to Army Chemical Biological Center (CBC) confirmed some points and brought more perspective:
  - Good capabilities, including reverse engineering
  - Expertise in flow of data, and in ownership and maintenance
  - Obsolescence of products is important
  - AM to produce tools
  - Attention to materials!

Conclusion: Recommendations

- AM can be very useful and viable, especially for small production volume
- Studies are necessary not only for specific items in the JPEO portfolio, but also for specific scenarios and missions
  - It is difficult to give a direct answer for a single technology or tool in JPEO portfolio
  - However, reasoning at the enterprise level is useful for introduction of AM (initial cost would provide capability on many different technologies)
- Begin with low-production components
- Understand which AM technology insertion is most effective in current lineup (we provided some metrics of interest). Not only cost, but also agility against new threats, viability, ease of operation in the field, etc.
- Detailed study on the post-processing requirements for AM (can an AM surface be easily post-processed for smoothness out in the field?)
- Use existing expertise: for example, CBC can run the Cost-Benefit Analysis recommended in ASA(ALT) guidelines

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THANK YOU

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BACKUP SLIDES

Opportunity 1: New Advanced Respiratory and Ocular Protection Capability

- What?

  New advanced respiratory and ocular protection capability against CBRN threats, improve integration with individual combat equipment, and minimize or eliminate rubber on the face to unencumber the user while operating in a CBRN environment

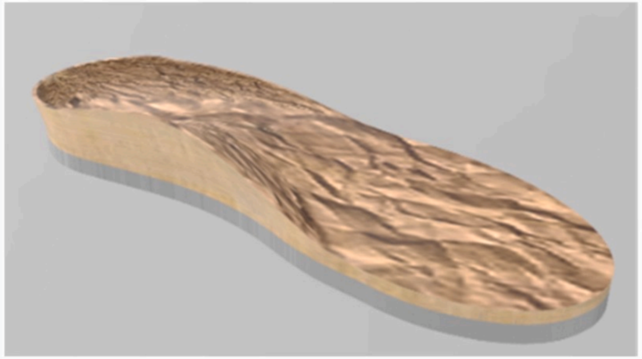
- How?

  Use AM to create more effective and usable respiratory & ocular protection equipment for people

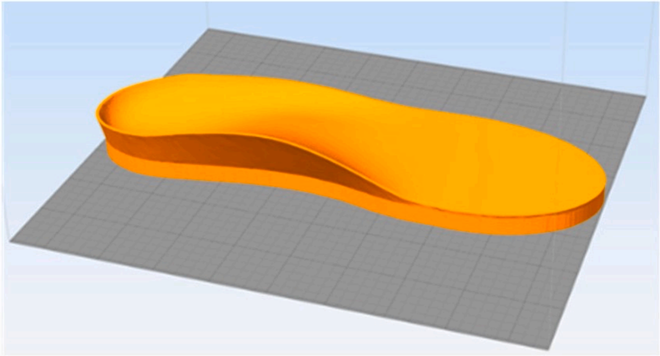
- Comments on feasibility
  - ➢ Making the components of face shields using AM rather than TM for a better fit for improved ergonomics/comfort and prevention of contamination from having a better seal.

Opportunity 1: Literature Review (1 of 4)

- Comparing to TM shoe insoles, AM shoe insoles (i.e., "orthopedic insoles") can be made much more cost effectively with a shorter lead time and a better/customized fit for end users.



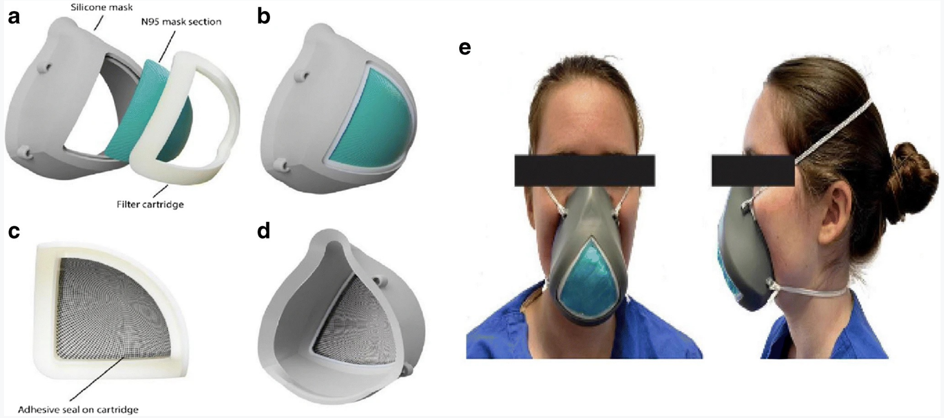
TM shoe insole
(Produced from the trial-and-error process)

