Manager's Decision Support for Additive Manufacturing (AM)

Society of Reliability Engineers
10th Annual RAM Training Summit
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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.

GROUP EXERCISE AT CONCLUSION

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.

DECISION SUPPORT

"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

AM INTRODUCTION

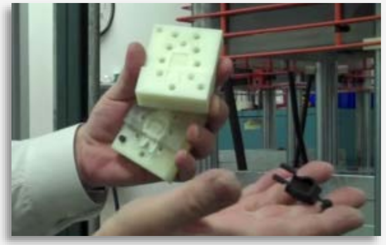
According to Joint Technology Exchange Group (JTEG) Technology Definitions "*additive manufacturing (AM), also referred to as 3D printing, is a layer-by-layer technique of producing three-dimensional (3D) objects directly from a digital model*.”

TED TALKS: https://www.youtube.com/watch?v=IbIdztMOomI

AM FUNDAMENTALS

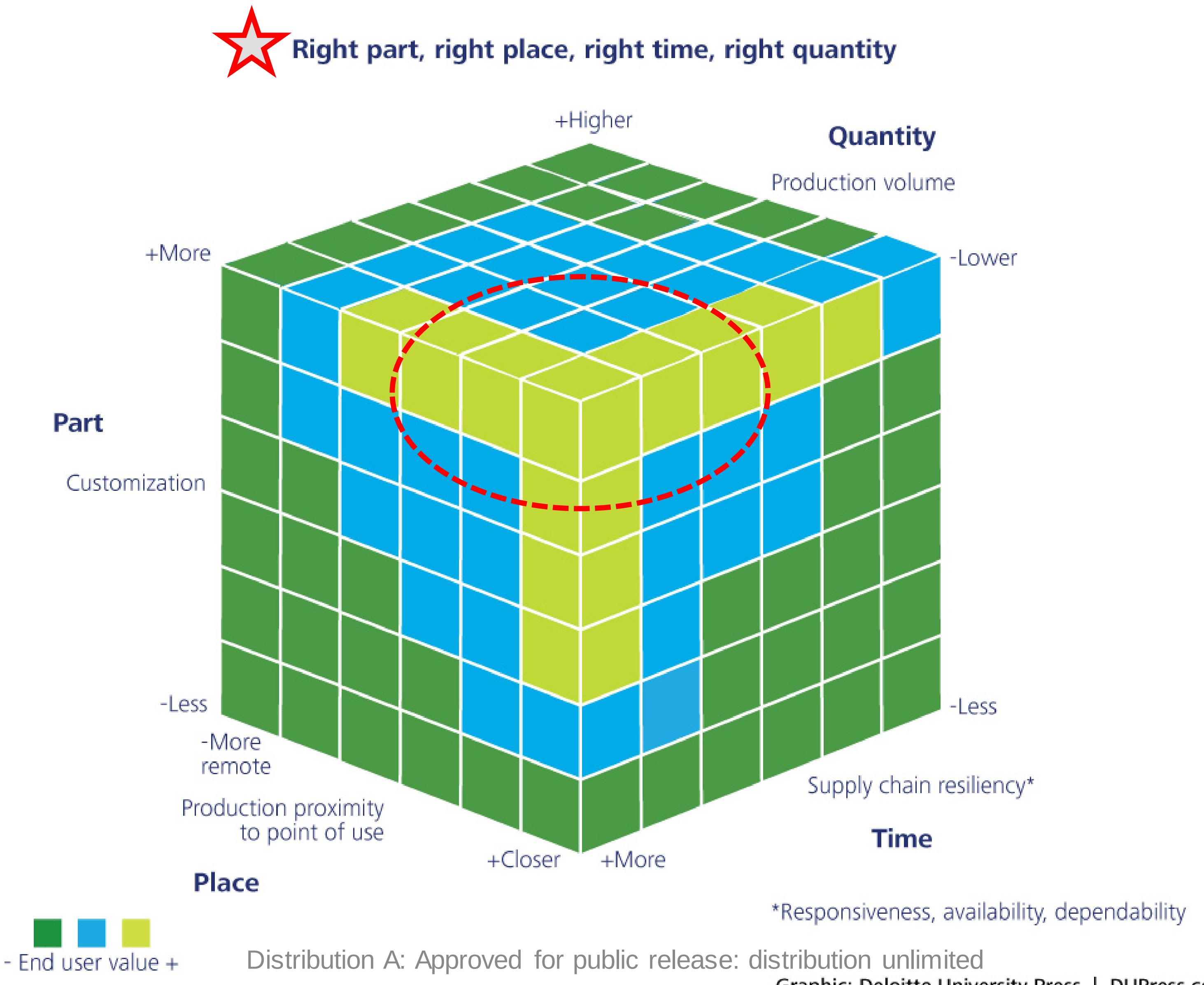
DRIVING PRODUCTIVITY AT EVERY STAGE

CONCEPT DEVELOPMENT	DESIGN VALIDATION	PRE-PRODUCTION	DIRECT MANUFACTURING
Communicate Design Intent	Functionally Test Designs	Bridge the Gap with Rapid Tooling	Production End-Use Parts



Source: 3D Systems, Inc.

