Manager’s Decision Support for Additive Manufacturing (AM)

Society of Reliability Engineers
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PURPOSE

- Describe Additive Manufacturing technology, 3D Printing, for fundamental understanding and application to reliability.

- Explain the variables inherent in 3D printing which yield risks and opportunities for decision makers.

- Introduce a framework/process designed to generate a decision support toolkit for managers.

- Conduct a group exercise, based on process steps, to assess reliability considerations for part production.
Open Discussion of Reliability  Considerations for AM

Conventional bracket
1. 
2. 
3. 

3D-Printed bracket
1. 
2. 
3. 

using the risk and opportunity framework depicted in this briefing…
But first, some AM background information.
“A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning levels of an organization (usually mid and higher management) and help people make decisions about problems that may be rapidly changing and not easily specified in advance.”

“Some authors have extended the definition of DSS to include any system that might support decision making.”

https://en.wikipedia.org/wiki/Decision_support_system
According to Joint Technology Exchange Group (JTEG) Technology Definitions "additive manufacturing (AM), also referred to as 3D printing, is a layer-by-layer technique of producing three-dimensional (3D) objects directly from a digital model."

TED TALKS: https://www.youtube.com/watch?v=lbldztMOomI
AM FUNDAMENTALS

Additive Manufacturing 101

ASTM F-42 committee definition: a process of joining materials to make objects from three-dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

Selective transformation of material having primitive form (liquid, powder, wire, sheet) into a solid 3D form prescribed by a CAD solid model

* End product changed from original AMRDEC example

AM enables a new design realm in which geometric complexity is not a constraint, and material can be located where you need it, and not where you don’t need it.
DRIVING PRODUCTIVITY AT EVERY STAGE

CONCEPT DEVELOPMENT
- Communicate Design Intent

DESIGN VALIDATION
- Functionally Test Designs

PRE-PRODUCTION
- Bridge the Gap with Rapid Tooling

DIRECT MANUFACTURING
- Production End-Use Parts

Source: 3D Systems, Inc.
SUPPLY CHAIN VALUE ENVELOPE

Right part, right place, right time, right quantity

Part
- More
- Less

Customization
- More remote
Production proximity to point of use

Place
- More
- Less

Time
+ Closer
+ More

Quantity
Production volume
- Lower
+ Higher

Supply chain resiliency*
*Responsiveness, availability, dependability

- End user value +

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Supporting a Continuous Supply Chain

Part Breaks | New Part Request | Part Fabrication
--------- | --------------- |------------------
0  | 6  | 12

Current Warfighter Downtime

New Part Arrives | New Part Installed
24  | 36  | 42

Additional Warfighter Uptime

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

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

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

Value Chain

Objective and Impact

**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

Sequenced Technology Elements

- **DoD.V.1.1 Identify and Capture AM Use Cases and Best Practices for Repair, Part Replacement, and New Part Manufacture**

- **DoD.V.1.2 Develop Adequate Cost Models for AM implementation**

- **DoD.V.1.3 Develop and Implement AM Decision Tools to Establish the Value Proposition**

- **DoD.V.2.1 Understand Risk of AM Approaches**

- **DoD.V.2.2 Inform Decision Authorities re: AM Technology**

- **DoD.V.2.3 Ensure Qualification and Certification Methods Accommodate AM Technologies**
AM DECISION PROCESS FLOW
Weigh Risks and Opportunities

User Requirements
- Cost
- Schedule
- Performance

AM Decision Factors
- Risks
- Opportunities

Informed Decision Space
- Acquisition impacts
LIST C/S/P REQUIREMENTS FOR DESIRED END STATE

USEFUL END ITEM

CAPABILITY GAP FILLED

Prototyping
Production
Spares
Cost
Schedule
Stiffness
Weight
Life

Lead times / Delivery dates

Performance

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RISK & OPPORTUNITY IDENTIFICATION ENGINE

**Internal Organization**
- Personnel Avail/Expertise
- Cross Training
- Assignment Duration
- Personnel Workloads

**Decision Making**

**Industry**
- Contracts
- Contractors
- Customers
- COTS

**Infrastructure**
- Critical System Backup
- System Repair
- Site Safety
- Physical Security
- Event Recovery
- Communications
- Systems

