Autonomous Logistics Operations Family of Tools (ALOFT)

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The Center *for* Location Science

Partners and Contributors

- Important list of people who have contributed to this effort
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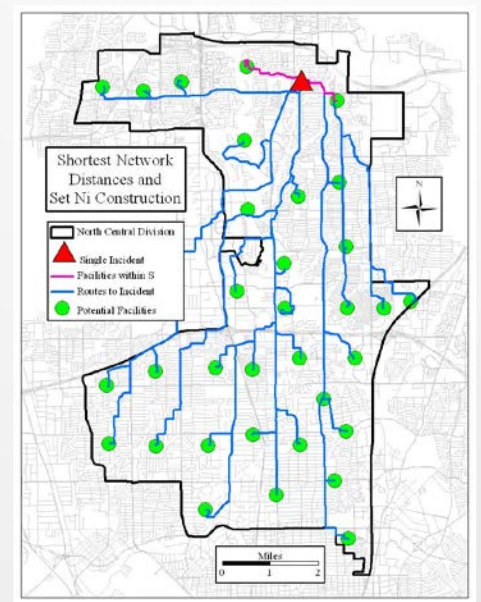
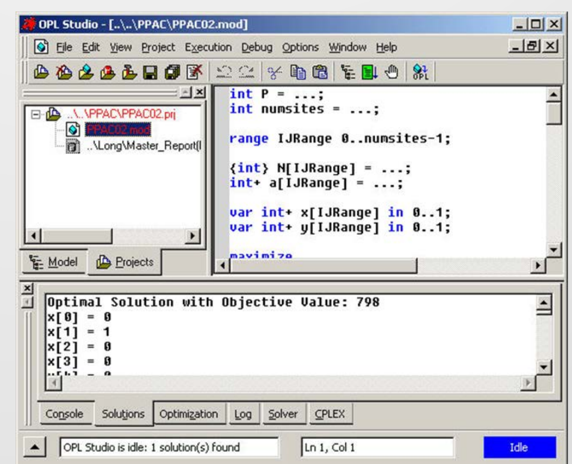
  - Susan Lyon

The Center *for* Location Science

In the Context of the Lab for Location Science

- The motivating mission of the Laboratory for Location Science is to integrate:
  - The theory, methods, tools, and techniques of Spatial Analysis
    - GIS, GIScience, Spatial Statistics, Network Analysis
  - The theory, methods, tools, and techniques of Operations Research
    - Optimization, Facility Location Modeling, Algorithmic and Heuristic solution procedures
- How can this integration solve problems that neither discipline can solve in isolation?





Applied to Logistics Operations with UAVs

- Interest from the Office of Naval Research
  - Logistics Branch
    - Not interested in UAVs for munitions
    - Not interested in UAVs for surveillance
      - Maybe a little…
    - Are interested in UAVs for delivery
      - Movement of supplies, equipment and personnel
      - To support operations
  - Platform Mix
    - Evaluate performance of platforms
    - At the operations level
    - Where to invest?

Why UAV Platform Mix?

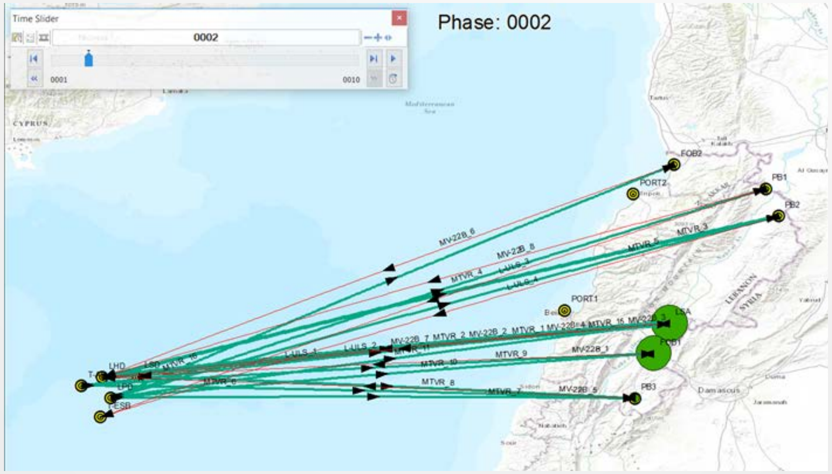
- Marine operations are changing
  - Logistics has to change with them
- Move from:
  - "Storming the beach"
  - Building an "Iron Mountain"
- To:
  - Distributed logistics
  - From a sea base – ships
  - Directly to units inland
- Want to move everything:
  - A Humvee
  - A single packet of food or medicine

What is the range of Platforms?

