CRITICAL THINKING.
SOLUTIONS DELIVERED.

Implementing Additive Manufacturing Technology into the Logistics Supply Chain

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Topics

- Introduction
- Logistics Supply Chains
- Future Logistics Supply Chains
- Additive Manufacturing – An Enabler
- Cost Drivers in the Supply Chain
- Future Research
- Summary and Conclusion

This single piece product has a weight reduction of 70% over the legacy-manufactured 17-piece assembly that it replaced. The result is an item that significantly reduces failure rate with a conservative estimate of 240% reliability improvement.

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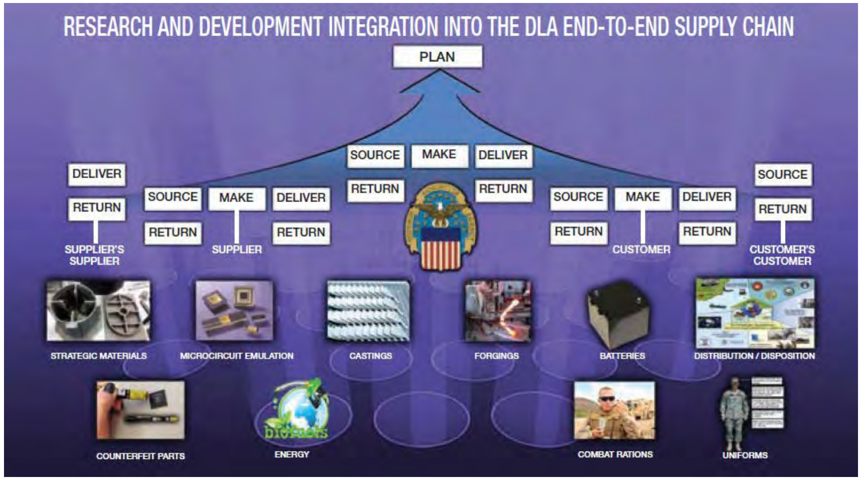
U.S. Military Aircraft Readiness	Flyable Aircraft Out of Aircraft Available to Units*
Marine Corps F/A-18s (A-D)	42%
Navy F/A-18s (A-D and E/F	52%
Air Force Strike Fighters (A-10, F-15C-F, F-16C-D, F-22A, F-35A)	71%

The military has struggled for years to maintain combat ready aircraft, a challenge driven by deep sequestration cuts and poor budget planning within the current LSC Framework

Source: AWST 2/16/2017 "The Hollow U.S. Fighter Force: Only A Fraction Can Fly"

Introduction



Source: DLA Loglines, May-June 2016 "DLA Research and Development – A Strategic Activity that Lives in an Operational Environment", Pg 2.

- Logistics Supply Chains exist in all organizations
- Meeting user needs is becoming difficult
  - Diminishing Manufacturing Sources and Material Shortages (DMSMS)
  - Forecasting uncertainty
- AM as an enabler
  - Increases availability
  - Helps solve DMSMS issues

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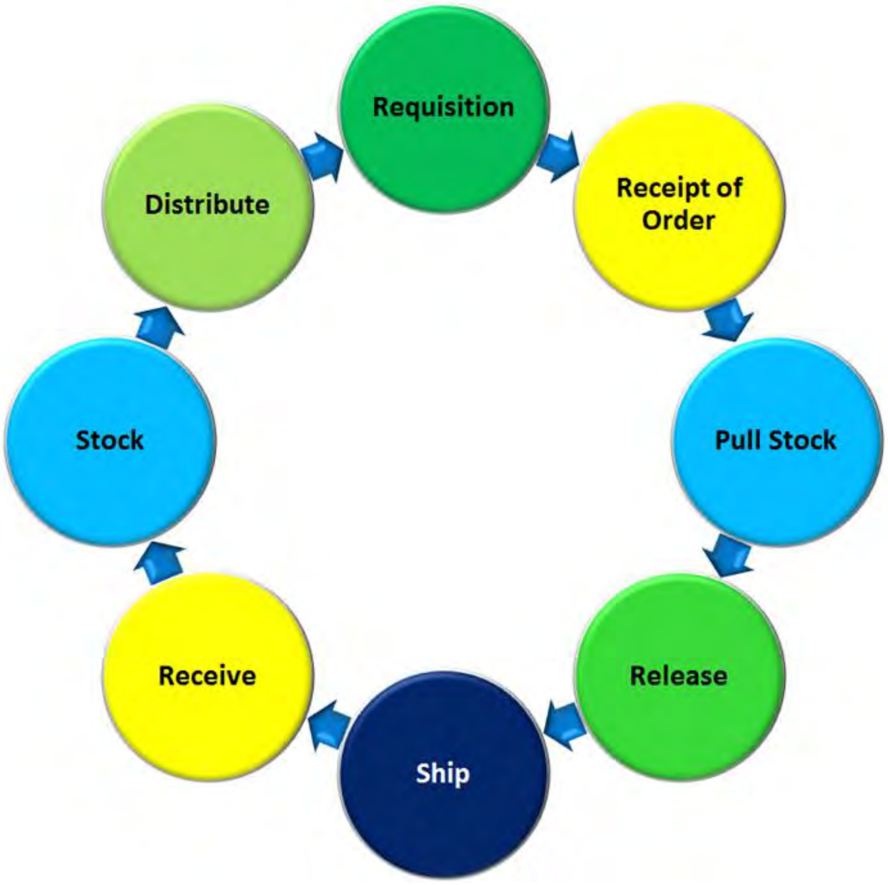
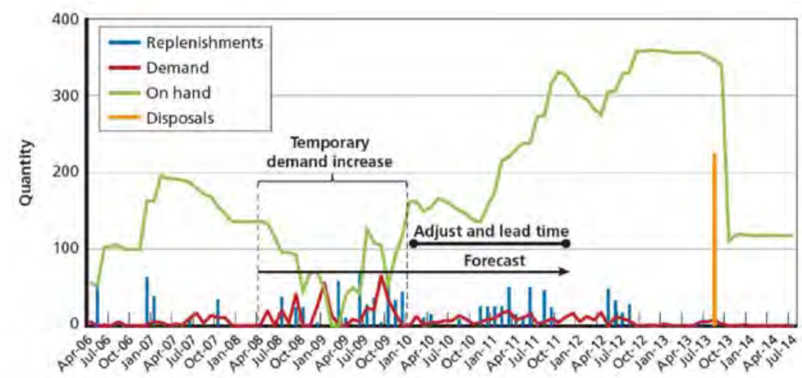


