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Networked Logistics and Additive Manufacturing

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Agenda

- Background and Motivation
- Problem Statement and Objectives
- Description of Logistical Structures
- Methodology
- Current Analysis
- Future Work

Motivation: Logistics

The raid on Camp Bastion was a bloody first for some Marine aviators

"The Marine Corps is currently not organized, trained, and equipped to meet the demands of a future operating environment characterized by complex terrain, technology proliferation, information warfare, the need to shield and exploit signatures, and an increasingly non-permissive maritime domain."

- Marine Corps Operating Concept 2016

Your Marine Corps

Taliban fighters try to storm base in Helmand province housing US Marines and Afghan forces

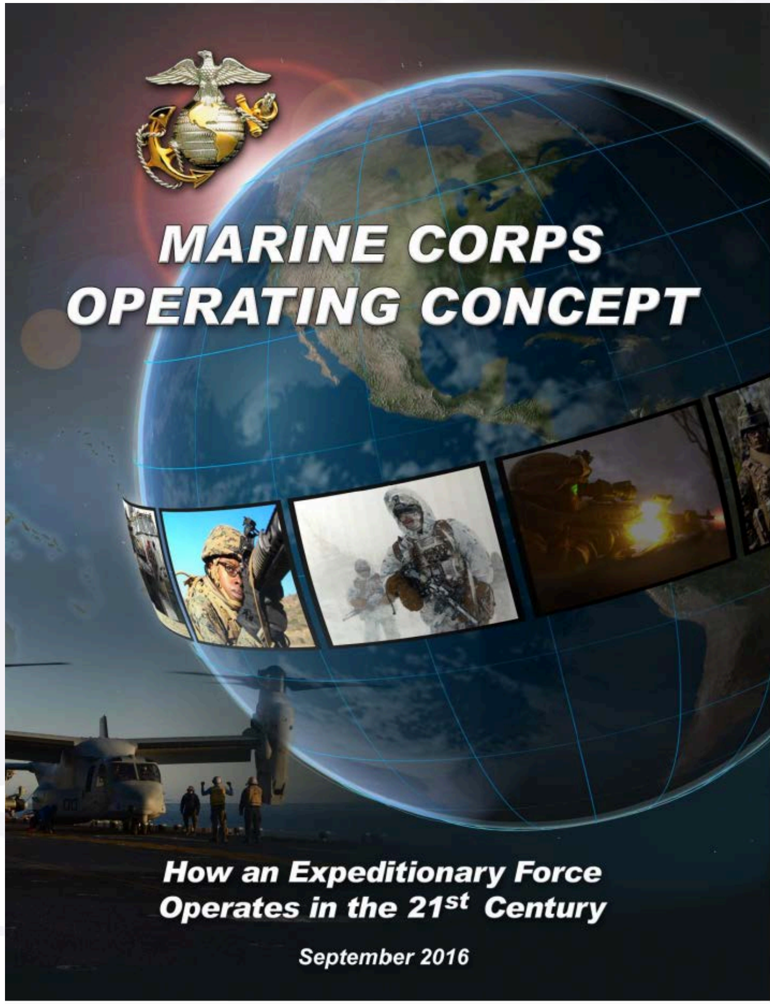
By: Shawn Snow March 1

+ 18.4K

A Marine fires a tracer round from an M240L machine gun during a night live-fire range at Camp Shorabak, Afghanistan, June 25 2017. (Sgt. Lucas Hopkins/Marine Corps)

Early Friday morning Taliban fighters attempted to storm a major Afghan military base in southern Afghanistan that houses Afghan forces and U.S. Marine advisers, according to military officials.

U.S. forces assisted Afghan troops in beating back the Taliban assault with air support, according to Resolute Support.



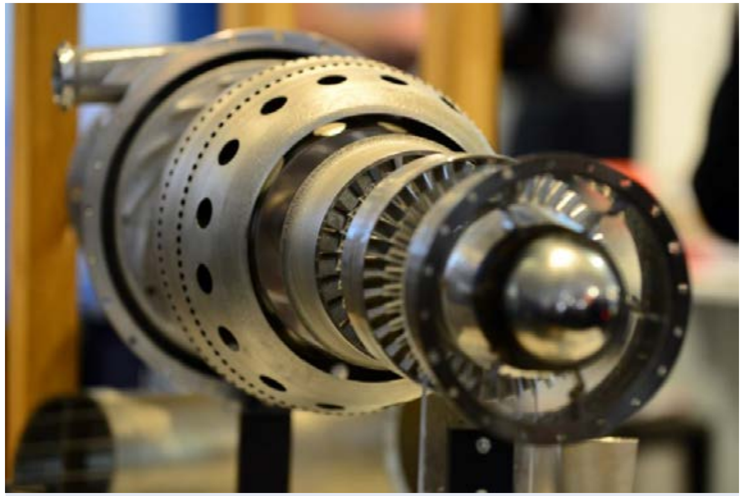
Motivation: Additive Manufacturing

New AM techniques offer promise

Potential transformational (vs incremental) change to logistics systems

The ExMan on the outside and inside.