SUPPLY CHAIN VALUE ENVELOPE



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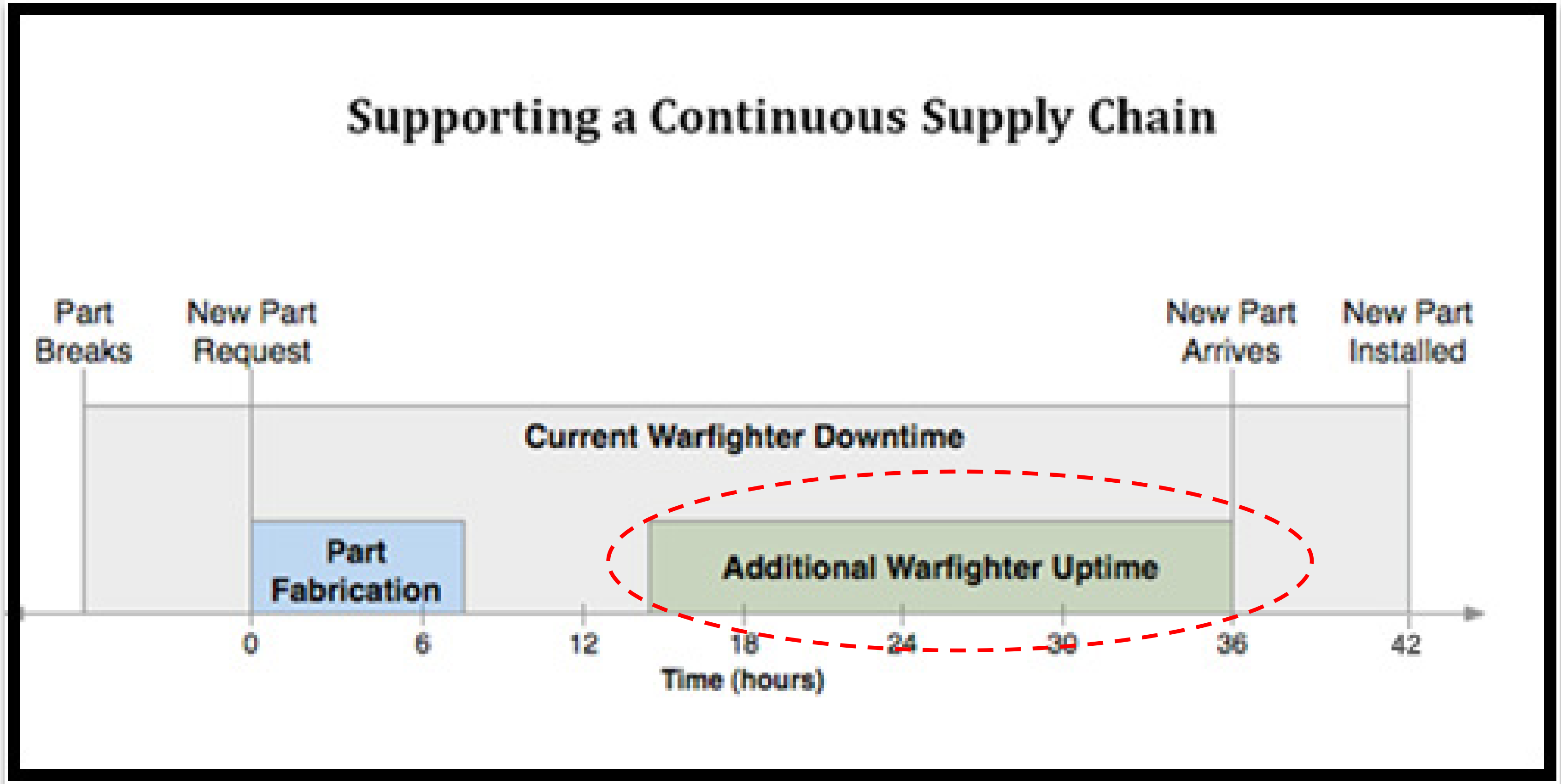
Graphic: Deloitte University Press | DUPress.com

BOTTOM LINE OPPORTUNITY IN DOD



Source: The Mitre Corporation

SIGNIFICANT BREAKTHROUGH IN DOD: SAFETY CRITICAL PART

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."

http://www.naval-technology.com/news/newsus-navair-tests-3-d-printed-safety-critical-parts-on-mv-22b-osprey-aircraft-4965373