Logistics Supply Chains (LSCs)

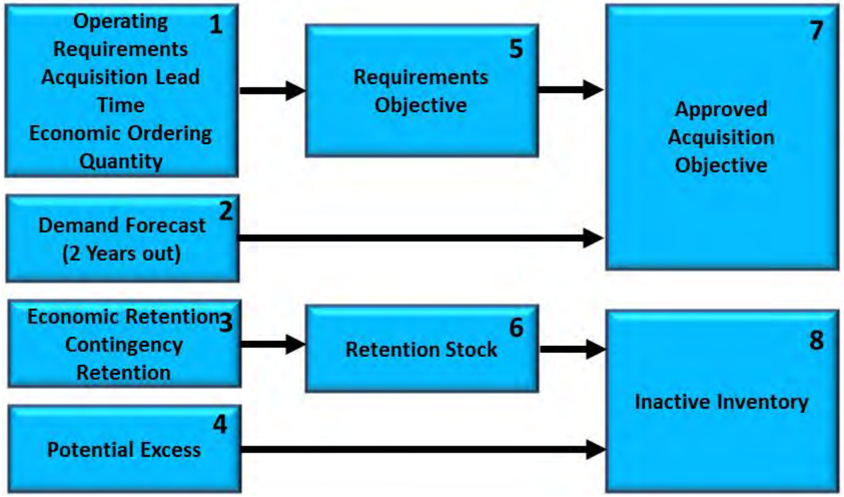
- Defense Logistics Agency (DLA)
  - Tag Line - "The Right Solution – On Time, Every Time."
  - Has over 5.2 million line items
  - Serves all services
  - In 2017 had $35B in sales
  - Has a large complex footprint worldwide
- A&D LSCs have similar structures

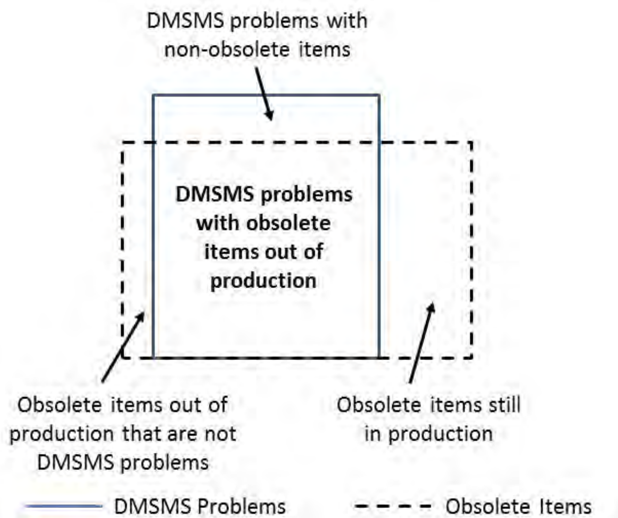


Weapon System	Weight (Tons)	Repair Parts per 1000 Miles Driven (Tons)	Repair Parts/ Weapon
M1A1 Main Battle Tank	60	13	21.7%
M1A2 Bradley Fighting Vehicle	32	1	3.1%
FCS (Forecast before Canceled)	20	2	10.0%

Logistics Supply Chains (cont.)