Source: Zelinksi (2019) https://www.additivemanufacturing.media/blog/post/metal-3d-printing-in-a-machine-shop-ask-the-marines



3D Printed Jet Engine.

Source: Shumer (2015) https://www.abc.net.au/news/2015-02-25/3d-printed-engine.jpg/6262494

Problem Statement and Objectives

The Problem

The current method of providing logistics to ground forces is extremely vulnerable to enemy attacks. How do we structure a system that is less predictable and more resilient?

- How to move large quantity of supplies without bulk storage facilities?
- How to reduce the predictability of logistics movements?
- How do changes in enemy activity and maintenance impact the overall system?

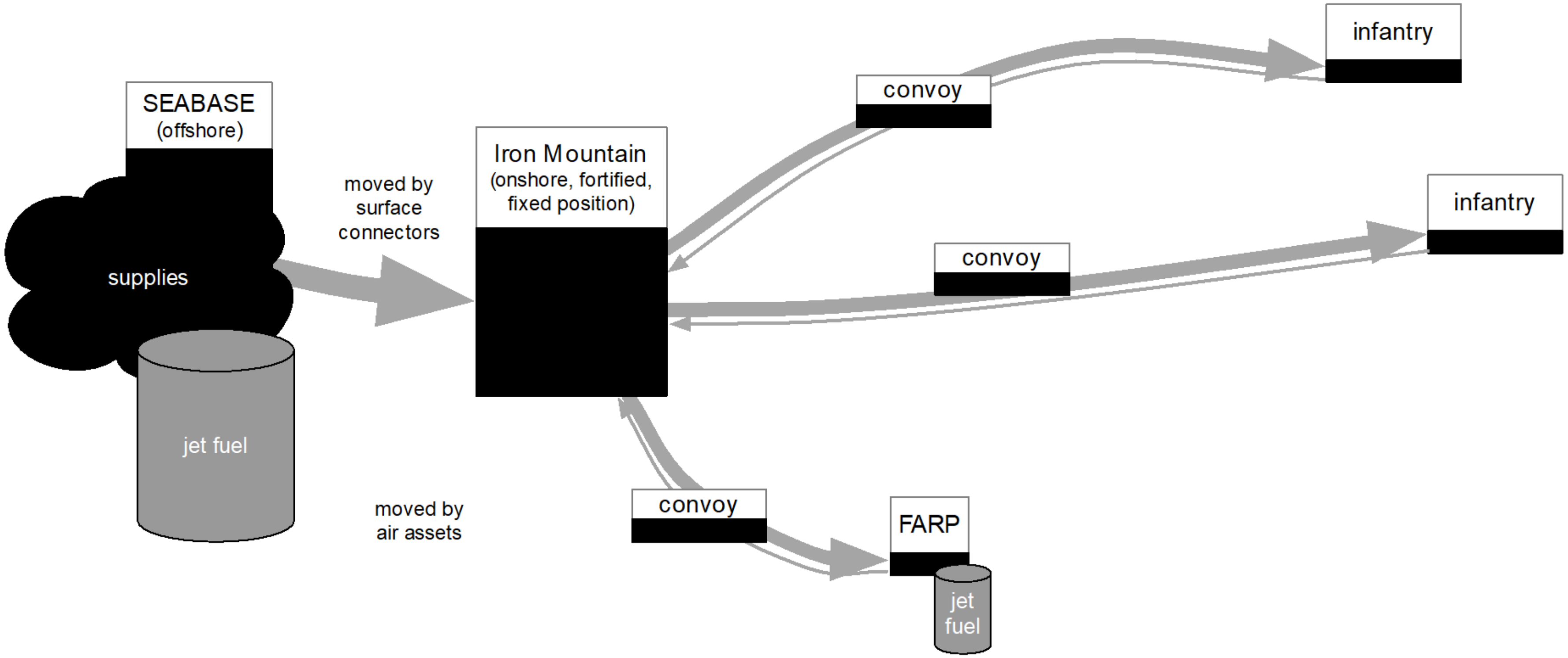
Study Objectives

- Assess the feasibility of a distributed logistics network to support combat operations.
- Identify resource requirements for a distributed logistical network.
- Assess the resiliency of the network.
- Identify how best to incorporate additive manufacturing as a new capability.