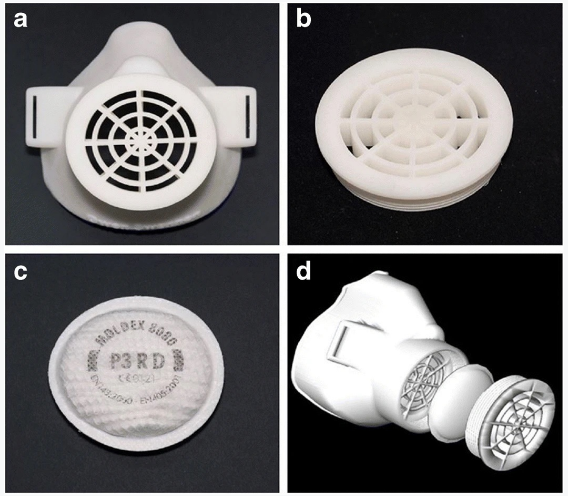


AM shoe insole
(Produced from the 3D scanned CAD/CAM data)

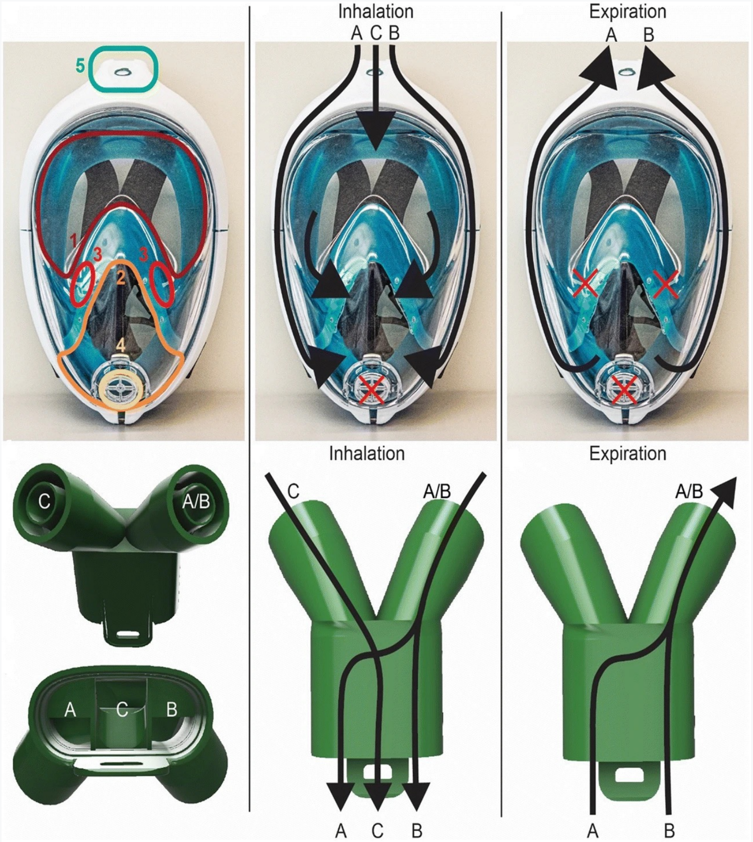
- We can apply the same design principle to the respiratory and ocular protection, where a customized fit on a face can produce more protection and better ergonomics for the end users.

Opportunity 1: Literature Review (2 of 4)