- Issues and Shortcomings
  - Demand Forecasting
  - Parts Shortages
  - Obsolete Parts
  - Counterfeit Parts
  - Diminishing Manufacturing Sources and Material Shortages
- Impacts
  - Warfighter availability
  - Excess inventory





Source: DLA SD22 Diminishing Manufacturing Sources and Material Shortages (DMSMS) Best Practices, January 2016

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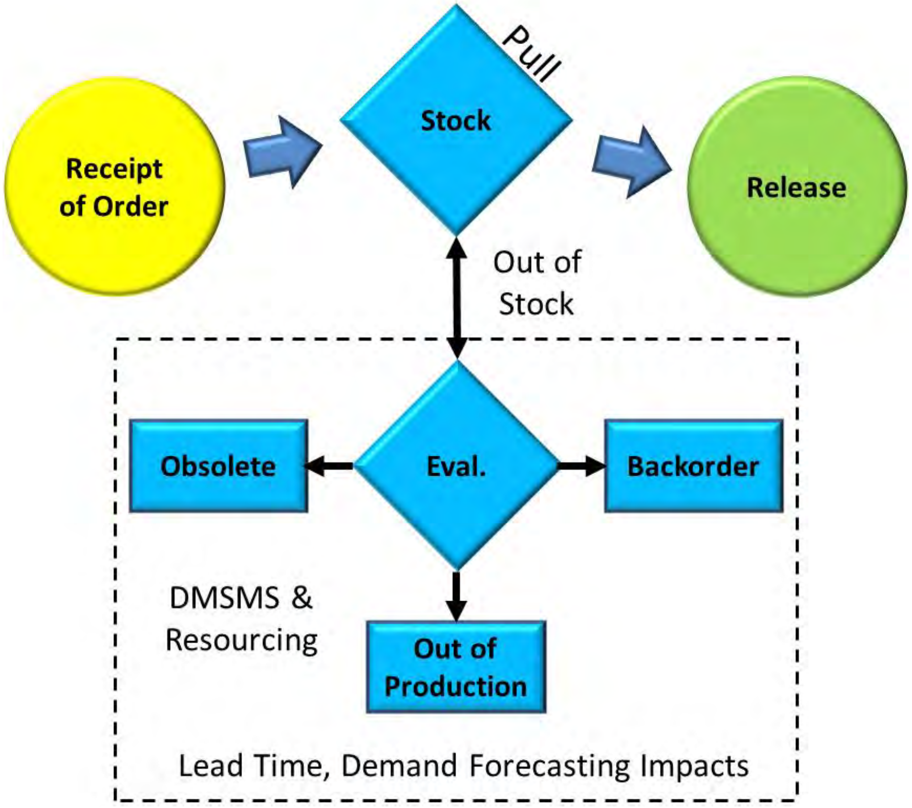

Future LSCs

- Factory of the Future (FoF)
  - Vertical integration
  - Just in time Delivery
- Integrated optimized framework
- Standards
- Enhanced Economic Ordering Quantity (EOQ) model

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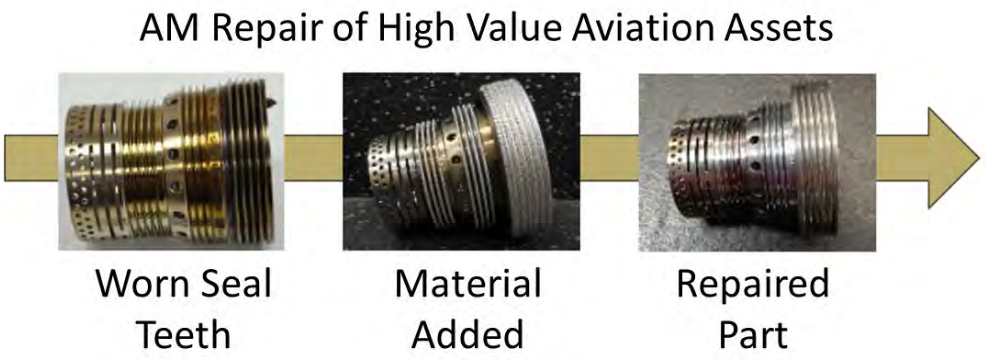


High value components, those that fall under DMSMS or have long lead times are being repaired using AM. The figure above shows a worn and AM repaired seal. The result is increased system readiness and future LSC resiliency.