- Everything from:
  - Small Quadcopters
    - Many models…possibly in swarms
    - Up to 50 pound lift capacity
  - Medium lift – up to 600 pound capacity
    - Quad-, Hex-, Octo-copters
    - Single rotor lift – autogyro
      - Snowgoose
  - Large Lift
    - Manned Aircraft Converted to Pilotless/Autonomous
      - K-Max – sling lift (6000 pounds)
- Employed the AUVSI Database to be able to test many platforms

What can the Spatial Analysis/GIS side do?

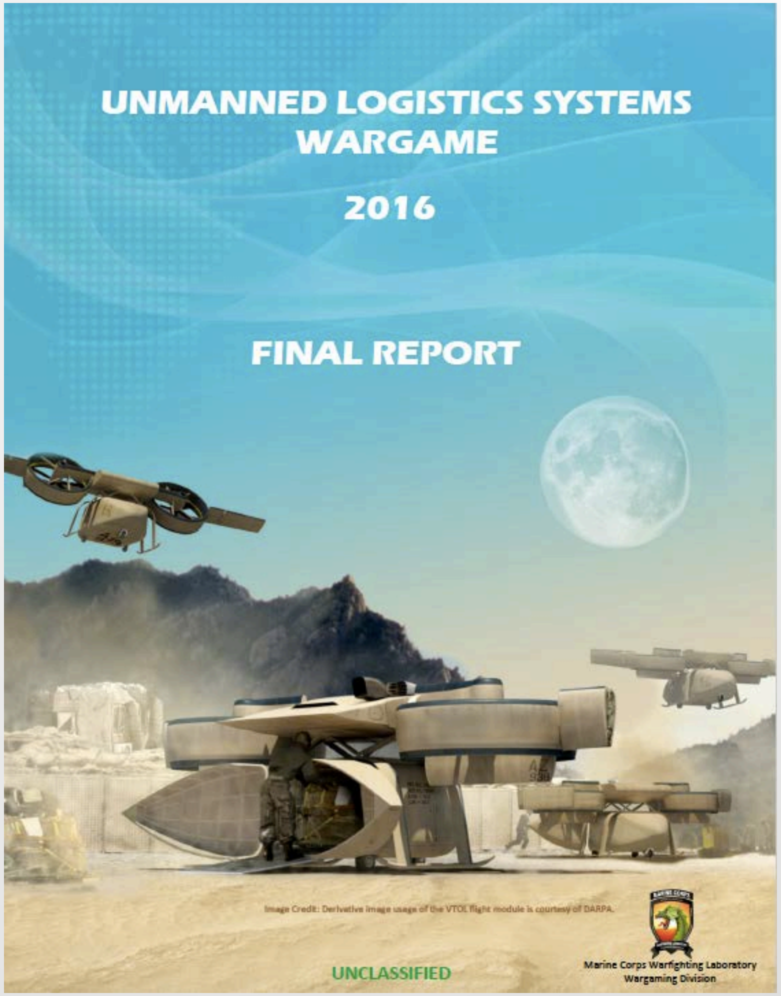
- Real-world Scenario Preparation
  - Database management
    - Platforms
    - Facilities
    - Supplies (Stocks)
    - Demands
  - Scenario Visualization



- Computation of parameters necessary for the optimization process, e.g.
  - OD matrices
  - Network connectivity
- Means of Transfer to the OR side