Current Logistical System

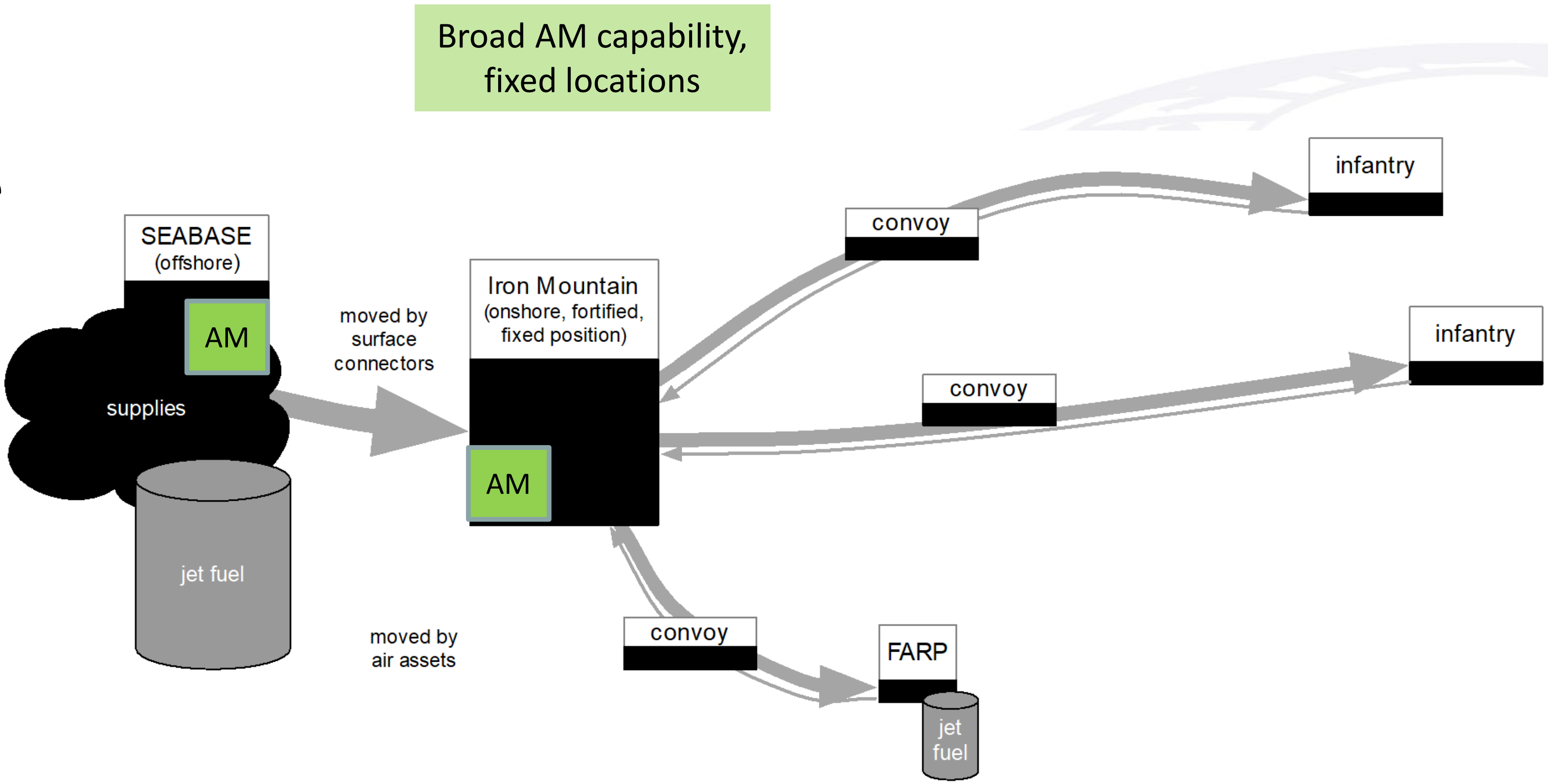
"Iron Mountain"

- Large stockpiles of supplies at a centrally located point
- Large convoys to deliver supplies with greater defensive capabilities
- Central supply node very immobile