Value Chain

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

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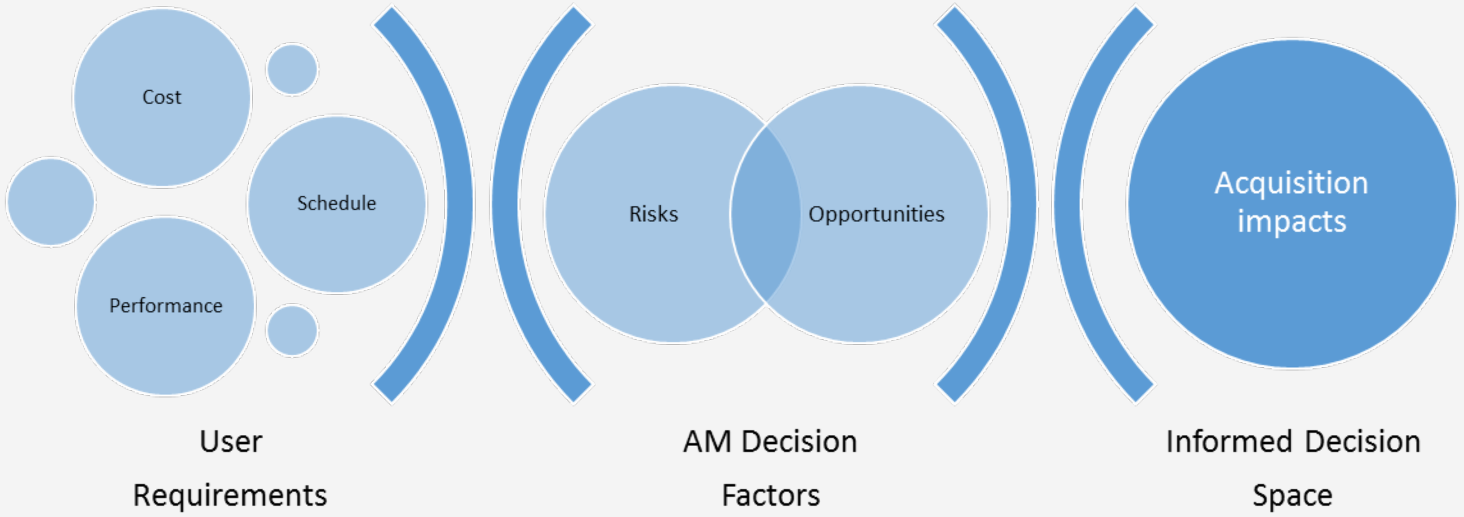
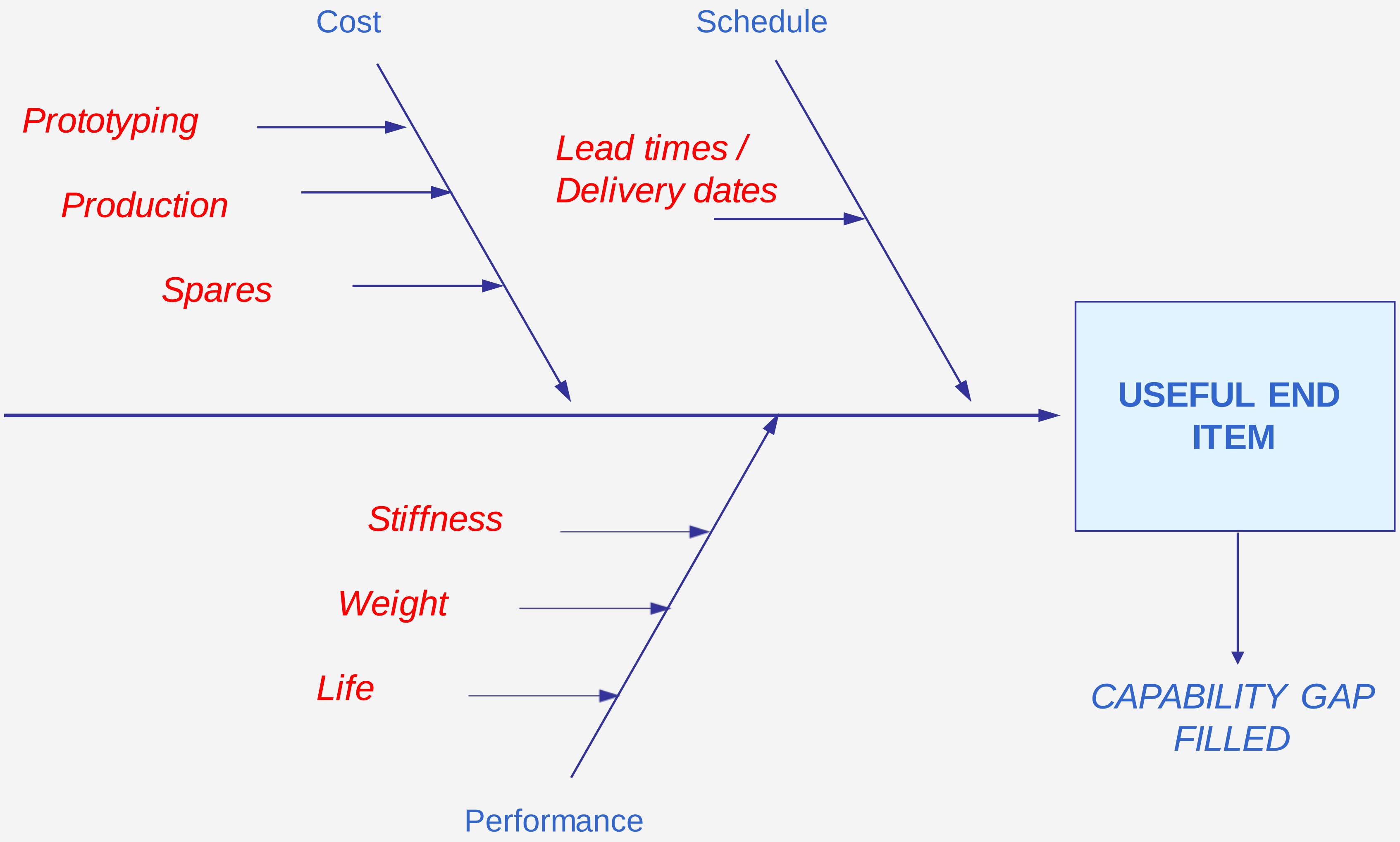
AM DECISION PROCESS FLOW
Weigh Risks and Opportunities

