Acquisition Research Program:
Creating Synergy for Informed Change

Shrinking the “Mountain of Metal”: The Potential of Three Advanced Technologies

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A DoD Operations Challenge

- A "mountain of metal" remains in theatre after military operations.
- Costs of traditional means for repairing much of the mountain to operable condition often exceeds its value.
- Potentially valuable equipment is left unavailable to US military forces or partners to which the equipment might be donated.

Q.: How can more of the "mountain of metal" be made operational?

Q.: How can the added cost and effort of increasing the value of the mountain be justified?

Problem Description

Five processes by which materiel from contingent operations should be disposed of (DOD Supply Chain Materiel Management Policy, 2011):

- Consume in theater
- **Reutilize** within DoD and other U.S. entities
- **Retrograde** (return to US depots) to **reset** (restore to full capability) U.S. forces
- Transfer or donate to allies or partner nations
- Turn-in to DLA Disposition Services

Problem Description

- Required replacement ***parts*** are low volume and diverse (no efficient warehousing)
- Required repair ***tools*** are low volume and diverse (often not available near damaged equipment)
- Required repair ***knowledge*** held by specialists often not in theatre
- Traditional repair materiel are far away (high transport costs)

Repair-For-Reuse
A Potential Solution

- Apply existing advanced technologies to facilitate in-theatre design, manufacture, and implementation of repair solutions.

- **Three Technologies with Potential:**
  - 3D Laser Scanning
  - Collaborative Product Lifecycle Management
  - Additive Manufacturing (3D Printing)

Technology 1

3D Laser Scanning

- Laser scans space from highly articulated mount, often combined with 360^{o} camera
- Software processes the “point cloud” into 3D image of the object or space.
- 3D image processed into CADD format for use in design and manufacturing.
- Currently used in automotive, offshore construction and repair, civil and transportation, building construction, fossil fuel and nuclear power plants

3D Laser Scanning

An Example

<u>Challenge</u>: Cement kiln inlet repair

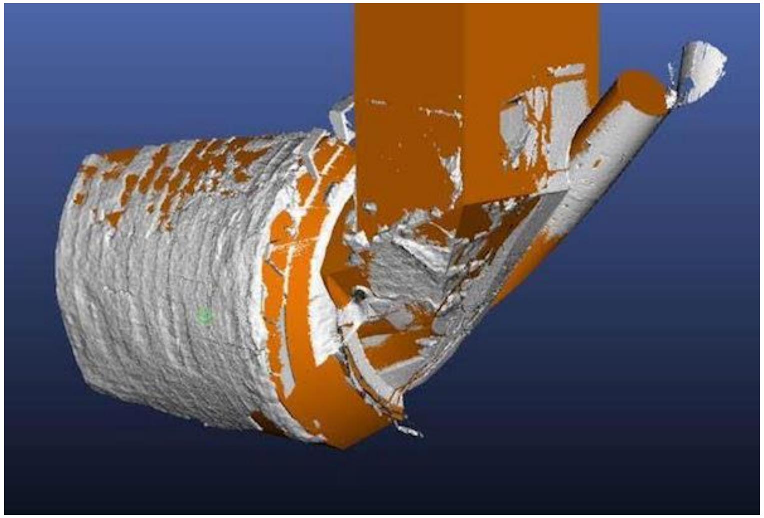
- Client needed quick, very accurate, and complete data
- Traditional methods too time consuming
- Traditional methods possibly inaccurate.

<u>Solution:</u> 3D scanning

- Captured all required information in just a couple hours.
- Data was processed on-site and confirmed

<u>Deliverables</u>:

- Point cloud to create a model (e.g. for manufacturing)



Point Cloud and Model overlaid and used to calculate volume and flow and to pre-fabricate new parts for the cement kiln

TruePoint: http://truepointscanning.com/Case_Studies/Laser-Scanning-Cement-Kiln.html

Technology 2

Collaborative Product Lifecycle Management

- To “integrate people, processes, and information”
- Electronically integrates design documents, data bases, 3D LST, etc., for participant collaboration across physical distances & time.
- Common, shared sets of documents improves access, collaboration, coordination, communication
- Common platform for program change management
- Basis for asset management during operations

Technology 3:
Additive Manufacturing (3D Printing)

- 3D design/image (e.g. from 3D LS) of final part. Create net that describes surfaces.
- Geometric slicing of image into horizontal layers for manufacturing
- Incrementally add small amounts of material in very thin layers of material to build-up part
- Variety of possible materials (plastic, titanium) & methods (e.g. for material bonding)
- Very complex parts possible. Little waste.
- No dominant method, materials, suppliers

Research Questions

Q.: How might 3DLST, PLM, and AM evolve across time and facilities based on their proximity to combat operations?