AM + Current Logistical System

- Reduce storage volume by keeping bulk raw materials vs spare parts
- AM *may* reduce lead times and costs for some parts
- Quality and reliability of AM parts may be *comparable*, *higher*, or *lower* than originals



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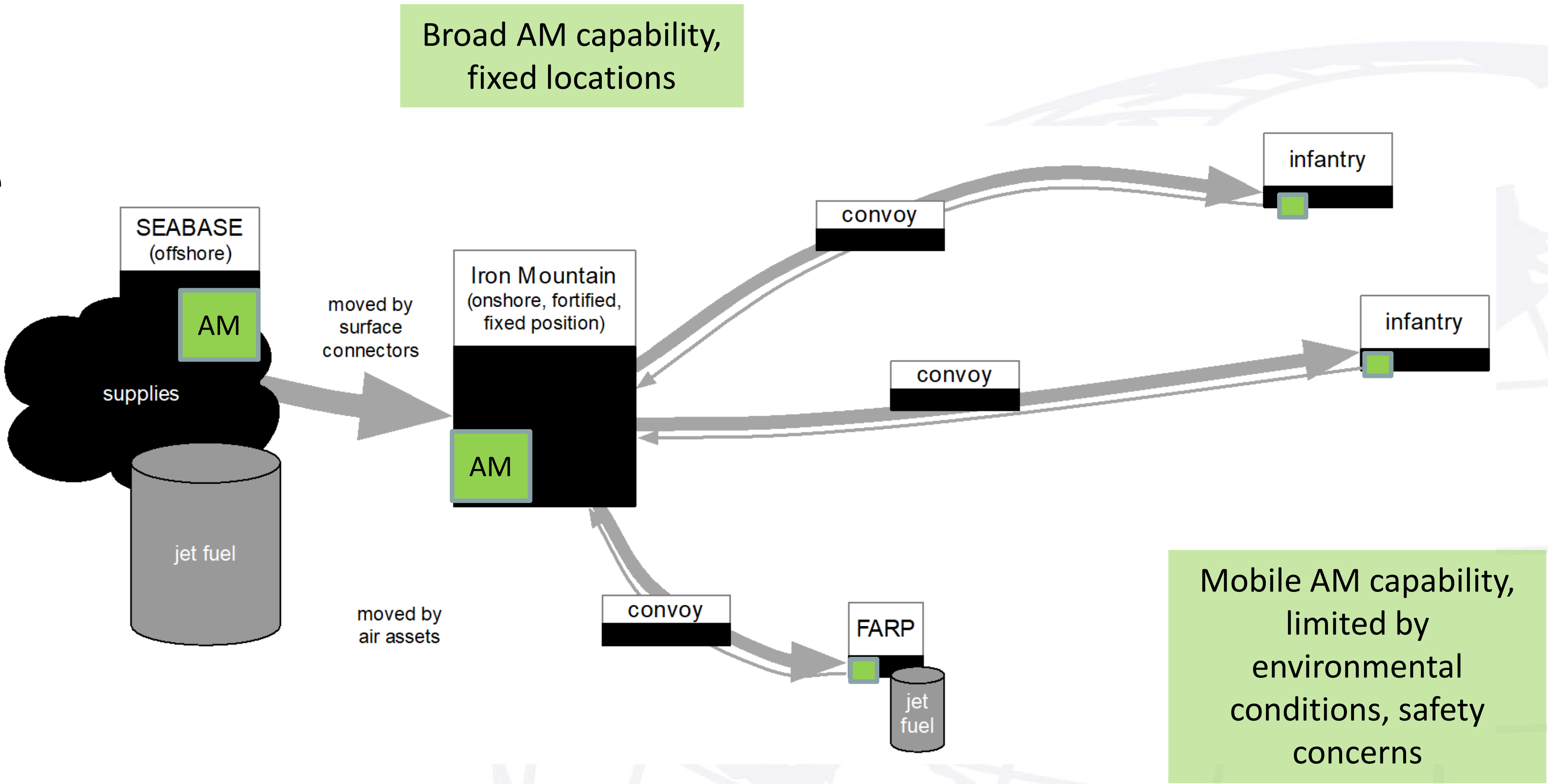
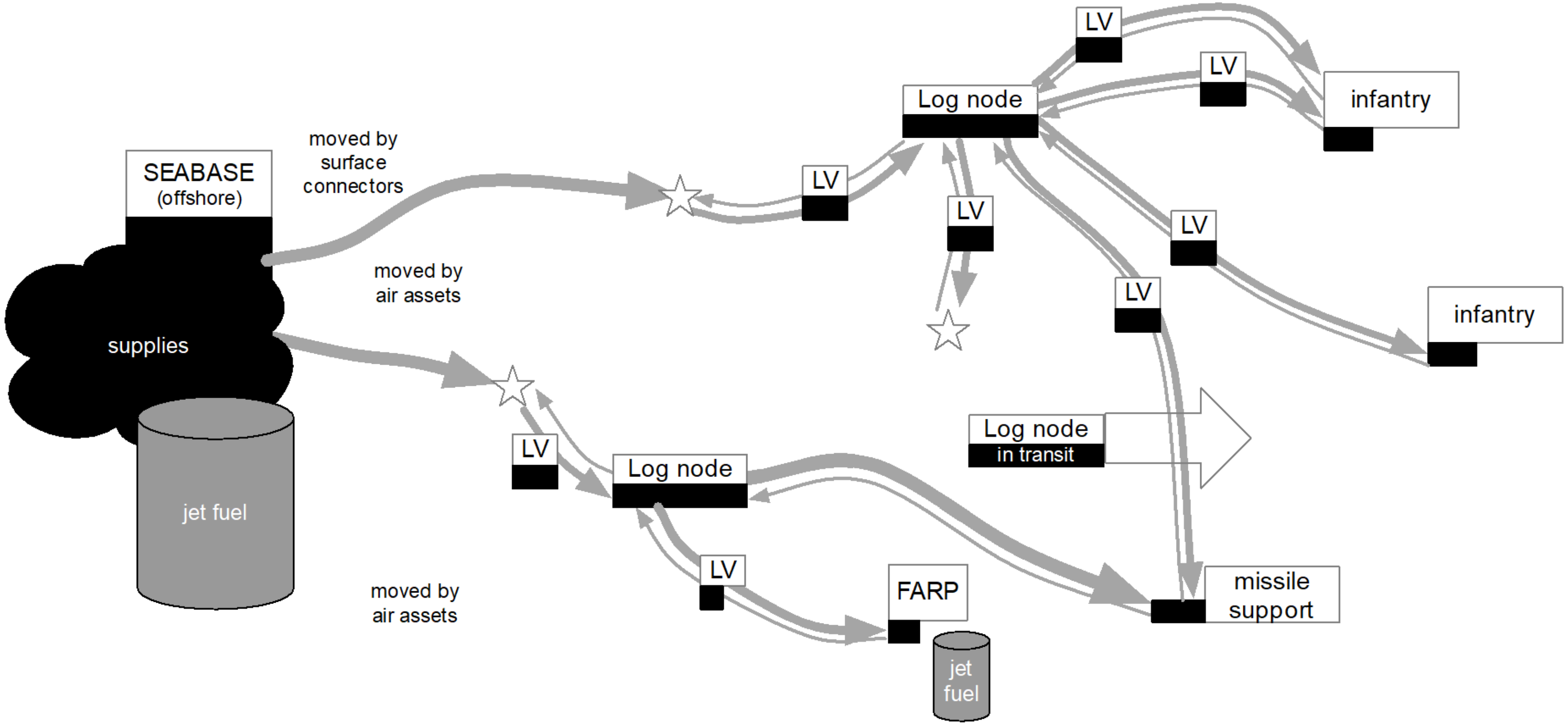