**Information**
- Information System Backup
- Software Availability
- Information Load
- Net Security
- ERP Systems

**Influences**
- Substitutes
- Budgets
- Senior Leadership
- Suppliers
- ACAT Status
- Policy Mandates

Source: Rice, J., Acquisition Research Journal, 2010

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### Technological aspects of AM

#### Opportunities

- Direct digital manufacturing of 3D product designs without the need for tools or molds
- Change of product designs without cost penalty in manufacturing
- Increase of design complexity (e.g., lightweight designs or integrated cooling chambers) without cost penalty in manufacturing
- High manufacturing flexibility; objects can be produced in any random order without cost penalty
- Production of functionally integrated designs in one-step
- Less scrap and fewer raw materials required

#### Limitations

- Solution space limited to ‘printable’ materials (e.g., no combined materials) and by size of build space
- Quality issues of produced parts: limited reproducibility of parts, missing resistance to environmental influences
- Significant efforts are still needed for surface finishing
- Lacking design tools and guidelines to fully exploit possibilities of AM
- Skilled labour and strong experience needed

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SCENARIO: TRADITIONAL PART PRODUCTION

Conventional Bracket

Function
- Simple
- Enhanced

Shape
- Simple
- Complex

Material
- Simple
- Multiple

Specifications

Manufacturing Process
- Conventional
- Additive Manufacturing
- CHAMP

Standard Part
Lots of wasted material
(Heavy, wasteful)
SCENARIO: AM PART PRODUCTION

Additive Manufactured Bracket

Function
- Simple
- Enhanced

Shape
- Simple
- Complex

Material
- Simple
- Multiple

Specifications

Manufacturing Process
- Conventional
- Additive Manufacturing
- CHAMP

Stress Concentration
(Cracks Form)

Topology Optimized Part

Better use of material
(Homogeneous Materials)

Source: University of Tennessee, Center for Hybrid Materials
Using Additive Manufacturing Processes (CHAMP), Chad Duty, PhD
# RISK & OPPORTUNITY HANDLING STRATEGIES

## AM Risk Strategies

<table>
<thead>
<tr>
<th>ID</th>
<th>Accept</th>
<th>Avoid</th>
<th>Control</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skilled labor</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Data security</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Shortened product life</td>
<td>x</td>
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</tr>
</tbody>
</table>

## AM Opportunity Strategies

<table>
<thead>
<tr>
<th>ID</th>
<th>Pursue</th>
<th>Defer</th>
<th>Reevaluate</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce suppliers</td>
<td></td>
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<td>x</td>
</tr>
<tr>
<td>Minimize raw materials</td>
<td></td>
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<td></td>
<td>x</td>
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<tr>
<td>Reduce weight</td>
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<td></td>
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<td>x</td>
</tr>
</tbody>
</table>

# ACQUISITION IMPACTS

<table>
<thead>
<tr>
<th>AM attributes compared to traditional manufacturing</th>
<th>Impact on product offerings</th>
<th>Impact on supply chains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing of complex-design products</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>New products that break existing design and manufacturing limitations</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>Customization to customer requirements</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>Ease and flexibility of design iteration</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
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<tr>
<td>Parts simplification/sub-parts reduction</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
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<tr>
<td>Reduced time to market</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>Waste minimization</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>Weight reduction</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
<tr>
<td>Production near/at point of use</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
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<tr>
<td>On-demand manufacturing</td>
<td>![Impact Symbol]</td>
<td>![Impact Symbol]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential impact</th>
<th>Very high</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
</table>

Source: Deloitte University Press | dupress.com
4.9.1 Basic Process.

Reliability growth is the result of an iterative design process. As the design matures, it is investigated to identify actual or potential sources of failures. Further design effort is then spent on these problem areas. The design effort can be applied to either product design or manufacturing process design. The iterative process can be visualized as a simple feedback loop, as shown in Figure 1. This illustrates that there are four essential elements involved in achieving reliability growth:

a) Failure mode discovery;

b) Feedback of problems identified;

c) Failure mode root cause analysis and proposed corrective action; and

d) Approval and implementation of proposed corrective action.

Furthermore, if failure sources are detected by testing, another element is necessary:

e) Fabrication of hardware.