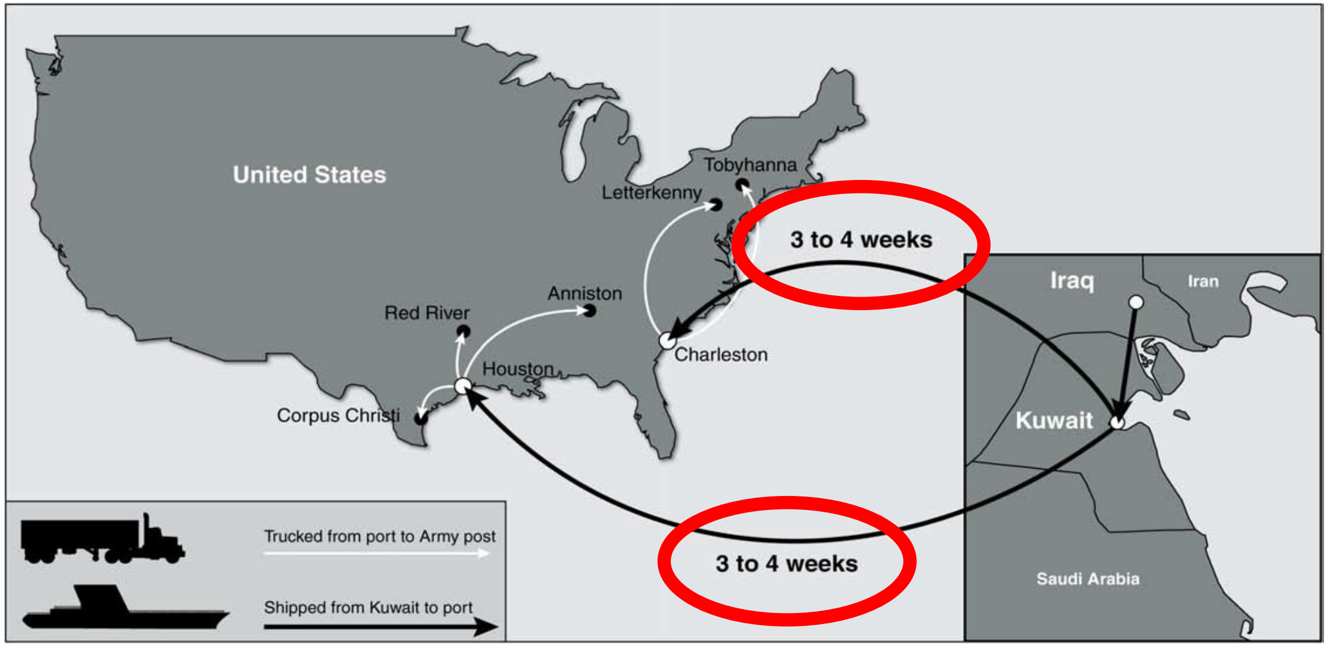
Q.: What scale of savings are possible through the adoption and use of 3DLST, PLM, and AM in a repair-for-reuse approach?