Additive Manufacturing

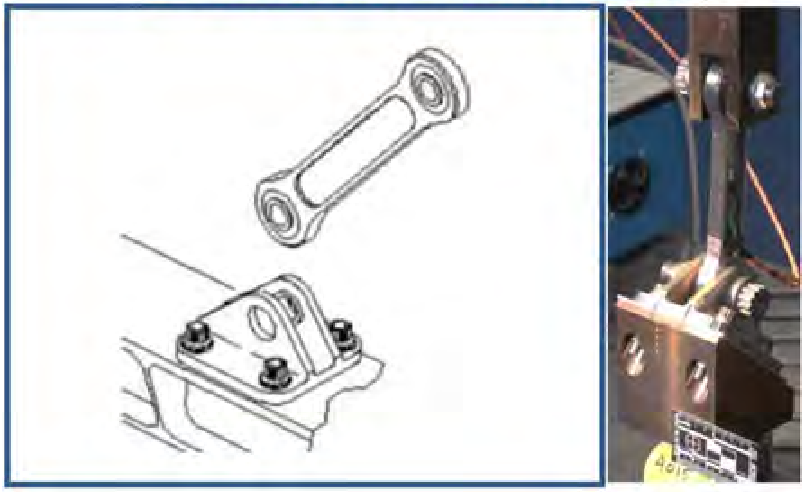
	AM Attributes compared to traditional manufacturing	Impact on product offerings	Impact on Logistics Supply Chains
1	Manufacturing of complex-design products	Very High	High
2	New products, break existing design and mfg limitations	Very High	High
3	Customization to customer requirements	Very High	High
4	Ease and flexibility of design iteration	High	Med
5	Part simplifications/sub-parts reduction	Med	Med
6	Reduced time to market	Med	Med
7	Waste minimization	Med	Med
8	Weight reduction	Med	Low
9	Production near/at point of use	Med	Very High
10	On-demand manufacturing	Low	Very High

Key:	Very High	High	Med	Low
	●	◉	◎	○

- **Innovation** – Novel geometries, tailored material properties
- **Part consolidation** – Fewer, more complex parts
- **Lower energy consumption** – Save energy with fewer production steps
- **Less waste** – Layer by layer no "hog outs"
- **Reduced time to market** – Fabricated when design is complete
- **Lightweighting** – Same function with less material
- **Agility of manufacturing operations** – Less tooling, Mfg. co-located

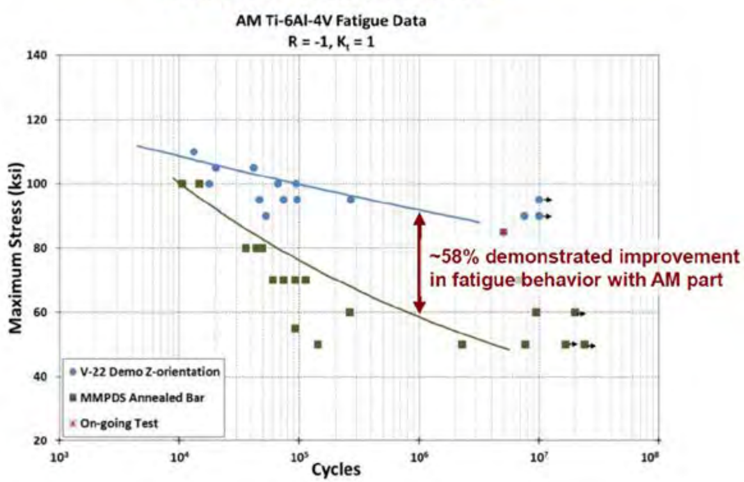
Additive Manufacturing (cont.)

V-22 Nacelle Link and Fitting



Fatigue: AM Versus Wrought Bar

Fatigue behavior exceeds that of bar



- Safety critical component
  - Lighter
  - 58% improved fatigue resistance
  - Qualified for Life
- Eliminates backlog
- Enhances system availability

Additive Manufacturing (cont.)

- AM Maturity plan
  - Integration of AM into LSC
  - Quality and certification of AM
  - Digital AM Framework
  - Integrated Digital Grid
  - AM Education and Training


National Aeronautics and Space Administration

MSFC-STD-xxxx
REVISION: DRAFT 1
EFFECTIVE DATE: Not Released

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

Engineering and Quality Standard for Additively Manufactured Spaceflight Hardware

DRAFT 1 – JULY 7, 2015

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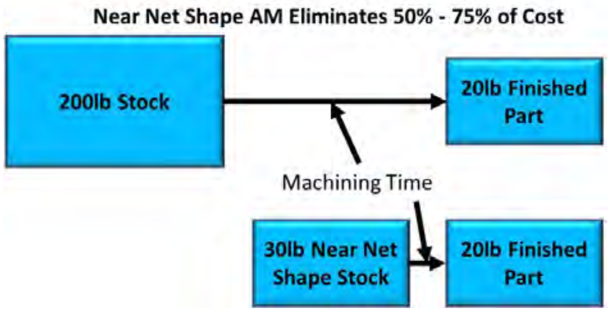
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE



- AM augmented with "near net shape" parts
  - Minimizes fab time
  - Saves energy
  - Eliminates backlogs
  - Saves cost