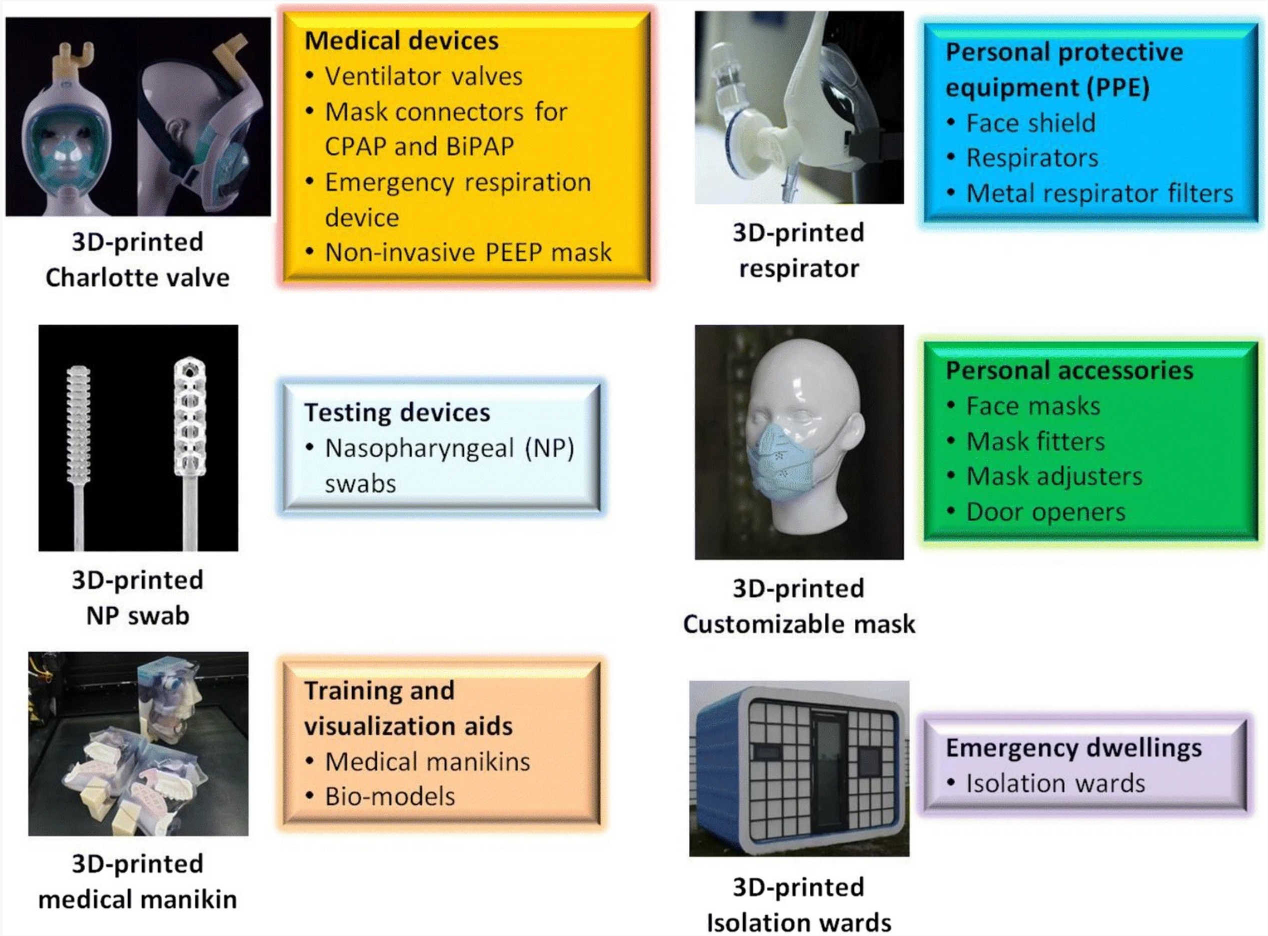
AM face mask examples



AM air valve example

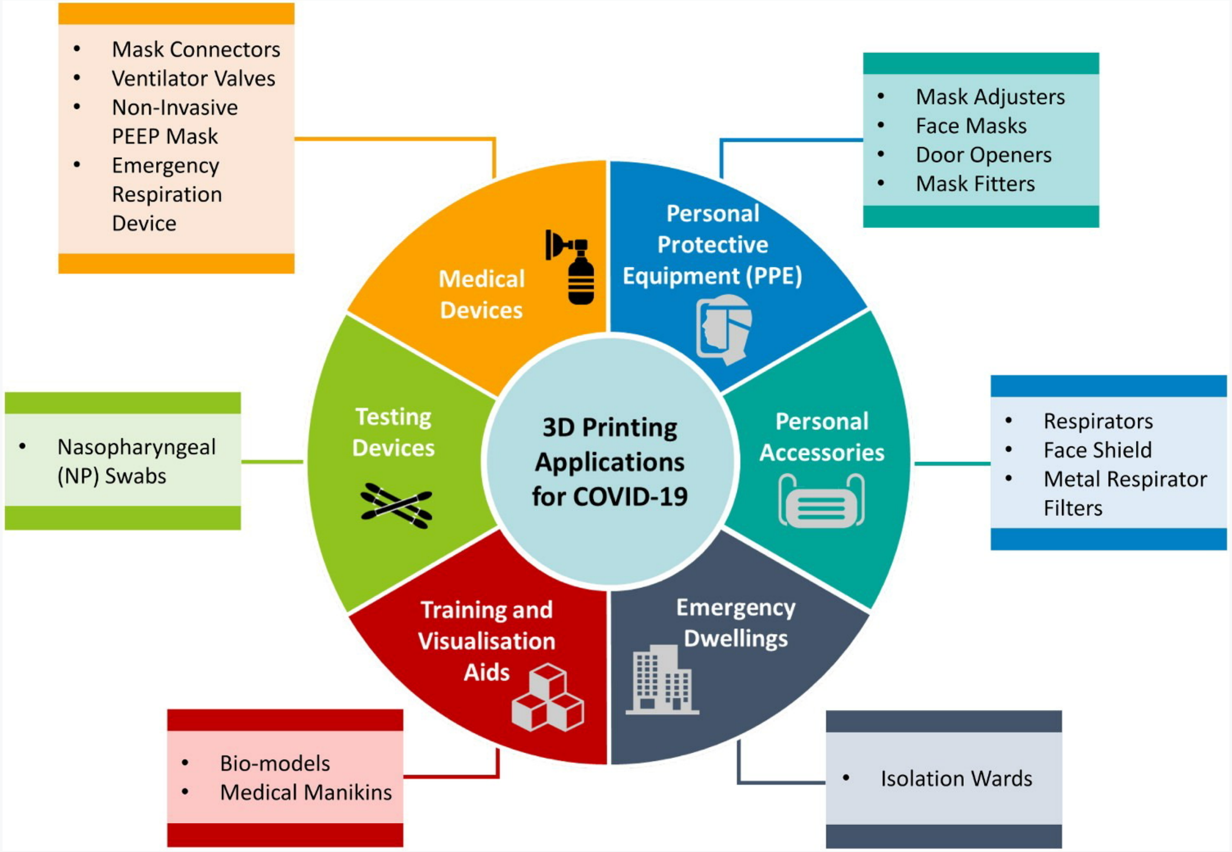
Opportunity 1: Literature Review (3 of 4)

- AM to replace TM for battle against virus (e.g., COVID-19) or Biological Warfare Agent
- Typical applications are:
  - ➢ Personal protective equipment
  - ➢ Testing supplies and equipment
  - ➢ Ventilation-related products
- AM enables product customization and complex design



Opportunity 1: Literature Review (4 of 4)