MCWL Scenario – Background

- The MCWL scenario is based on the United States Marine Corps (USMC) Installations and Logistics (I&L) Command's Unmanned Logistics Systems (ULS) 2016 wargame
  - The wargame was conducted at the unclassified level with a notional scenario set in 2025 and consisted of two vignette-based moves (Move I and Move II)
- This scenario is based on Move I, which focuses on logistics Classes I (food and water), III (fuel), and V (ammunition)



MCWL Scenario – Facilities

- This logistic supply system is a hub-and-spoke distribution model with the seabase serving as the initial hub
- The operation is set in the littoral environment of the coast of West Africa
- Manned and unmanned platforms are assigned to facilities for deliver goods
- Mode is a bitwise operator that specifies what kind of platforms (sea, air, land, amphibious) can access a facility

Node	Name	Mode	X	Y	Platform
1	LSA	12	-9.462485	5.322574	1 (S-ULS) 6 (M-ULS) 12 (MTVR)
2	BLT	12	-9.520849	5.413603	-
3	Kilo Co	12	-9.334639	5.469172	-
4	Lima Co	12	-9.60393	5.528302	2 (S-ULS)
5	Weapons Co	12	-9.527214	5.589981	-
6	India Co	12	-9.055495	5.135118	3 (S-ULS)
7	India Co 1st Plt	12	-9.026156	5.1661	-
8	Recon Team 1	12	-9.154586	5.394503	-
9	Recon Team 2	12	-9.685896	5.577157	-
10	LX(R)	8	-9.837746	4.976472	1 (L-ULS)
11	T-AKE	8	-9.730035	4.986402	1 (L-ULS)
12	LHD	10	-9.704956	4.923426	3 (MV-22B) 2 (CH-53K)

MCWL Scenario – Platforms

- Unmanned and manned logistics vehicles are assigned based on the MCWL Move 1 Scenario
- Specifications and characteristics of each platform are listed below

Node	Name	Platform
1	LSA	1 (S-ULS) 6 (M-ULS) 12 (MTVR)
4	Lima Co	2 (S-ULS)
6	India Co	3 (S-ULS)
10	LX(R)	1 (L-ULS)
11	T-AKE	1 (L-ULS)
12	LHD	3 (MV-22B) 2 (CH-53K)

Figure	Platform	Autonomy
	S-ULS	Unmanned
	M-ULS	Unmanned
	L-ULS	Unmanned
	MV-22B	Manned
	CH-53K	Manned
	MTVR	Manned

Name	Speed (nm/hr)	Capacity (lbs)	Range (nm)	Acquisition Cost	Cost Per Hour	Cost Per Nautical Mile	Prob of Fail	Crew	Mode
S-ULS	32	50	13	90000	100	3	0.15	0	8
M-ULS	64	500	54	650000	300	5	0.1	0	8
L-ULS	230	5000	350	7500000	1550	8	0.075	0	8
MV-22B	248	20000	428	72614579	11000	44	0.025	3	8
CH-53K	156	27000	110	92796000	10000	64	0.025	4	8
MTVR	52	30000	260	195271	4000	77	0.05	3	4

MCWL Scenario – Supplies and Demands

- Facilities in this scenario have either:
  - A stock of supplies to be delivered
  - A demand (need) for supplies
- The amounts of stocks and demands by facility are specified below:

Node	Name	Stock				Demand			
1	LSA	Water: 10	Fuel: 16	Ammo: 12	Medicine: 2	Water: 55	Fuel: 2	Ammo: 0	Medicine: 0
2	BLT	–	–	–	–	Water: 63	Fuel: 205	Ammo: 120	Medicine: 4
3	Kilo Co	–	–	–	–	Water: 10	Fuel: 0	Ammo: 3	Medicine: 1
4	Lima Co	–	–	–	–	Water: 10	Fuel: 0	Ammo: 3	Medicine: 1
5	Weapons Co	–	–	–	–	Water: 10	Fuel: 0	Ammo: 3	Medicine: 1
6	India Co	–	–	–	–	Water: 9	Fuel: 0	Ammo: 2	Medicine: 1
7	India Co 1st Plt	–	–	–	–	Water: 2	Fuel: 0	Ammo: 1	Medicine: 1
8	Recon Team 1	–	–	–	–	Water: 1	Fuel: 3	Ammo: 1	Medicine: 1
9	Recon Team 2	–	–	–	–	Water: 1	Fuel: 3	Ammo: 1	Medicine: 1
10	LX(R)	Water: 0	Fuel: 2,000	Ammo: 100	Medicine: 4	–	–	–	–
11	T-AKE	Water: 100	Fuel: 2,000	Ammo: 100	Medicine: 100	–	–	–	–
12	LHD	Water: 2,000	Fuel: 100	Ammo: 100	Medicine: 4	–	–	–	–