Source: AWST, 1/11/2017 – "Airbus To 3D Print Airframe Structures"

Near net shape titanium helps optimize AM in the manufacturing environment

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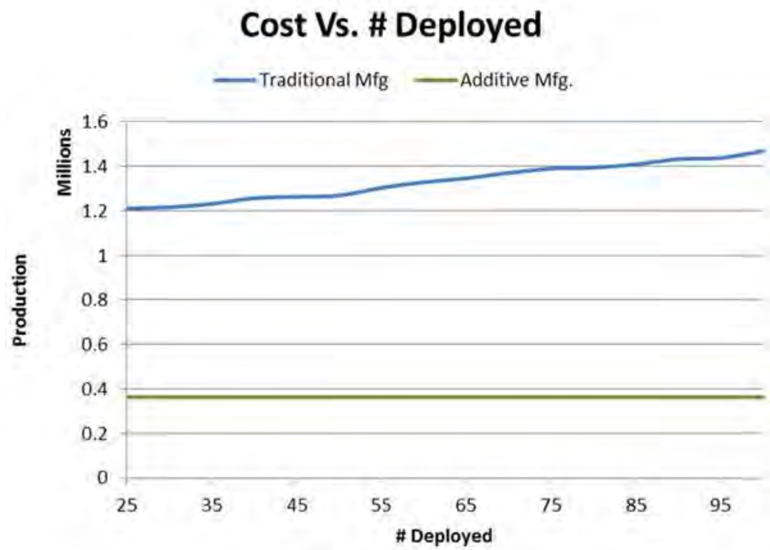
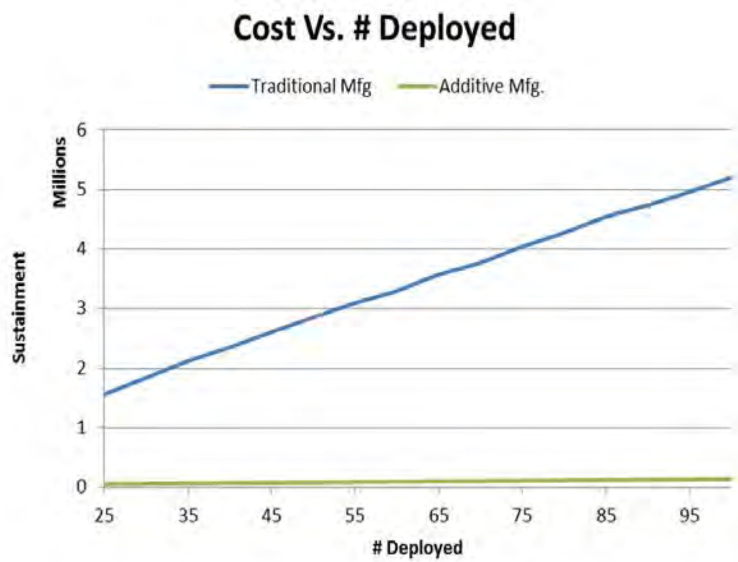
Strategic Vision for Future AM Engines

Typical Engine Developments	Prototype Additive Engine
DDT&E Time	
7-10 years	2-4 Years
HW Lead Time	
3-6 Years	6 Months
Prototype Costs	
$20-50 Million	$3-5 Million