- AM can be used for rapid emergency responses and to solve supply chain disruptions during the COVID-19.
- The ability of AM to customize a product to the needs of the user is a key advantage over TM.
- The current AM technology is justifiable for low volume production to bring a product to market.
- If mass production is necessary, more 3D printers need to be deployed and run in parallel.



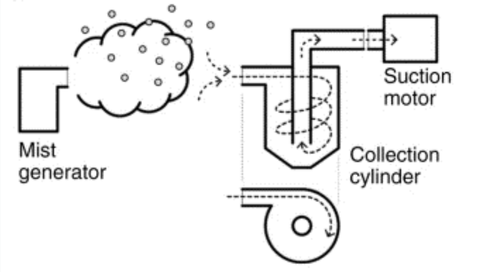
Opportunity 2: Tactical Lightweight, Low-cost Biological Surveillance System for BWA Aerosols

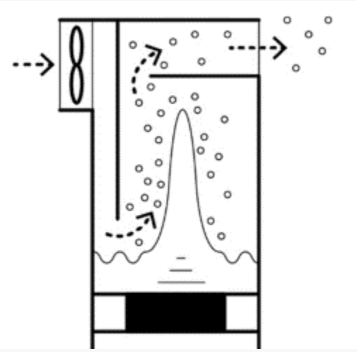
- What?