MCWL Overview – Map

Node 1 (LSA)

Node 2 (BLT)

Node 3 (Kilo Co)

Node 4 (Lima Co)

Node 5 (Weapons Co)

Node 6 (India Co)

Node 7 (India Co 1st Plt)

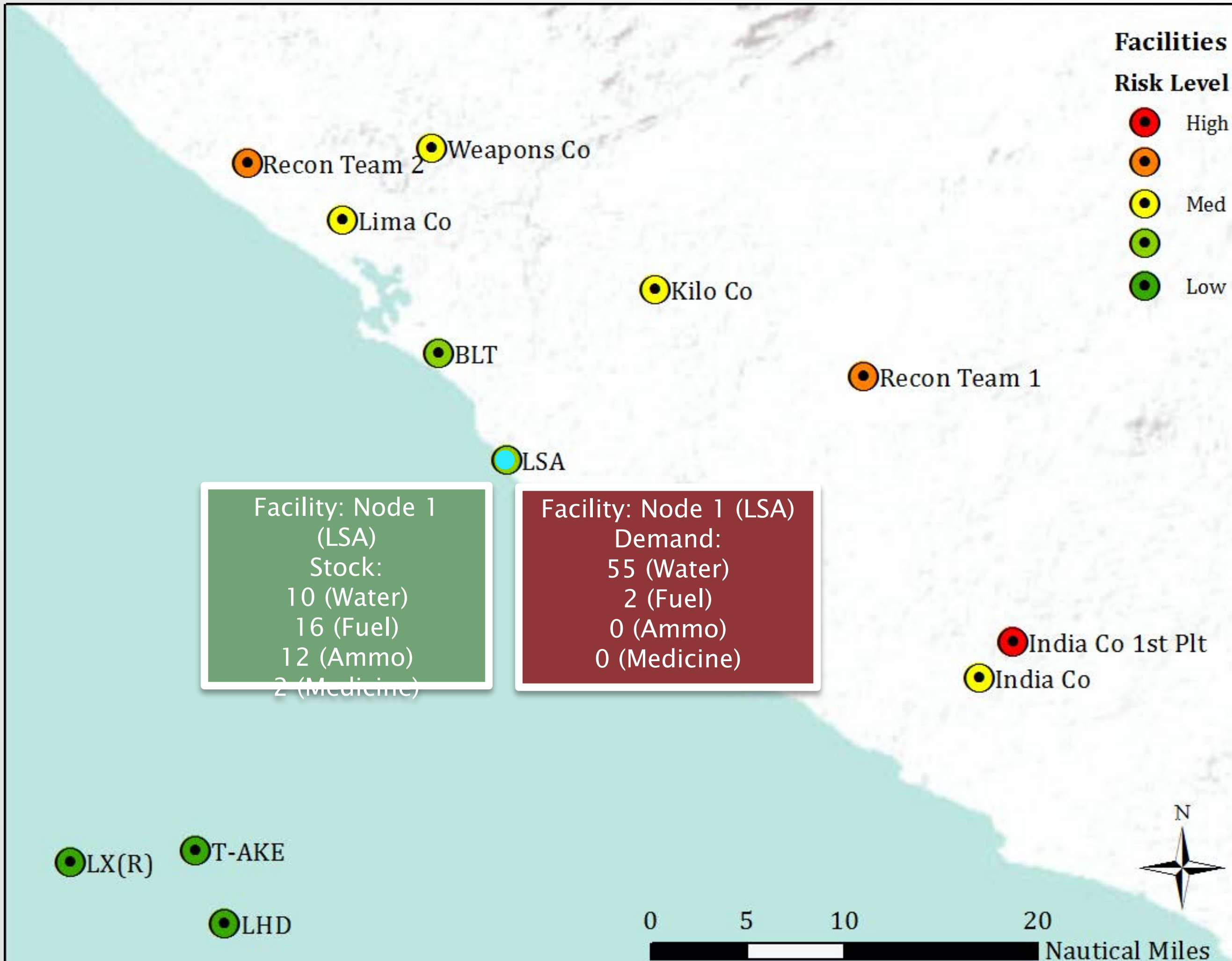
Node 8 (Recon Team 1)