Cost Drivers in the Supply Chain

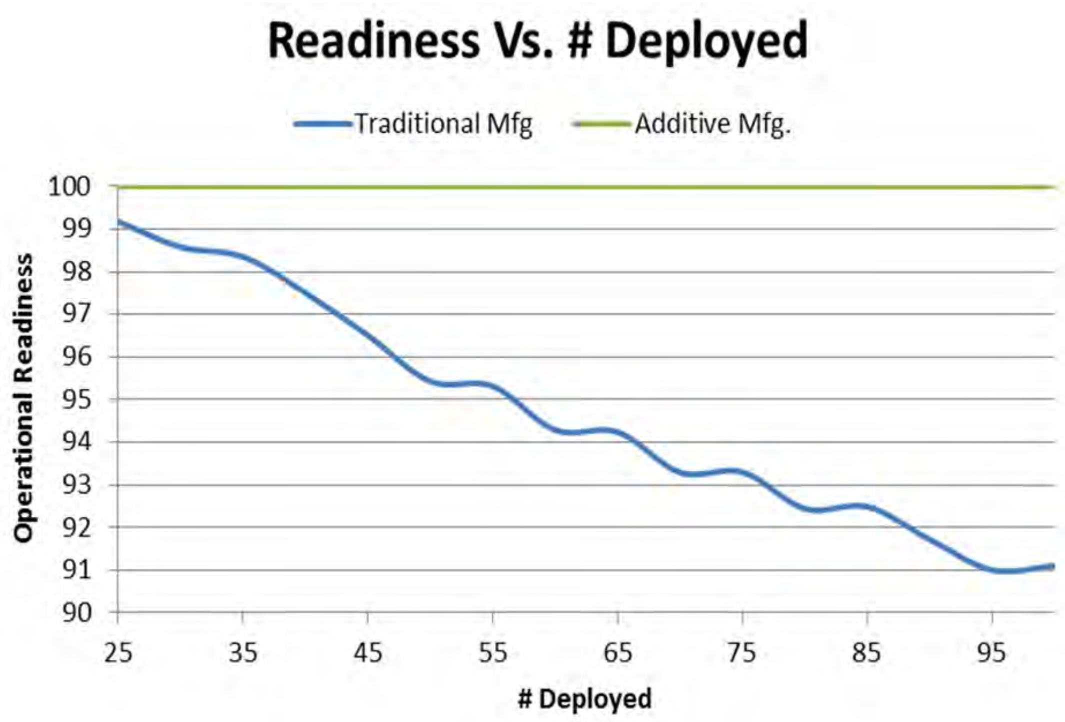




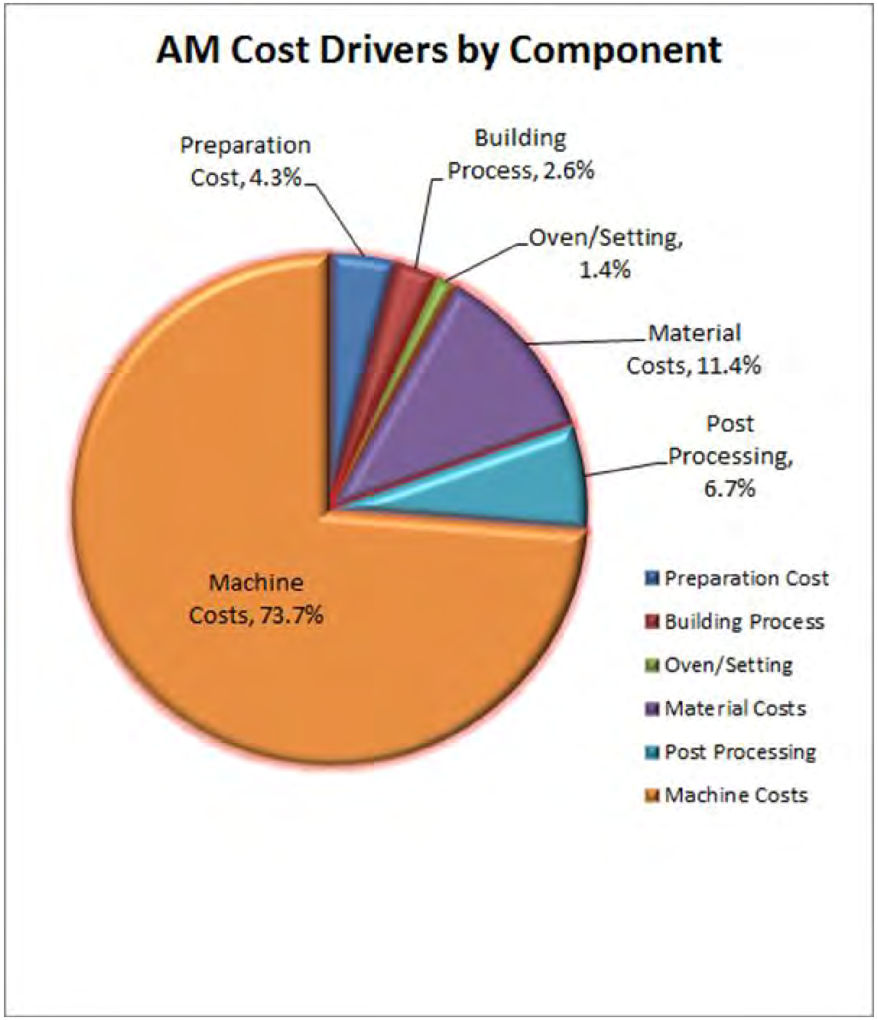
- AM potential production cost savings of 3:1 over conventional techniques
- AM can realize even more in the sustainment phase

Cost Drivers in the Supply Chain (cont.)

- AM supports virtually 100% readiness in weapon systems
  - Make on site
  - Minimal footprint
  - Capitalized costs minimized



Cost Drivers in the Supply Chain (cont.)