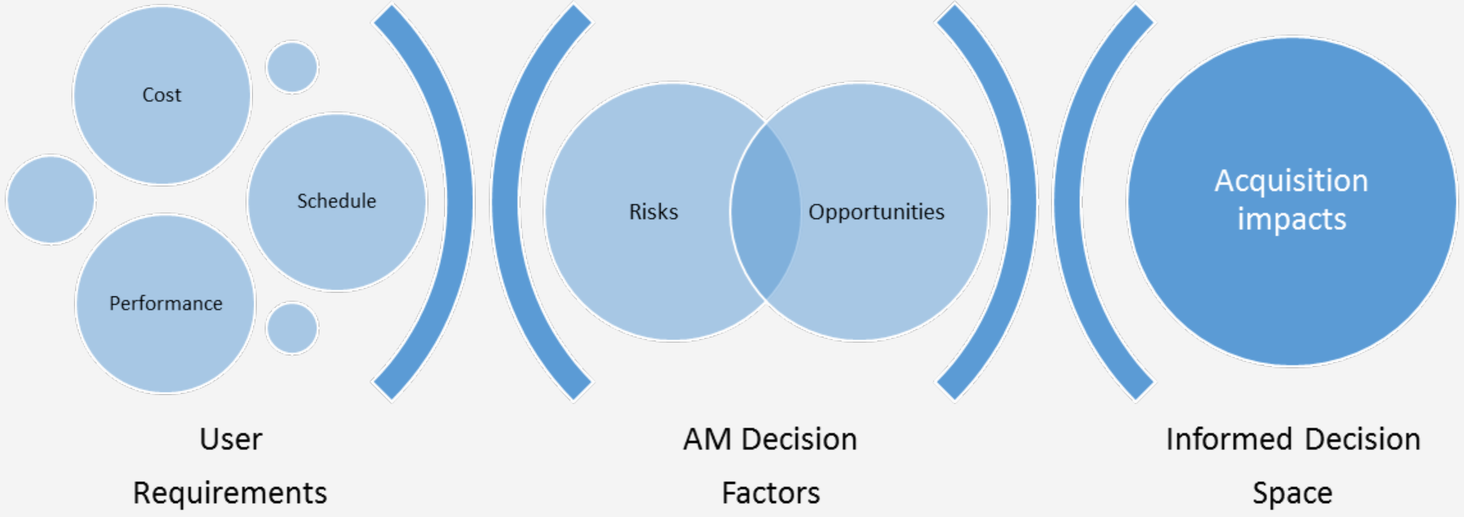


LIST C/S/P REQUIREMENTS FOR DESIRED END STATE

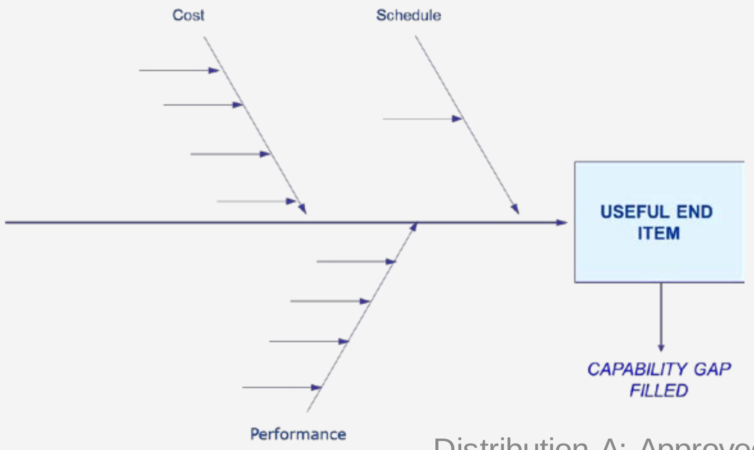


AM DECISION PROCESS FLOW

Process



Tools



RISK & OPPORTUNITY IDENTIFICATION ENGINE

Information

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

Industry

Contracts
Contractors
Customers
COTS

Internal Organization

Personnel Avail/Expertise
Cross Training
Assignment Duration
Personnel Workloads
Decision Making

Infrastructure

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

Substitutes
Budgets
Senior Leadership
Suppliers
ACAT Status
Policy Mandates

Influences

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

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

DECISION SUPPORT TOOL: OUTPUT

Technological aspects of AM

Opportunities	Limitations
☐	☐
☐ Direct digital manufacturing of 3D product designs without the need for tools or molds	☐ Solution space limited to 'printable' materials (e.g., no combined materials) and by size of build space
☐ Change of product designs without cost penalty in manufacturing	☐ Quality issues of produced parts: limited reproducibility of parts, missing resistance to environmental influences
☐ Increase of design complexity (e.g., lightweight designs or integrated cooling chambers) without cost penalty in manufacturing	☐ Significant efforts are still needed for surface finishing
☐ High manufacturing flexibility: objects can be produced in any random order without cost penalty	☐ Lacking design tools and guidelines to fully exploit possibilities of AM
☐ Production of functionally integrated designs in one-step	☐ Low production throughput speed
☐ Less scrap and fewer raw materials required	☐ Skilled labour and strong experience needed

Suppliers

System Repair

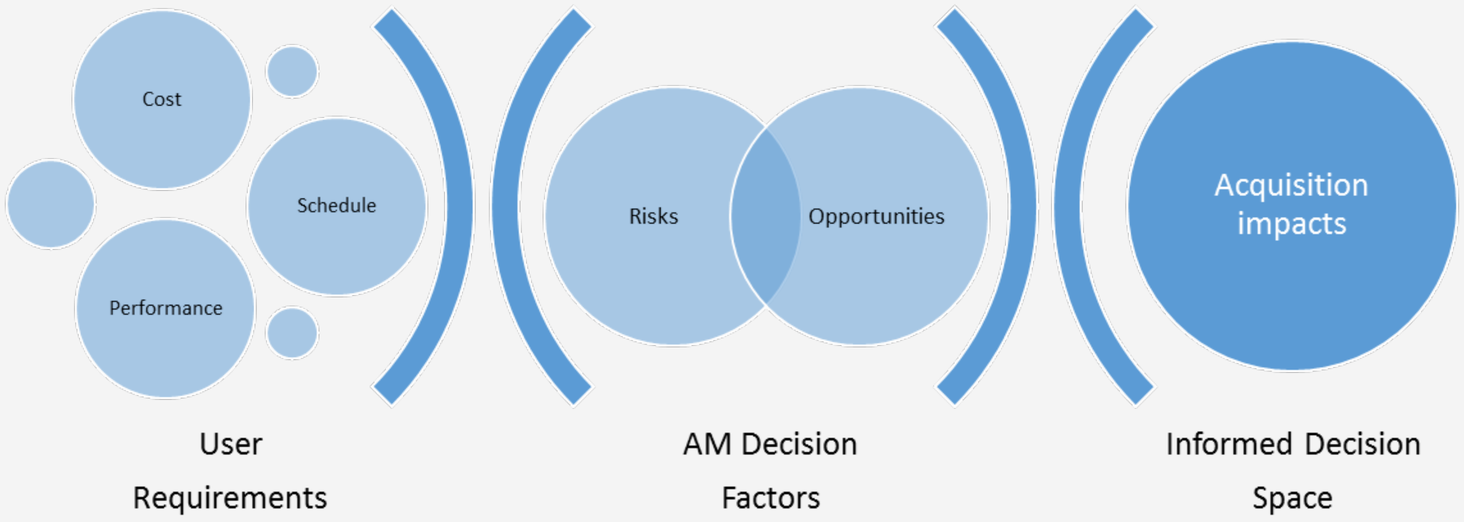
Information Security

Contracts

Source: http://www.insidemetaladditivemanufacturing.com/uploads/7/4/4/0/7440869/5290733.jpg?1427081598