Node 9 (Recon Team 2)

Node 10 (LXR)

Node 11 (T-AKE)

Node 12 (LHD)



Facilities | Platforms | Supplies and Demands | Map | Optimal Solution

What can the OR/Optimization Side Do?

- Formulate a model
  - That represents the multiple objectives of the logistics mission
    - Minimize prioritized unmet demand
    - Minimize risk to manned aircraft
    - Minimize operating costs
  - That models the constraints on:
    - Facilities
    - Platforms
  - Through space and time
- Provides the optimal
  - Deployment plan
  - Can be brought back to GIS

Obj 1. Minimize discounted, prioritized unmet demand

$$Min\ z = \sum_t discount_t \sum_n \sum_i utility_{n,i} SHORTED_{n,i,t}$$

Obj 2. Minimize crew risk

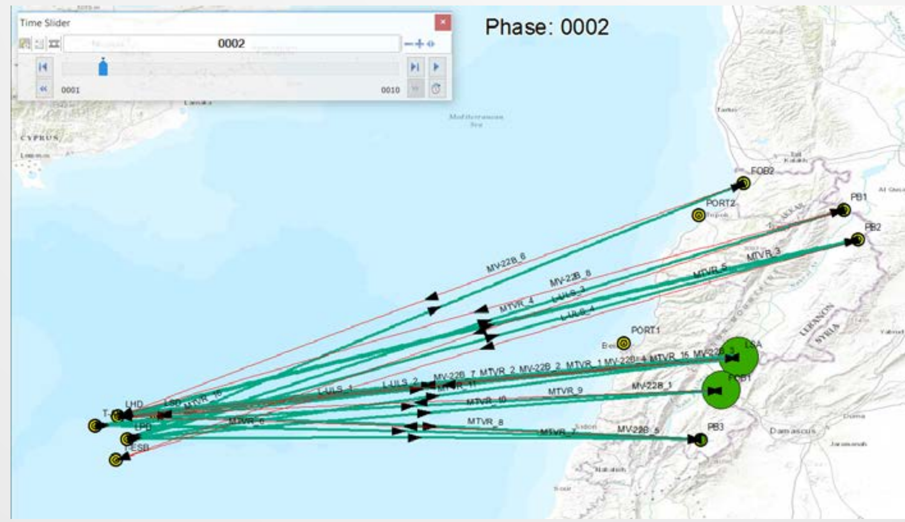
$$Min\ z = \sum_{(t,t')\in timeArcs} \sum_{(n,n')\in nodeArcs} \sum_v crew_v nodeRisk_{v,n'} link_{v,n,n',t,t'}$$

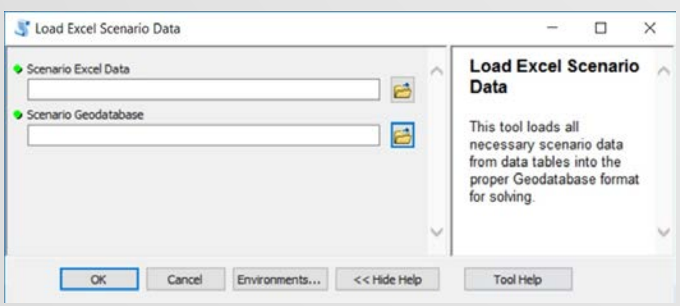
Obj 3. Minimize discounted, operating costs