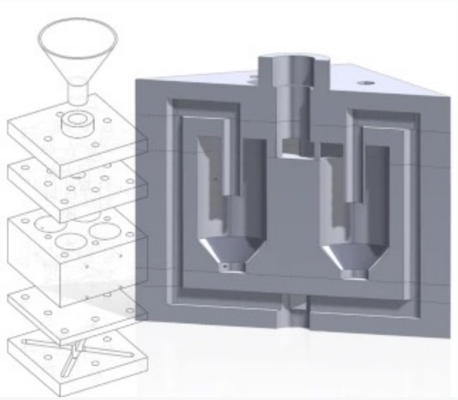
  Tactical lightweight, low-cost biological surveillance system to collect, detect, and identify Biological Warfare Agent (BWA) aerosols

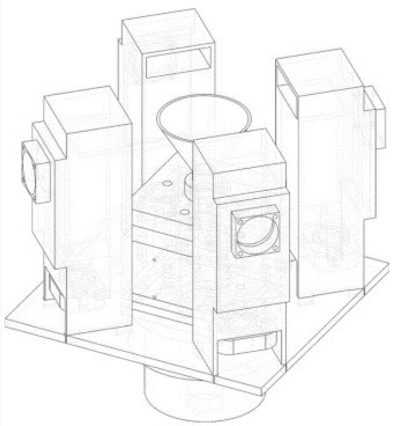
- How?
  - Use AM to create lightweight and low-cost outer frames for such systems
- Comments on feasibility
  - The detection, collection, and identification of BWA aerosols appears to be great topic for AM technology implementation if we can create a device to achieve these goals using the AM technology.
  - There are literatures that deal with chemical sensing for BSW aerosols. To this end, the florescence-based technology seems to be the most common technology. Thus, one possibility is to propose the use of AM technology to create the florescence-based detection system.
  - Another possibility is to create an air-sampling unit using AM technology as some researchers published their air-sampling unit design. Then, using the established detection technology (e.g., the florescence-based detection system) to detect the BWA.

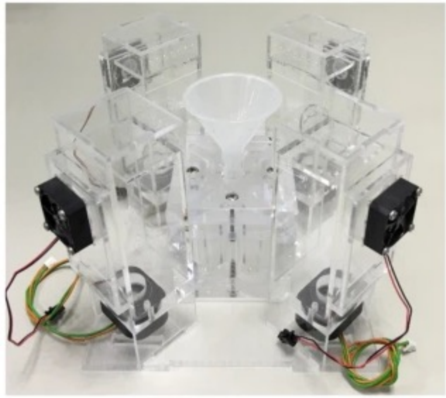
Opportunity 2: Literature Review (1 of 4)