Proposed Logistical System

"Iron Network"

- Smaller stockpiles of supplies
- Smaller convoys with with more frequent movements
- Less predictable movement patterns
- Logistical nodes often changing locations



AM + Proposed Logistical System

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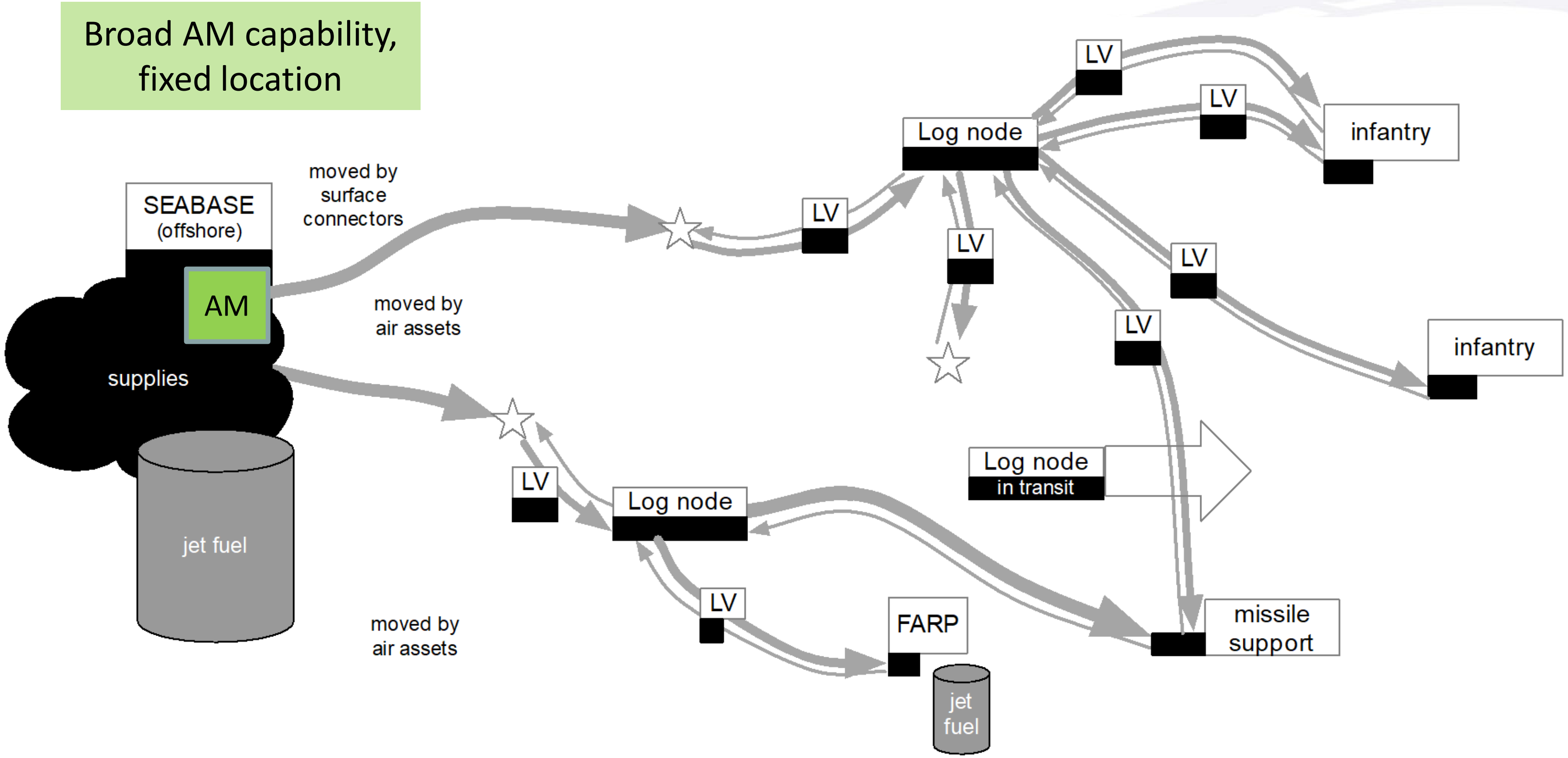