Research Plan

- **Literature review:** Current disposal methods, types of materials, complexities that the technologies can address, relative costs.
- **Develop repair-for-reuse scenarios:** Forecasts of evolution of each technology.
- **Repair-For-Reuse Evolution Map:** Applications across time (now, a near-term, long-term) and across repair sites (e.g. FOB, MOB, home depot).
- **Estimate costs and savings:** KVA to estimate relative costs. Estimate cost savings.
- **Conclusions and Recommendations**

A) Traditional Process

Retrograde to US to Reset

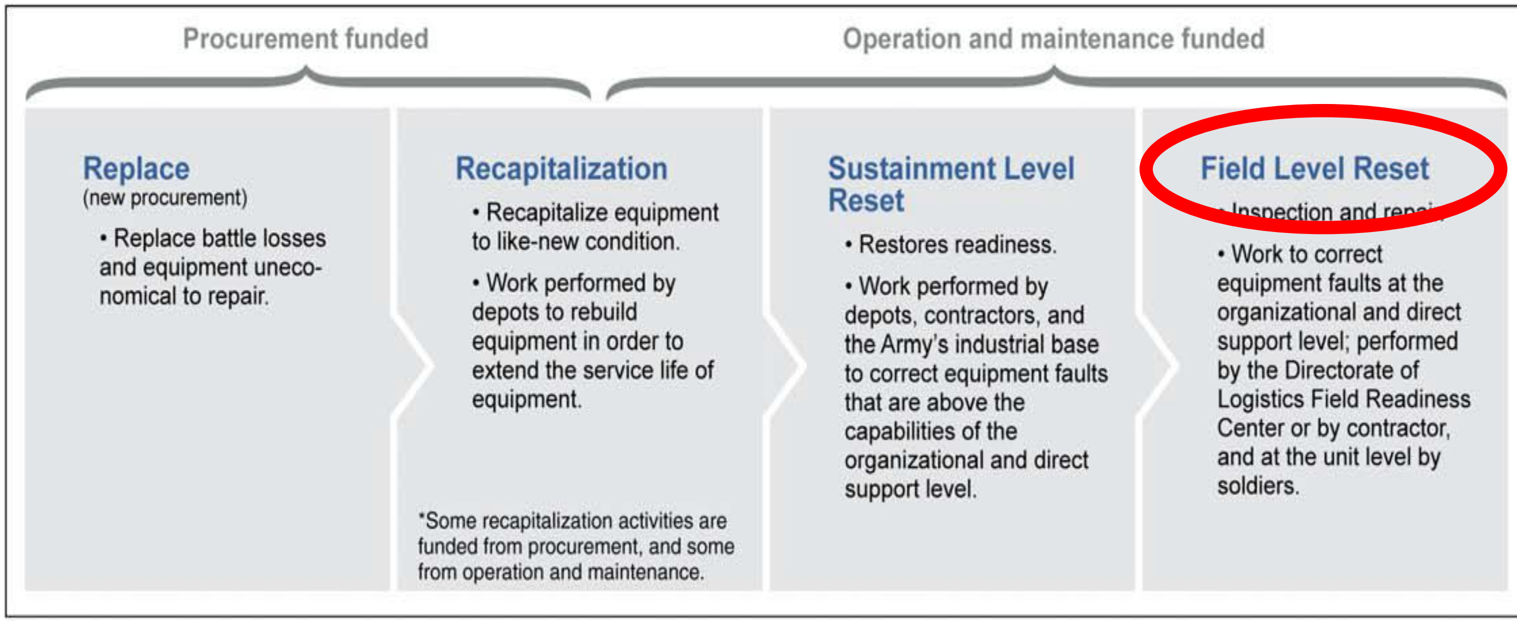


Source: GAO analysis of DOD data.

Equipment stays with units – typical 1 year cycle, ≈100% returned to US for repair