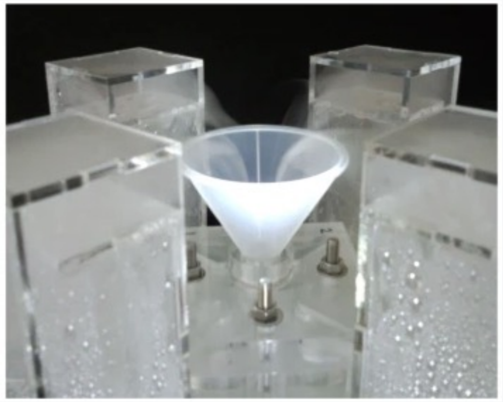










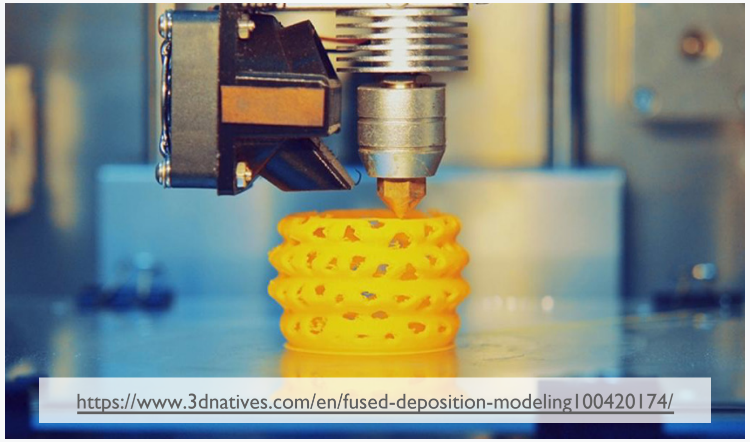


Development of an air sampling/collecting device

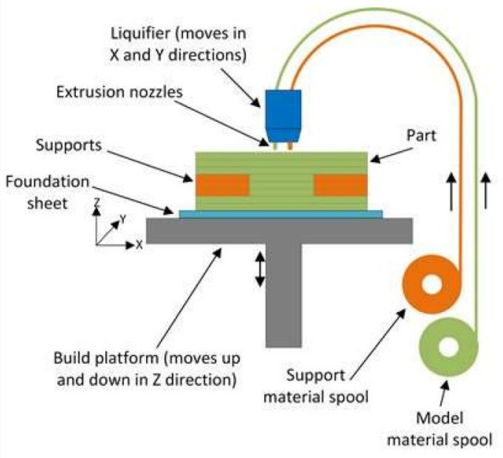
(We propose to produce air sampling device using the AM technology)

Opportunity 2: Literature Review (2 of 4)

- Why AM instead of TM?
- Fused deposition modeling (FDM) is an extrusion-based 3D printing technology
- In FDM, the material is melted for printing in high temperature (i.e., excess of 150°C) which should kill any biological agent that might be on the surface.
- The build plate must also be heated to between 50 °C and 100°C.
- Thus, as the FDM product is built, the components are sterile. However, once humans start handling the part, there is a possibility for virus to adhere to the component surface.
- In order to kill COVID-19, heat virus-containing objects for:
  - 3 minutes at temperature above 75°C (160°F).
  - 5 minutes for temperatures above 65°C (149°F).
  - 20 minutes for temperatures above 60°C (140°F).
- Thus, AM is inherently sterile due to the elevated temperature during the production
- TM typically require complicated assembly process, comparing to AM, since TM typically cannot match the part complexity of AM.



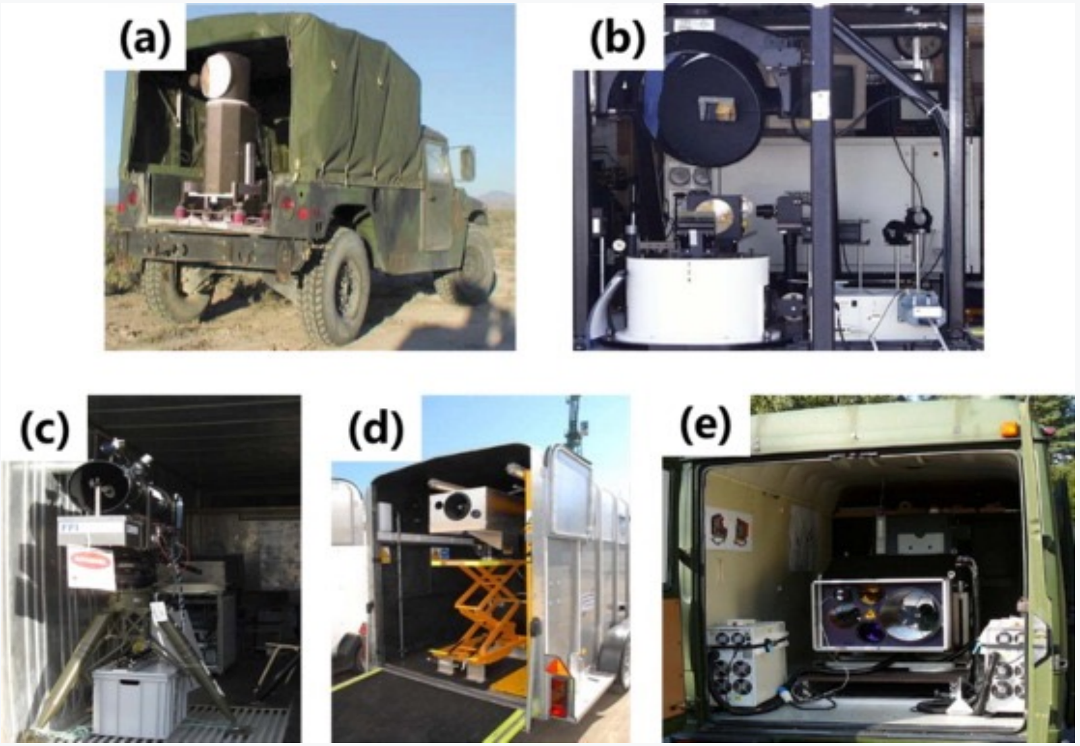
FDM



FDM schematics

Opportunity 2: Literature Review (3 of 4)