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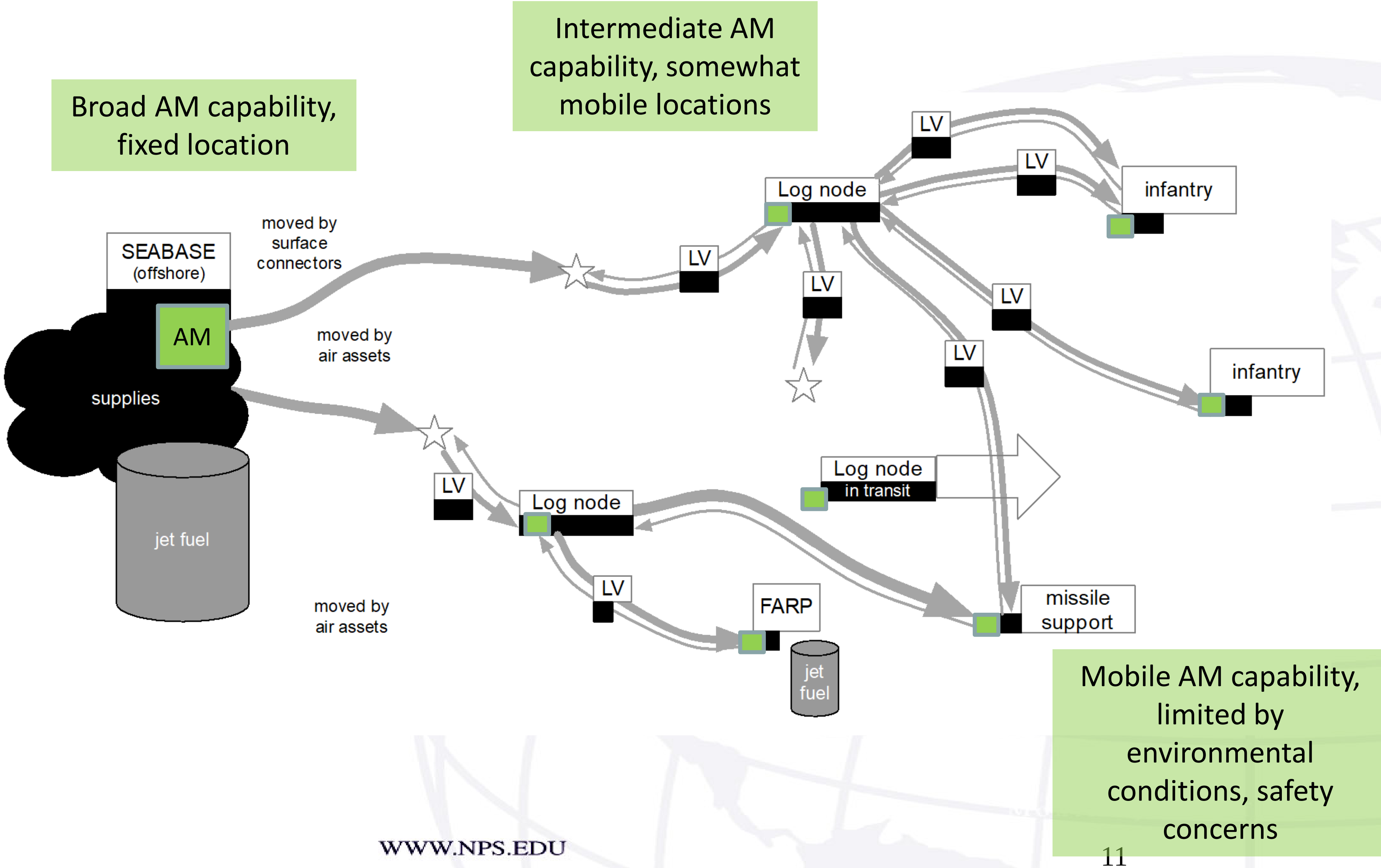


Iron Network Simulation

Critical Assumptions

All assets have arrived in the area at the start of the simulation

- Debarkation or movement into a contested region is not the purpose of the simulation so all assets have their required resources at the start of the simulation

Inventory levels are visible to all units

- Logistical units have an electronic system that allows them to see the supply status of their adjacent units in the area at all times.

Units providing supplies to the logistics nodes do not run out of resources

- The units supplying the logistics nodes are not modeled so they are assumed to have sufficient resources to meet the needs of the units in the simulation.

Vehicles are not restricted by terrain

- The vehicles have the ability to transit via any route that is fastest to get to their destination.

Maintenance events cause delays

- Maintenance events cause significant delays but do not down vehicles for more than a few days.

Iron Network Simulation

*Model Instantiation**

Discrete Event Simulation

- Ruby programming language,
  SimpleKit stochastic simulation library

Model Objects

- 2 x Supported Infantry Companies
- 1 x Supported FARP
- 1 x Supported Missile site
- 3 x Logistics Nodes
- 4 x Supply types (MRE, water, ammunition, fuel)

Decision Factors

- External resupply time
- Max vehicle wait time
- Number of Logistics Vehicles

Factor	Description	Low level	High level
external resupply time	Wait time for logistics node resupply (days)	2	10
max wait time	Maximum time logistics vehicles wait before departing (days)	0.5	3.0
number of LV	Number of vehicles per logistics node	8	20
log node min	Triangular distribution minimum value	0.5	1.5
log node max	Triangular distribution maximum value	2.5	3.5
log node mode	Triangular distribution mode	1.5	2.5
onload mean	Mean time (days) to load vehicle (gamma distribution)	0.25	0.65
onload shape	Shape parameter for loading vehicle (gamma distribution)	8	12
offload mean	Mean time (days) to unload vehicle (gamma distribution)	0.1	0.5
offload shape	Shape parameter for unloading vehicle (gamma distribution)	8	12
enemy attack	Probability of an enemy attack	0.01	0.1
enemy kill	Probability of an attack resulting in destruction of the logistics vehicle	0.01	0.03
maintenance	Probability of an unscheduled maintenance issue	0.5	0.25

*Gregory E. Lynch, Major, USMC (2019). Networked logistics: Turning the iron mountain into an iron network (Master's thesis). Naval Postgraduate School, Monterey, CA (in process).