AM DECISION PROCESS FLOW

Process



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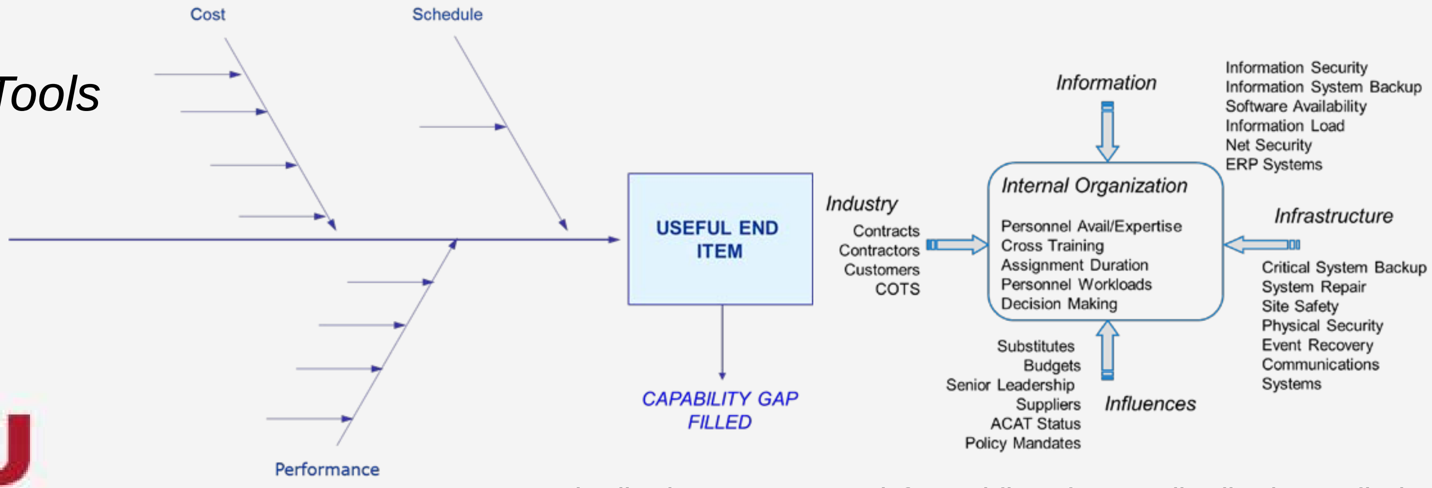
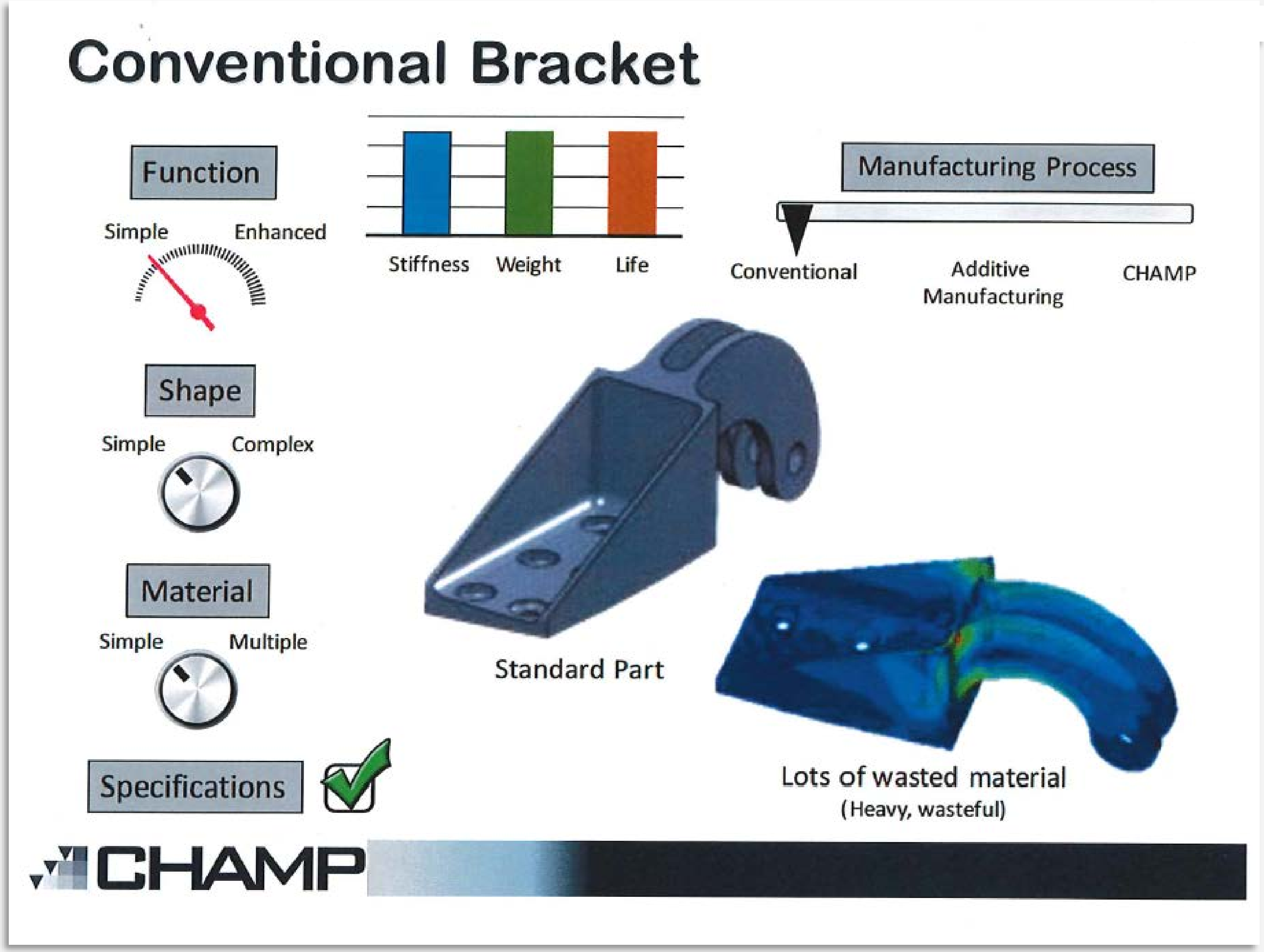
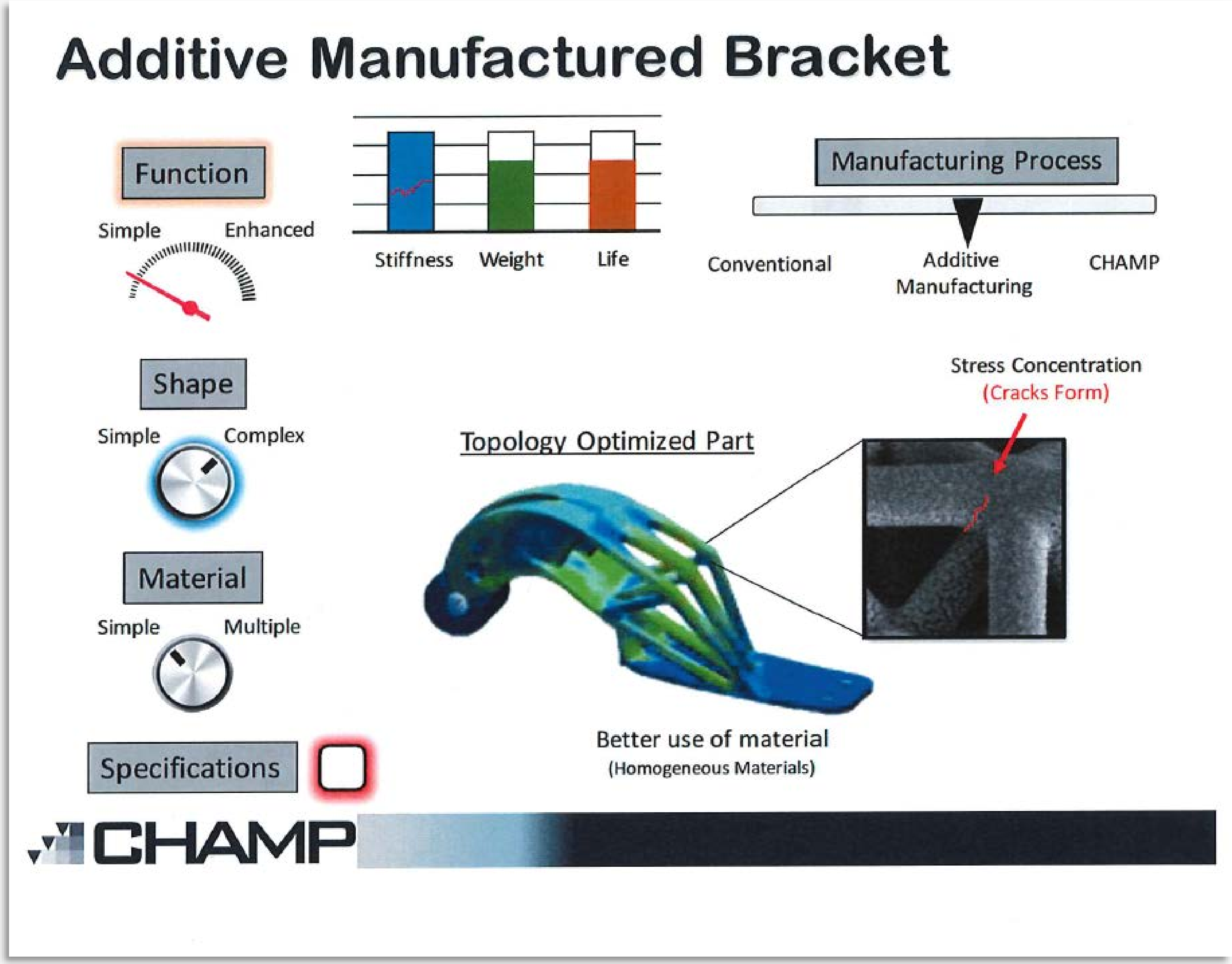