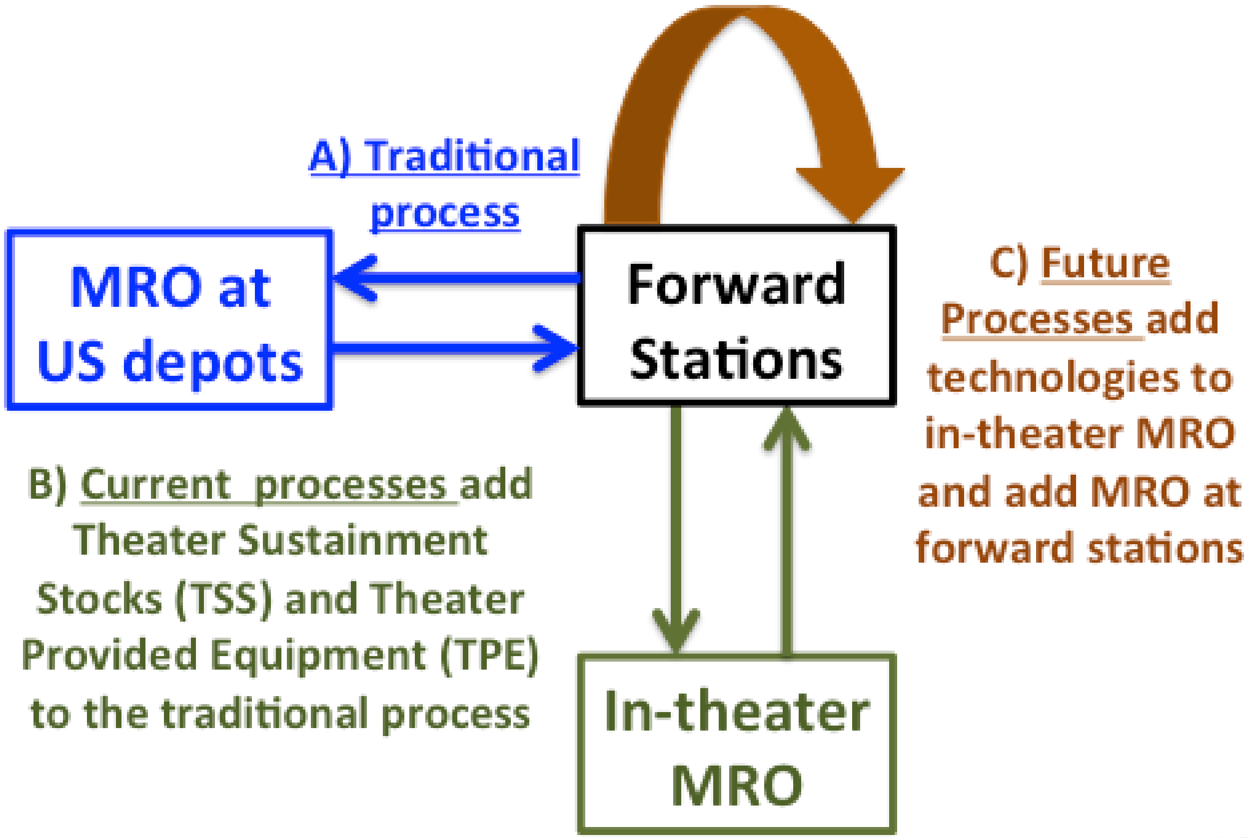
B) Current Process

Theater Sustainment Stocks and Theater Provided Equipment



Source: GAO analysis of DOD data.

Modeling the Shrinking of the Mountain



- Modeled the Army's Up-Armor HMMWV fleet as a case study

Technology Application Evolution Forecasts: Current Processes

Current Applications		Innovative Technology: 3D Scanning Technology (3DST)	Additive Manufacturing (AM)	Product Lifecycle Management (PLM)
Location	US depot	-Limited use for basic parts	-Limited use for basic parts with few materials -Test broader application of basic AM	-Parts and component data storage & sharing -Component life tracking -Inventory analysis
	In-Theater	-None or experimental	-Limited use with basic materials	-Limited use
	Forward station	-None	-None	-None

Current Maintenance Repair Overhaul (MRO) Applications of Three Advanced Technologies

Technology Application Evolution Forecasts: Near Future (5-10 years)Processes

- Literature-based forecasts of 3 technology's evolutions

Location: Near-Future Applications	Innovative Technology: 3D Scanning Technology (3DST)	Innovative Technology: Additive Manufacturing (AM)	Innovative Technology: Product Lifecycle Management (PLM)
US depot	-3DST for AM of basic parts replacement is SOP -Test integrated & automated 3DST & AM	-AM for basic parts with basic materials is SOP -Test AM with multi-materials -Test integrated & automated 3DST & AM -Test AM of integrated components	-Automated inventory management is SOP -Test conditional MRO management -Test communication & integration across processes -Test automation across processes -Test providing MRO knowledge & skills with parts
In-Theater	-Damage assessment at micro & nano scales is SOP -Test portable 3DST applications -Test integrated & automated 3DST & AM	-Portable AM is SOP -Test very portable AM -Test integrated & automated 3DST & AM -Test integrated AM & traditional processes	-Test integrated diagnosis & MRO -Test MRO forecasting & planning based on component conditions
Forward station	-Test real time damage assessment applications -Test very portable scanning applications	-None	-Test real time user experience data collection and use in MRO