Following redesign, detection of failure sources serves as verification of the redesign effort. This is shown in Figure 2.
**RELIABILITY CONSIDERATIONS FOR AM**

- OPEN DISCUSSION -

**Scenario:** Replacement of structural brackets for deployed UAVs.

- **Conventional bracket**
  1. Risks
  2. Opportunities
  3. Impacts

- **3D-Printed optimized bracket**
  1. Risks
  2. Opportunities
  3. Impacts
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BACKUP
### AM PROCESSES

#### Table 2. AM Major Manufacturing Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat photopolymerization</td>
<td>A liquid photopolymer (i.e., plastic) in a vat is selectively cured by light-activated polymerization. The process is also referred to as light polymerization. Related AM technologies: Stereolithography (SLA), digital light processing (DLP)</td>
</tr>
<tr>
<td>Material jetting</td>
<td>A printhead selectively deposits material on the build area. These droplets most often are comprised of photopolymers with secondary materials (e.g., wax) used to create support structures during the build process. An ultraviolet light solidifies the photopolymer material to form cured parts. Support material is removed during post-build processing. Related AM technologies: Multi-jet modeling (MJM)</td>
</tr>
<tr>
<td>Material extrusion</td>
<td>Thermoplastic material is fed through a heated nozzle and deposited on a build platform. The nozzle melts the material and extrudes it to form each object layer. This process continues until the part is completed. Related AM technologies: Fused deposition modeling (FDM)</td>
</tr>
<tr>
<td>Powder bed fusion</td>
<td>Particles of material (e.g., plastic, metal) are selectively fused together using a thermal energy source such as a laser. Once a layer is fused, a new one is created by spreading powder over the top of the object and repeating the process. Unfused material is used to support the object being produced, thus reducing the need for support systems. Related AM technologies: Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)</td>
</tr>
<tr>
<td>Binder jetting</td>
<td>Particles of material are selectively bonded together using a liquid binding agent (e.g., glue). Links also may be deposited to impart color. Once a layer is formed, a new one is created by spreading powder over the top of the object and repeating the process until the object is formed. Unbound material is used to support the object being produced, thus reducing the need for support systems. Related AM technologies: Powder bed and inkjet head (PBH), powder-based 3D printing (PP)</td>
</tr>
<tr>
<td>Sheet lamination</td>
<td>Thin sheets of material (e.g., plastic or metal) are bonded together using a variety of methods (e.g., glue, ultrasonic welding) to form an object. Each new sheet of material is placed over previous layers. A laser or knife is used to cut a border around the desired part and unneeded material is removed. This process is repeated until the part is completed. Related AM technologies: Laminated object manufacturing (LOM), ultrasonic consolidation (UC)</td>
</tr>
<tr>
<td>Directed energy deposition</td>
<td>Focused thermal energy is used to fuse (typically metal) material as it is being deposited. Directed energy deposition systems may employ either wire-based or powder-based approaches. Related AM technologies: Laser metal deposition (LMD)</td>
</tr>
</tbody>
</table>

**Figure 1. Additive manufacturing (AM) process flow**

![AM Process Flow Diagram](image)

Graphic: Deloitte University Press | DUPress.com


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COST / BENEFIT / RISK ANALYSIS

There are numerous similar methods of analysing costs, benefits and risks associated with a decision or plan. The general procedure involved is as follows:

**Cost / Benefit**

1. Define, or breakdown the plan / decision / process into its elements by drawing up a flowchart or list of inputs, outputs, activities and events.
2. Calculate, research or estimate the cost and benefit associated with each element. (Include if possible direct, indirect, financial and social costs and benefits)
3. Compare the sum of the costs with the sum of the benefits.

**Benefit / Risk**

4. Rank the elements into a hierarchy that reflects the [sic] impact of their potential success / failure on the whole process. If the variation in the potential impact of the ranked elements is significant, then:
5. Assign weighting values to each element.
6. Estimate the likelihood of success or failure of each element.
7. Multiply the likelihood of success or failure for each element by its weighting value.
8. Compare the risk (result of 7) with the costs and benefits associated with (3).

Workforce can utilize DAU assets for application of AM in the context of product lifecycle.
DAU ADDITIVE MANUFACTURING
(3D PRINTING) LEARNING ASSETS

• Additive Manufacturing Community of Practice (AM CoP) at
  https://www.dau.mil/cop/am/Pages/Default.aspx
  - Interdisciplinary focus - logistics, manufacturing, engineering, acquisition law

• Additive Manufacturing ACQuipedia Article
  https://www.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=000624f0-61dd-4982-bca3-122334e57a20

• Twenty-six Additive Manufacturing training video vignettes in DAU Media Library

• Special AM-focused Defense AT&L Magazine at