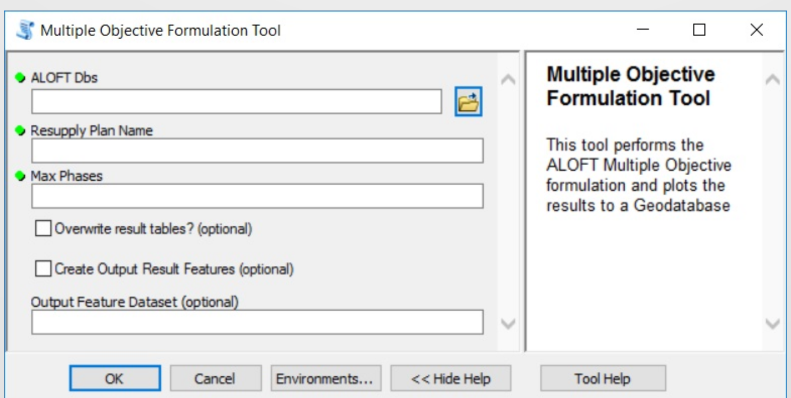
$$Min\ z = \sum_{(t,t')\in timeArcs} discount_{t'} \sum_{(n,n')\in nodeArcs} \sum_v operatingCostPerDistanceUnit_v ranges_{n,n'} link_{v,n,n',t,t'}$$

The Testbed Environment

- Set of tightly integrated tools
  - OTS GIS Functionality
  - Custom GIS Scripting
  - Linkage to LP Solution software
    - Gurobi via Python/PuLP
  - Customized Display
  - Integration with Simulation

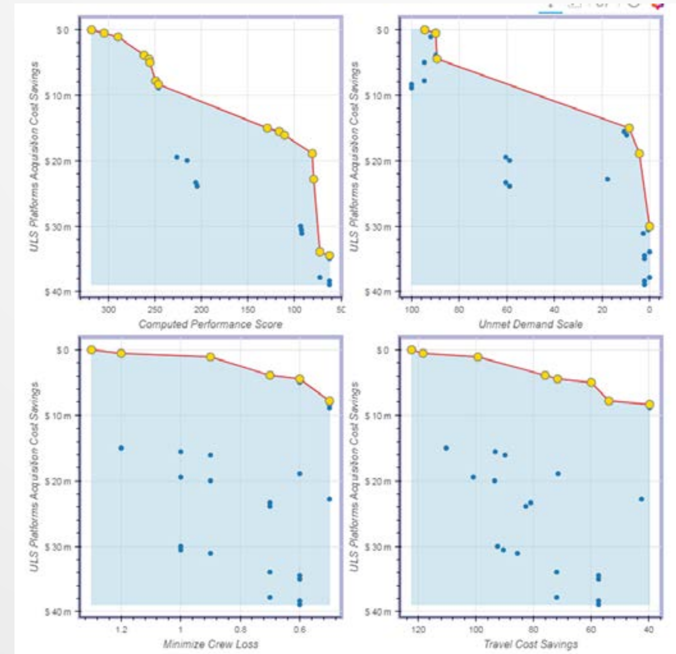






Platform Mix Analysis

- In order to analyze platform mix we must change platform mix
  - Solve over a range of mixes
  - Compare performance to cost
  - Pareto optimal boundaries
- Example for MCWL
  - 27 different platform mixes
  - For S-, M-, and L-ULS either:
    - Keep the # of available platforms same as MCWL
    - Reduce the number of available platforms to zero
    - Double the # of platforms compared to MCWL
- ParetoPlot_MCWL1_Cargo_MultiObj_UDCLTD.html
- ParetoPlot_MCWL1_Cargo_MultiObj_UDCLTDscaled1.html
- ParetoPlot_MCWL1_Cargo_Sequential_UDCLTD.html



Paths Forward

- Changes/Additions to the Optimization Approach
  - Are the constraints/objectives realistic
  - Extending scenarios, Random scenarios
  - Sensitivity of solutions
  - Find the bounds of tractability
  - Additional models where facility location changes but mix stays the same
- Additions to the Platform Mix analysis
  - Add statistical tests of performance to the Pareto Analysis
- And a thousand more possibilities…
- Questions?