Approach: Data Farming

Large-scale computational experiments are transformative

"Petaflop machines like Roadrunner have the potential to fundamentally alter science and engineering…[allowing scientists to] perform experiments that would previously have been impractical."

The New York Times, June 9, 2008

Experimentation is hard: "2^{100} is forever"

—Maj Gen Jasper Welch

Even with today's most powerful computers, brute force exploration of 100 variables at 2 levels for a simulation that runs in one second would take many times the age of the universe…so we need to be smart!

Moore's Law is not enough!

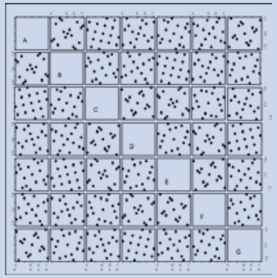
The "curse of dimensionality" cannot be solved by hardware alone.

Petaflop = 1 quadrillion ops/second
Cost of "Roadrunner" = $133 million

Data farming is overcoming the curse of dimensionality…

With large-scale efficient experimental designs, we generate "better big data" and regularly study hundreds of factors for longer-running simulations in hours, days, or weeks on high-performance computing clusters…

Simulation Experiments & Efficient Designs
Center for Data Farming
Naval Postgraduate School



Preliminary results

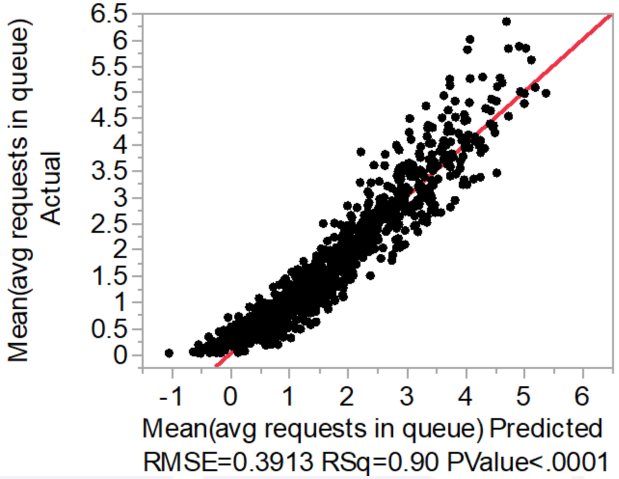
Design:

- base: NOLH with 65 design points (dps)
- shifted and stacked for 1025 total dps
- 20 replications
- 20,500 simulated 180-day operations
- ~8 hrs CPU time on a laptop

Brute force comparisons:
13 factors at 65 levels = 369×10^{21} dps
13 factors at only 5 levels = 1.18 trillion dps

Regression metamodel for Mean(avg requests in queue)

Good fit, two most important terms are number of LV, external resupply time



Term	Estimate	Std Error	t Ratio
number of LV	-0.245	0.0034	-71.30
external resupply time	0.209	0.0051	40.97
enemy attack	9.4267	0.4581	20.58
onload mean	1.8833	0.1037	18.17
log node min	-0.709	0.0409	-17.35
enemy kill	28.717	1.7055	16.84
(external resupply time-6.06244)*(number of LV-14.0312)	-0.023	0.0015	-16.02
log node mode	-0.652	0.0409	-15.96
log node max	-0.63	0.0409	-15.39
(number of LV-14.0312)*(number of LV-14.0312)	0.0142	0.0011	13.04
offload mean	0.9917	0.0979	10.13
(enemy attack-0.055)*(enemy kill-0.02016)	636.52	65.015	9.79
max wait time	0.1568	0.0166	9.47

Preliminary results

Interaction profiler for Mean(avg requests in queue)

If external resupply time is high, then adding LVs makes a big difference

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Preliminary results

Partition tree for Mean(avg requests in queue)

RSquare			
0.566	0.822	1025	4

177
2.00
0.961

Worst leaf: <13 LVs, external resupply time >= 6 days

Best leaf: >=16 LVs, external resupply time < 5 days

Ongoing

Total asset visibility critical toward for a distributed network

Initial tests being conducted

Conducting analysis on outliers

Future analysis to determine network breaking point

Preparing a comparison model to simulate the current logistical model

Future Work

Compare model performance with historical logistical support

Incorporate emerging technologies (Unmanned Logistics Systems/3D printing/etc.) to see their impact

Questions?

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https://harvest.nps.edu