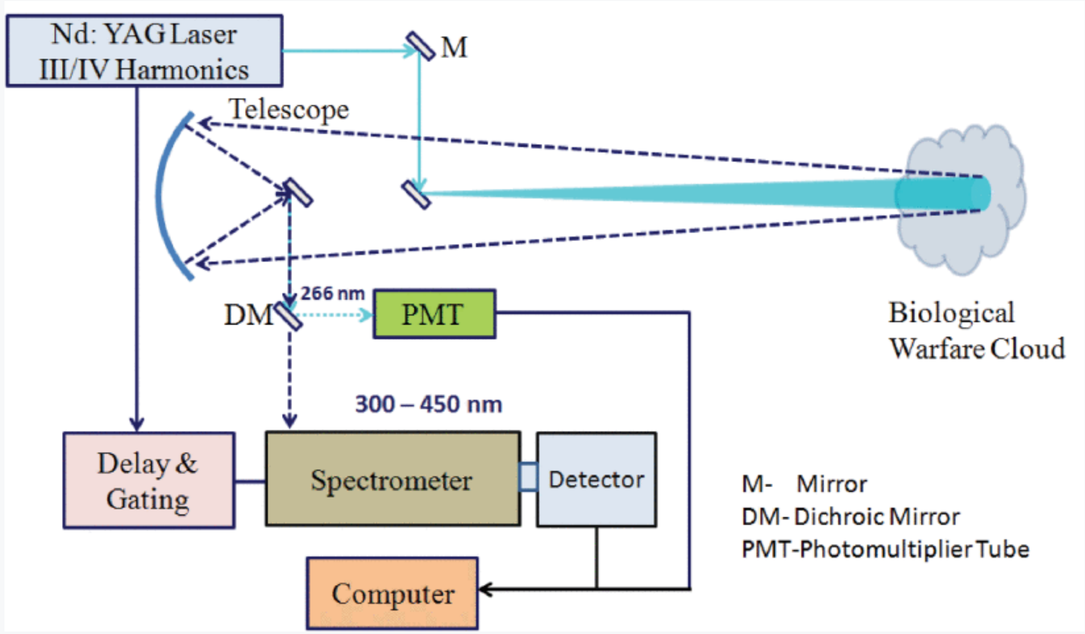
- To pursue the detection technologies and to create equipment for BWA aerosol early warning and field detection, we will need to focus on the following:
  - Infrared (IR) laser elastic backscatter technology
  - Ultraviolet (UV) laser induced fluorescence (LIF) technology
  - Light detection and ranging (LIDAR) technology



Example of LIF LIDAR system or detecting biological aerosols

Opportunity 2: Literature Review (4 of 4)

- Schematics of UV LIDAR system



- BWA aerosol collection: Yes, AM technologies can be used to create collection devices
- BWA aerosol detection: (Can AM technologies be used?)
- BWA aerosol identification: (Can AM technologies be used?)

Additional Items To Consider (I.E., “Customer Requirements (WHAT)” Per House of Quality) (1 Of 2)

1. Alignment and integration with rest of DoD
2. Improve requirements and investment
3. Using common authoritative source
4. Speed up access to information
5. Increase system integration and interdependence (SoS)
6. Data sharing (while keeping data protection)
7. Increase ability to handle emerging threats
8. Reduce timelines to identify and assess capability gaps
9. Requirement traceability

Additional Items To Consider (I.E., “Customer Requirements (WHAT)” Per House of Quality) (2 Of 2)

10. Manage and track interfaces
11. Assess portfolio health
12. Add portfolio schedule
13. Identify changes in mission if cost / schedule / requirements change
14. Add/understand trades at the capability level to trades at the programmatic level (functional breakdown)
15. Standardize and share performance data
16. Define policies for data management (how to document, represent, store)
17. Increase automation

Evaluation of AM, TM, And AM/TM Hybrid (2 of 2)

	AM	TM	AM/TM Hybrid
Data protection/security	Required	Required	Required
Data repositories/access	Required	Optional (OEM only)	Required
Agility of operation	Agile	Not as agile as AM	Agile. TM is the bottleneck.
Agility against new threats	Agile	Not as agile as AM	Agile. TM is the bottleneck.
Digital twin	Required	Optional (OEM only)	Required
Economically effective production lot size	$1 – 10^3$	10^3+ (Note: TM production can be done as low as 1 although it may not be economically effective.	1+ (Depending on application)