SCENARIO: TRADITIONAL PART PRODUCTION



Source: University of Tennessee, Center for Hybrid Materials Using Additive Manufacturing Processes (CHAMP), Chad Duty, PhD

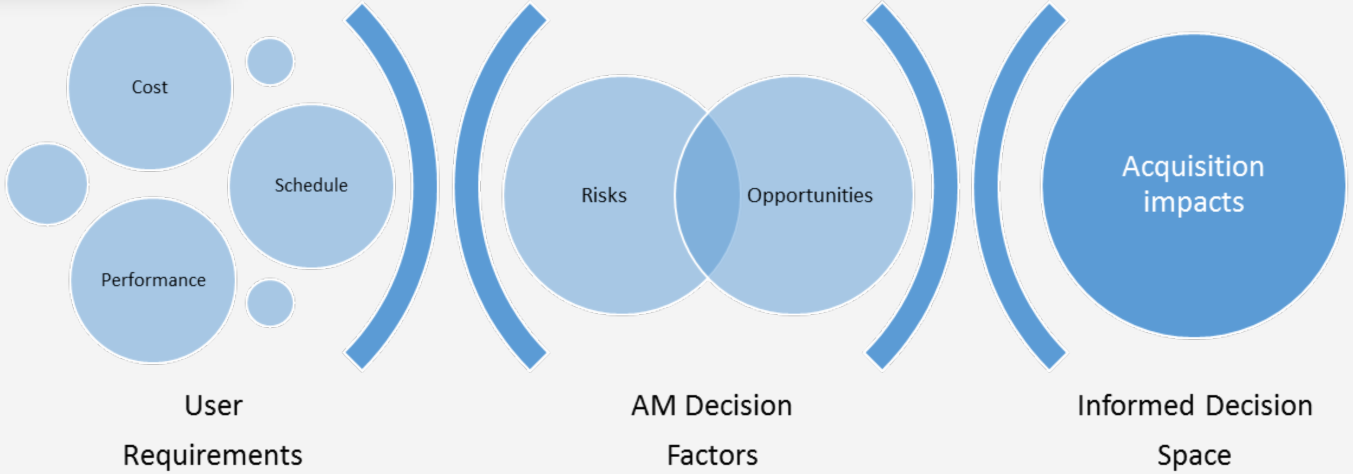
SCENARIO: AM PART PRODUCTION



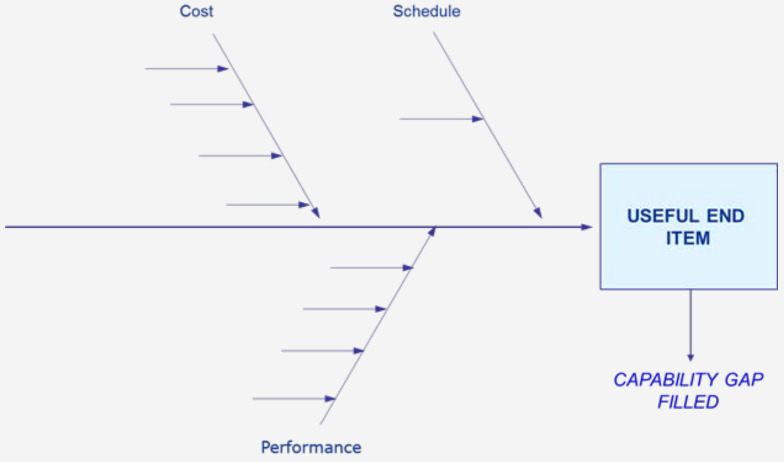
Source: University of Tennessee, Center for Hybrid Materials Using Additive Manufacturing Processes (CHAMP), Chad Duty, PhD