Near Future Maintenance Repair Overhaul (MRO) Applications of Three Advanced Technologies

Technology Application Evolution Forecasts: Distant Future (10+ years) Processes

		Innovative Technology		
	Distant-Future Applications	**3D Scanning Technology (3DST)**	**Additive Manufacturing (AM)**	**Product Lifecycle Management (PLM)**
Location	**US depot**	-Scanning for AM for basic parts replacement is SOP -Integrated scanning & AM manufacturing is SOP -Test fully integrated 3DST, AM, PLM	-AM for diverse parts with multi-materials is SOP -Integrated 3DST & AM is SOP -Integrated component AM is SOP -Integrated AM & traditional processes is SOP -Test 4D component design and AM -Test AM-based parts design & micro/nano AM	-Conditional MRO is SOP -Providing MRO knowledge & skills with parts is SOP -Test fully integrated and automated 3DST, AM, PLM
	In-Theater	-Integrated scanning & manufacturing is SOP -Portable scanning is SOP	-AM for diverse parts with multi-materials is SOP -Integrated & automated portable 3DST & AM is SOP	-Integrated and automated diagnosis & MRO is SOP -Providing MRO knowledge & skills with parts is SOP
	Forward station	-Very portable user scanning damage assessment is SOP -Real time damage assessment & communication to MRO	-Integrated & automated very portable 3DST & AM is SOP	-Integrated diagnosis & MRO is SOP -Providing MRO knowledge & skills with parts is SOP -Real time user experience collection and use in MRO is SOP

Distant Future Maintenance Repair Overhaul (MRO) Applications of Three Advanced Technologies

KVA Modeling Results

No.	Process	Scenario: Traditional: As-Was ROK	Traditional: As-Was ROI	Current: As-Is ROK	Current: As-Is ROI	Near Future: To-Be ROK	Near Future: To-Be ROI	Future: Radical To-Be ROK	Future: Radical To-Be ROI
1	Diagnosis at forward station	NA	NA	NA	NA	1612%	1512%	1180%	1080%
2	Repair at forward station	NA	NA	NA	NA	708%	608%	386%	286%
3	Retrograde forward station to US depot	21%	-79%	21%	-79%	15%	-85%	3%	-97%
4	Retrograde forward station to in-theater facility	NA	NA	508%	408%	364%	264%	68%	-32%
5	Diagnosis at US depot	190%	90%	195%	95%	526%	426%	NA	NA
6	Repair at US depot	211%	111%	217%	117%	433%	333%	NA	NA
7	Overhaul at US depot	51%	-49%	52%	-48%	59%	-41%	28%	-72%
8	Transport from US depot to forward station	21%	-79%	21%	-79%	15%	-85%	3%	-97%
9	Diagnosis at in-theater facility	NA	NA	195%	95%	422%	322%	1501%	1401%
10	Repair at in-theater facility	NA	NA	246%	146%	530%	430%	220%	120%
11	Overhaul at in-theater facility	NA	NA	52%	-48%	58%	-42%	28%	-72%
12	Transport in-theater facility to forward station	NA	NA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TOTAL	74%	**-26%**	96%	**-4%**	148%	**48%**	169%	**69%**

ROI = (Benefits – Costs)/Costs

KVA Modeling Results

Current (As-Is) & future (To-Be) processes save over traditional (As-Was) processes.