- Top three AM cost drivers
  - Machine cost
  - Material
  - Post Processing
- Traditional Manufacturing
  - Processing
  - Material
  - Post Processing

Source: Lindeman, et al, "Analyzing Product Lifecycle Costs for a Better Understanding of Cost Drivers in Additive Manufacturing", 2012

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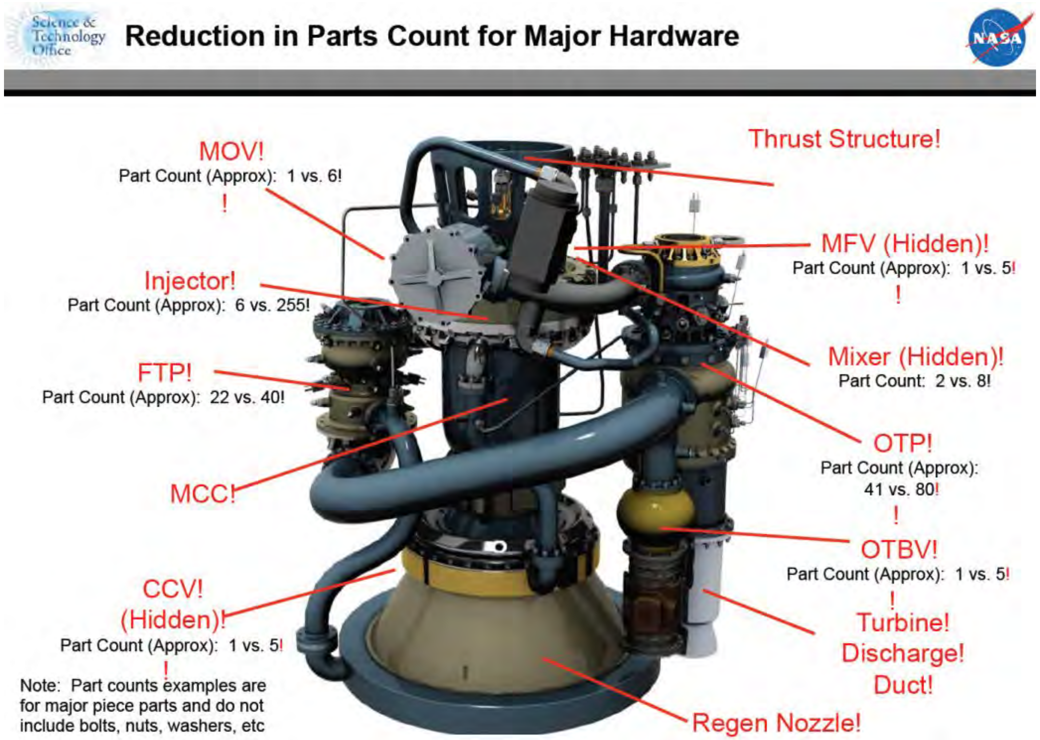

NASA's Science and Technology Office shows future parts count reduction using AM

Future Research

A Dutch startup is using 3D printing to produce a large, complex structure to build a bridge made of printed steel

Source: DHL, 3D Printing and the Future of Supply Chains, Nov 2016, Pg 15.

- Assess standardization
- Address scalability limitations
- Monitor economic benefits
- Evaluate actual lead times with AM
- Engage in FoF and vertical integration
- Monitor disposal cost trends as AM is integrated in the LSC

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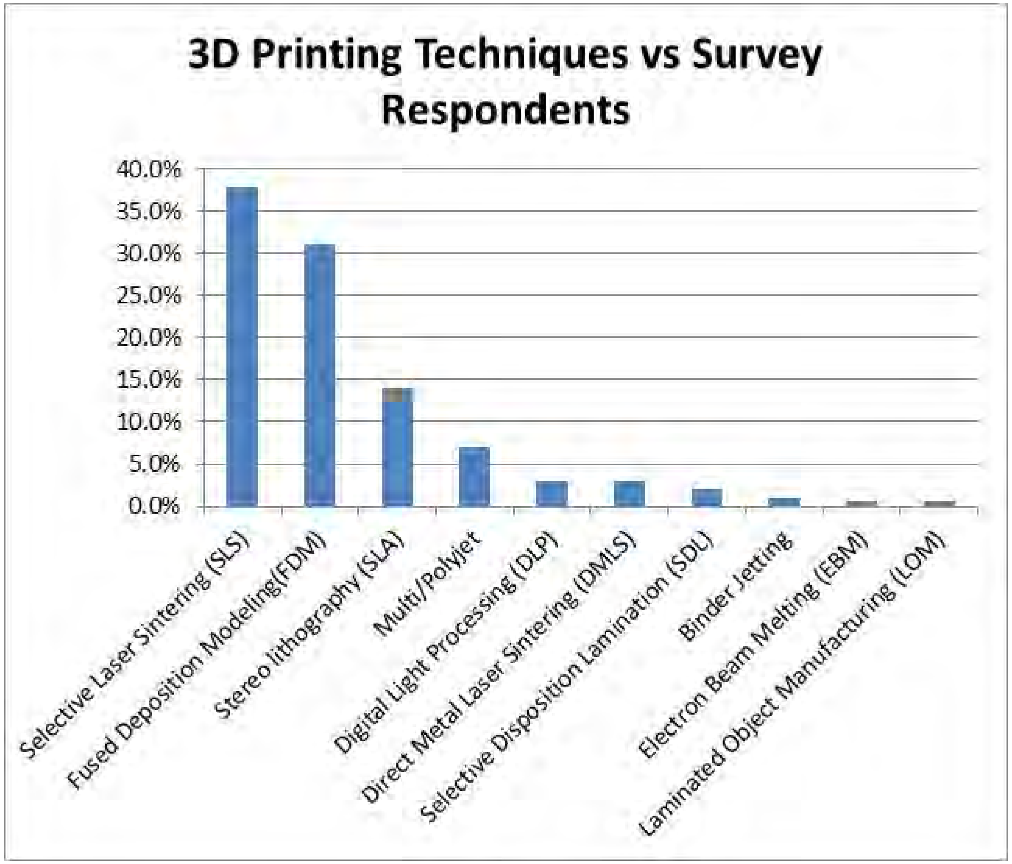
Method	Respondents
Selective Laser Sintering (SLS)	38.0%
Fused Deposition Modeling(FDM)	31.0%
Stereo lithography (SLA)	14.0%
Multi/Polyjet	7.0%
Digital Light Processing (DLP)	3.0%
Direct Metal Laser Sintering (DMLS)	3.0%
Selective Disposition Lamination (SDL)	2.0%
Binder Jetting	1.0%
Electron Beam Melting (EBM)	0.5%
Laminated Object Manufacturing (LOM)	0.5%
Total	100.0%