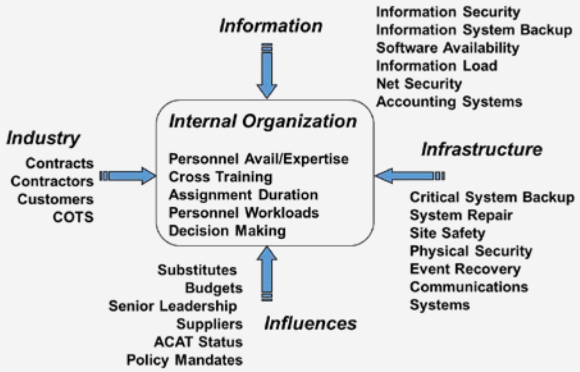
Part

Process



Tools





RISK & OPPORTUNITY HANDLING STRATEGIES

AM Risk Strategies

ID	Accept	Avoid	Control	Transfer
Skilled labor			x	
Data security				x
Shortened product life	x			

AM Opportunity Strategies

ID	Pursue	Defer	Reevaluate	Reject
Reduce suppliers				x
Minimize raw materials		x		
Reduce weight	x			

Source: DoD RIO Guide (https://www.acq.osd.mil/se/pg/guidance.html)

ACQUISITION IMPACTS

AM attributes compared to traditional manufacturing	Impact on product offerings	Impact on supply chains
Manufacturing of complex-design products	●	◕
New products that break existing design and manufacturing limitations	●	◕
Customization to customer requirements	●	◕
Ease and flexibility of design iteration	◕	◑
Parts simplification/sub-parts reduction	◑	◑
Reduced time to market	◑	◑
Waste minimization	◑	◑
Weight reduction	◑	◔
Production near/at point of use	◑	●
On-demand manufacturing	◔	●

Potential impact	Very high	High	Medium	Low
	●	◕	◑	◔

Source: Deloitte University Press | dupress.com

PROCESS SUMMARY

Part

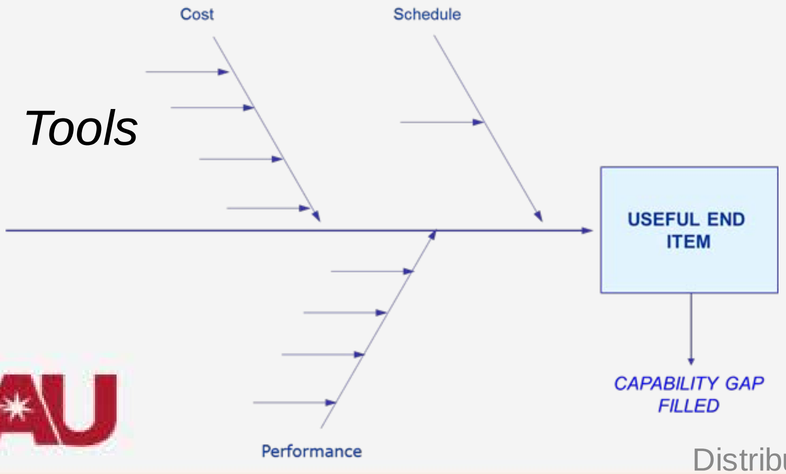
Process

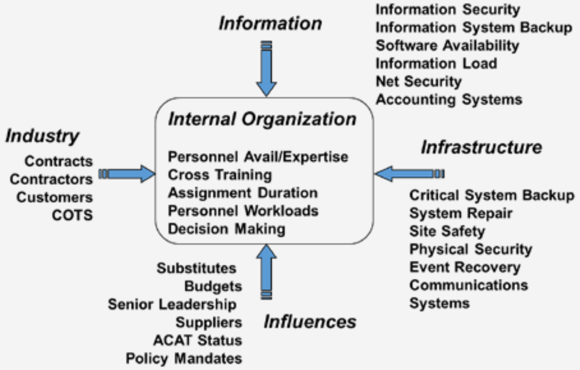
User Requirements

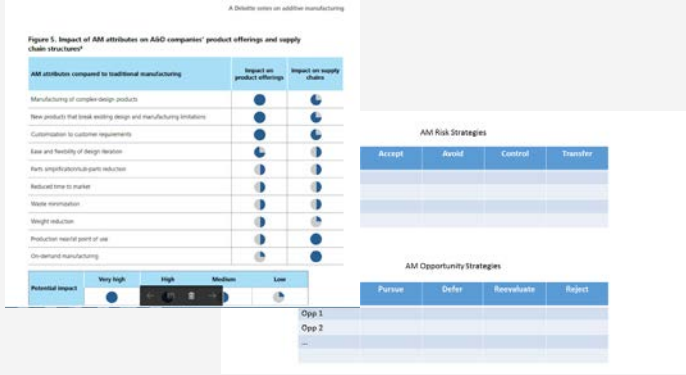
AM Decision Factors

Informed Decision Space

Tools







RELIABILITY GROWTH PROCESS

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.

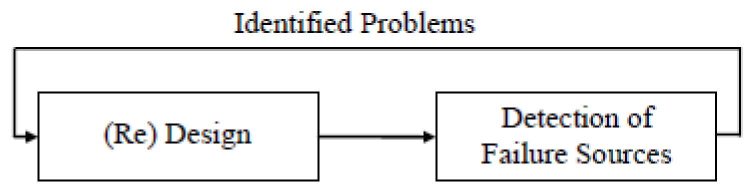


FIGURE 1. Reliability Growth Feedback Model.