		--------------Scenario--------------				
		Variance from As-Was			Variance from As-Is	
No.	Process	As-Is	To-Be	Radical To-Be	To-Be	Radical To-Be
1	Diagnosis at forward station	NA	NA	NA	NA	NA
2	Repair at forward station	NA	NA	NA	NA	NA
3	Retrograde forward station to US depot	-1%	-6%	-18%	-6%	-18%
4	Retrograde forward station to in-theater	NA	NA	NA	-143%	-439%
5	Diagnosis at US depot	6%	336%	NA	331%	NA
6	Repair at US depot	6%	223%	NA	217%	NA
7	Overhaul at US depot	1%	8%	-23%	7%	-24%
8	Transport from US depot to forward	-1%	-6%	-18%	-6%	-18%
9	Diagnosis at in-theater facility	NA	NA	NA	227%	1306%
10	Repair at in-theater facility	NA	NA	NA	283%	-26%
11	Overhaul at in-theater facility	NA	NA	NA	6%	-24%
12	Transport in-theater facility to forward station	NA	NA	NA	-140%	-439%
	TOTAL	22%	74%	95%	51%	73%

Future (To-Be) processes can save significantly over current (As-Is) processes.

Forecasted Costs & Savings

Sceanrio	Cost ($Mil)	Savings vs. As-Was ($Mil)	Savings vs. As-Was (% fleet value)	Savings vs. As-Is ($Mil)	Savings vs. As-Is (% fleet value)
As-Was	$5,449.17	NA	NA	NA	NA
As-Is	$4,200.40	**$1,248.77**	**31%**	NA	NA
To-Be	$2,724.59	**$2,724.59**	**68%**	**$1,475.82**	**37%**
Radical To-Be	$2,386.03	**$3,063.14**	**76%**	**$1,814.38**	**45%**

Estimated Costs and Savings in Army's Up Armor HMMWV fleet of Four Scenarios

Based on ROI definition & value of Army Up-Armor HMMWV fleet (≈ $4.03b)

Forecasted Savings

- US Army equipment in Afghanistan: $28.4b (Banian, 2013)
- DOD materiel in Iraq: $19.3b (Cruz, 2013)
- Total estimate: $47.7b

- Distant Future scenario savings estimate: **$21.46b** (=$47.7b * 45%)

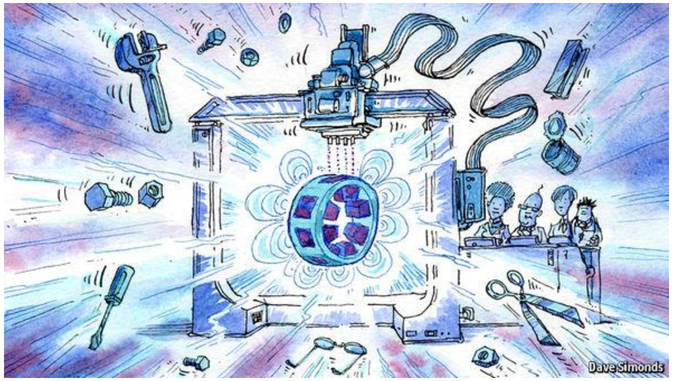
Conclusions

- **To capture very large potential savings DoD should accelerate its adoption of 3DST, AM, & PLM for maintenance, repair, and overhaul operations.**
  - Expand use in applications that have been demonstrated to provide benefits
  - Test use for a broader spectrum of applications (e.g., materials, parts types, processes)
  - Revise processes to exploit these technologies
- **Impacts on Practice**
  - More military operations support located closer & at forward stations
  - Damage diagnosis & repair faster, more accurate, & targeted.
  - MRO demands forecasted in real time based on data from embedded sensors

Questions
Comments
Discussion

3D Printing

An Advanced Example



Additive manufacturing

Magnetic moments

3D printers promise better, cheaper and more powerful magnets

The Economist, Nov. 19, 2016

http://www.economist.com/news/science-and-technology/21710233-3d-printers-promise-better-cheaper-and-more-powerful-magnets-magnetic-moments

"Unlike the simple bars and horseshoes of children's magnets, **the 3D-printed variety {of magnets} can be made in all manner of shapes. Their fields can thus be tailored into patterns far more complex than a simple north-south alignment.** These unconventional magnets have huge value in the design and performance of many products that rely on magnetic components: from hospital body-scanners to audio speakers, and from hard disks to wind turbines. In particular, **anything that involves an electric motor or a generator also uses magnets. A modern car, for instance, contains a hundred or more electric motors** of various sorts, to open and close the windows, adjust the seats, run the heating and, increasingly, to turn the wheels. All require magnets to make them work. The unconventional shapes needed to generate the complex magnetic fields they need to do their jobs properly can, though, be difficult to make."