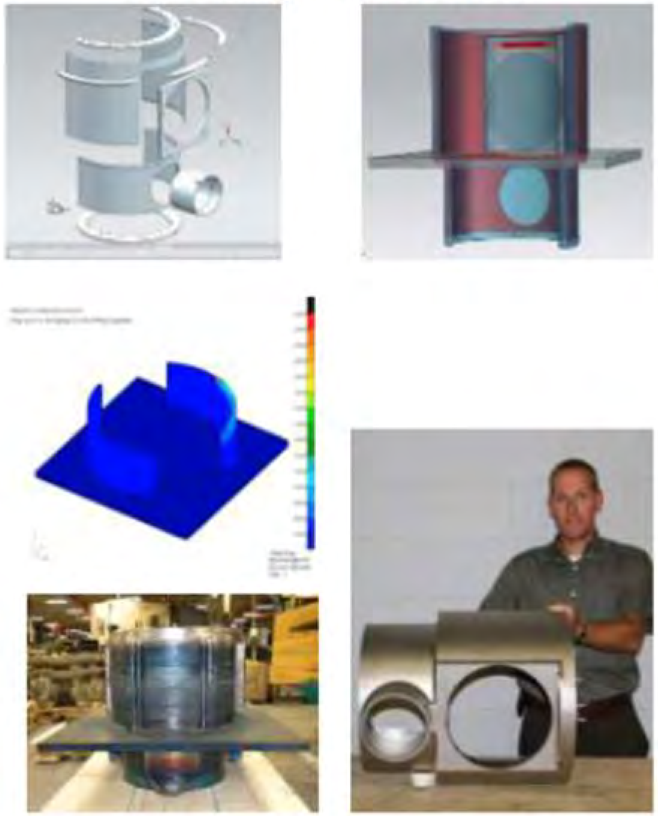
Top 3D printing Technologies for next generation logistics supply chains

Source: DHL, 3D Printing and the Future of Supply Chains, Nov 2016, Pg 6.

Summary and Conclusions

- Economists have labeled additive manufacturing the third industrial revolution.
- These advances have brought additive manufacturing to a turning point.
- In the near future, 3D printing could make massive changes to manufacturing processes and logistics functions:
  - **Global Logistics:** International logistics cost growth will drive MFG facilities back to the USA.
  - **Inventory Levels:** AM finds its main value in creating customer-specific, complex items. Products are made only when ordered leading to falling warehouse inventory.
  - **Fulfillment:** Made-to-order parts changes the entire manufacturer-wholesaler-retailer relationship will change. Since retailers do not need to keep stock of their own, orders can be fulfilled directly through the manufacturer.
  - **Stock Location:** 3D printers allow parts for machinery, cars or medical equipment that are produced in a short time resulting in cost savings and elimination of warehouses and stock locations.
  - **Transportation Routes:** 3D printers, when situated close to end users or strategic markets, reduce transport costs and minimize supply chain length
  - **Consumer Relationships:** Consumer relations will evolve with more personalization. Customers owning 3D printers will print at home, help meet demand and reduce the cost of doing business.

AM Demonstration for Producing Titanium Rotor



Images courtesy of CIMP-3D and General Dynamics Land Systems

Source: http://info.plslogistics.com/blog/6-effects-3d-printing-has-on-supply-chains

Questions?

Thank You