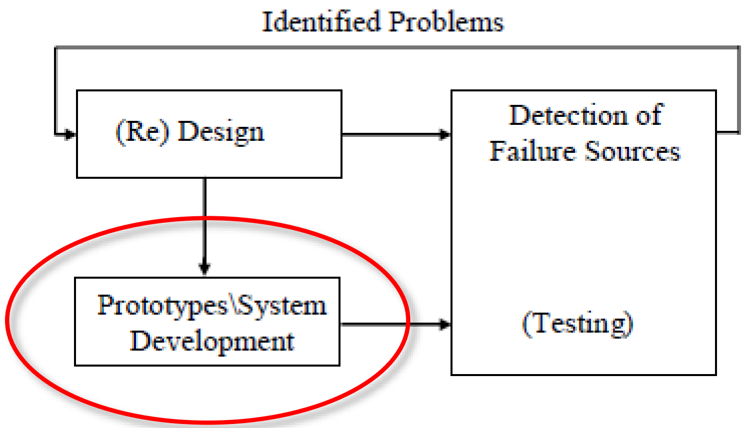


FIGURE 2. Reliability Growth Feedback Model

Source: MIL-HDBK-189C, June 2011 and revalidated effective 18 March 2016.

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

Vat photopolymerization
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)

Material jetting
A print head 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)

Material extrusion
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)

Powder bed fusion
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)

Binder jetting
Particles of material are selectively joined together using a liquid binding agent (e.g., glue). Inks 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 (PBIH), plaster-based 3D printing (PP)

Sheet lamination
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)

Directed energy deposition
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)

Sources: Deloitte analysis; ASTM International, Standard terminology for additive manufacturing technologies, designation F2792 – 12a, 2013, p. 2

Defense AT&L: November-December 2016

Figure 1. Additive manufacturing (AM) process flow

Graphic: Deloitte University Press | DUPress.com

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).

Source: http://www.ifm.eng.cam.ac.uk/research/dstools/cost-benefit-risk-analysis/

ADDITIVE MANUFACTURING WORKFLOW LEARNING FRAMEWORK

PORTFOLIO

AM Learning Solutions

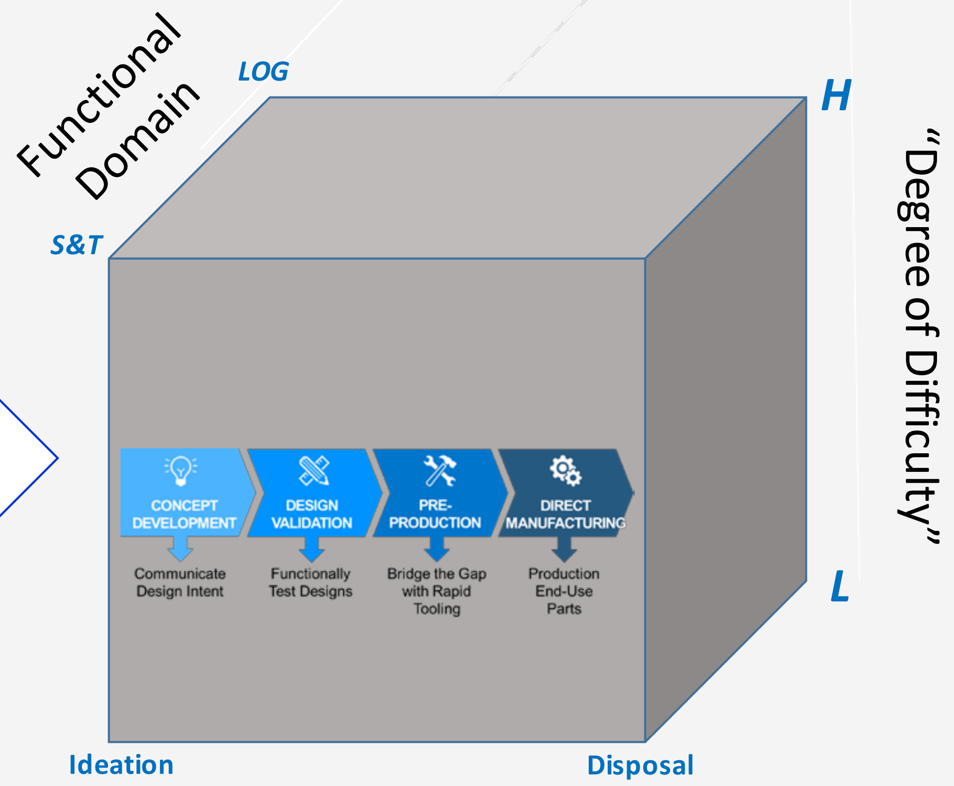
DECISION SUPPORT TOOLKIT

ABC

MULTI-MEDIA COMMUNITY OF PRACTICE

Informs AM application

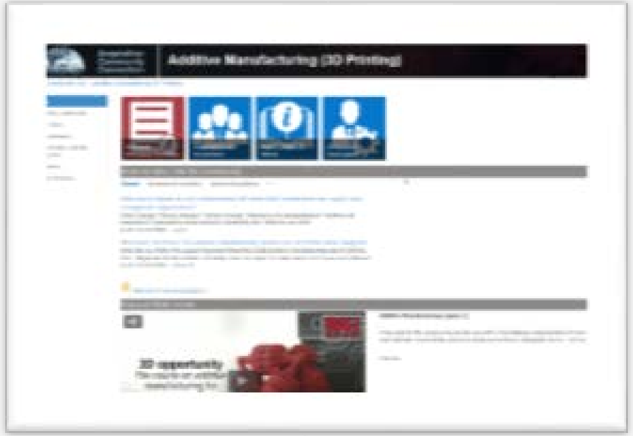
APPLICATION MODEL



Lifecycle phase/event

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*** https://www.dau.mil/cop/am/Pages/Default.aspx [Bottom of web page]
- **Special AM-focused Defense AT&L Magazine at** https://www.dau.mil/library/defense-atl/p/Defense-ATandL---November-December_2016