Unmanned Vehicle Logistics Modeling: Results and Integration for Autonomous Logistics Operations Family of Tools (ALOFT)

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The ALOFT Project

- **A**utonomous **L**ogistics **O**perations **F**amily of **T**ools
  - Integration of GIS and OR to explore logistical problems
- Emphasis on unmanned vehicles
- Emphasis on USMC research needs
  - Platform Mix Problem

    This problem asks, "How does an organization efficiently allocate the mixed set of autonomous logistics systems needed to support distributed operations in the future?"
  - More broadly: A toolset for helping to model what a viable military logistics operation supported by unmanned vehicles looks like.

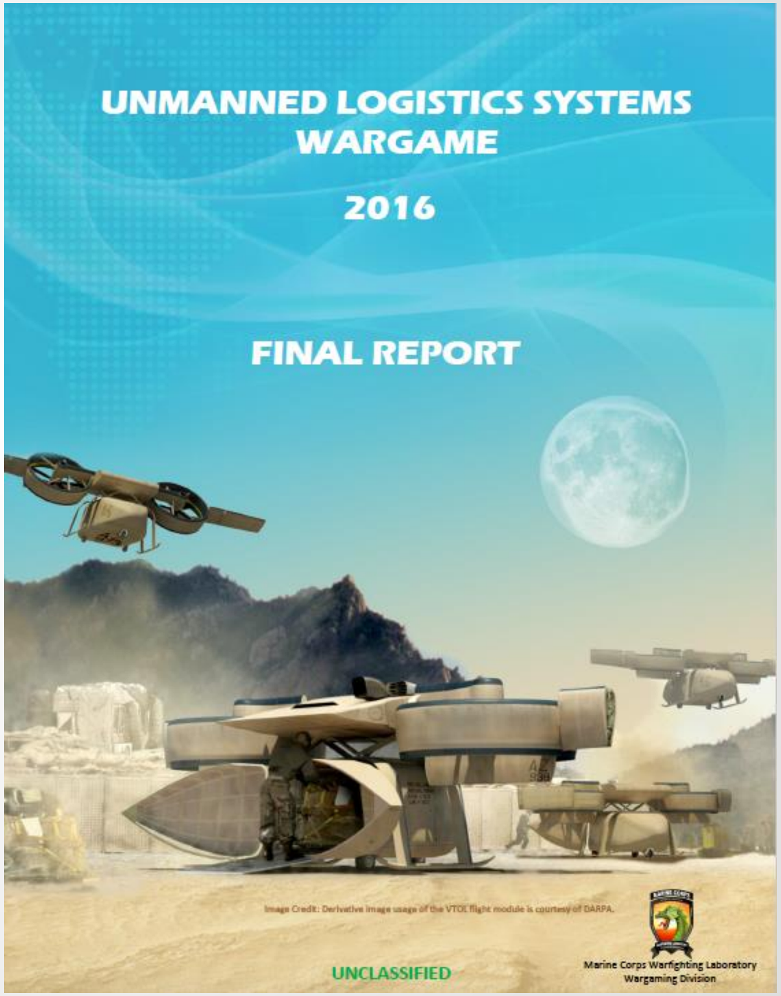
Problem

- Given:
  - Set of nodes demanding resupply – quantity by type of supply
  - Set of nodes holding inventory – quantity by type of supply
  - Set of manned and unmanned resupply vehicles with different speeds, ranges, carrying capacities, and ability to visit specific nodes
- Do:
  - Meet all demand (to the extent that inventory supports this)
- Objectives:
  - Minimize time to complete deliveries, prioritize deliveries, minimize risk to pilots, minimize resource usage
- Given solutions with different vehicle mixes under different conditions, what mixes produce the most desireable solutions?

Example Scenarios

Marine Corps Warfighting Laboratory (MCWL) Scenario

- 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 focuses on logistics Classes I (food and water), III (fuel), and V (ammunition)



MCWL Scenario – Platforms

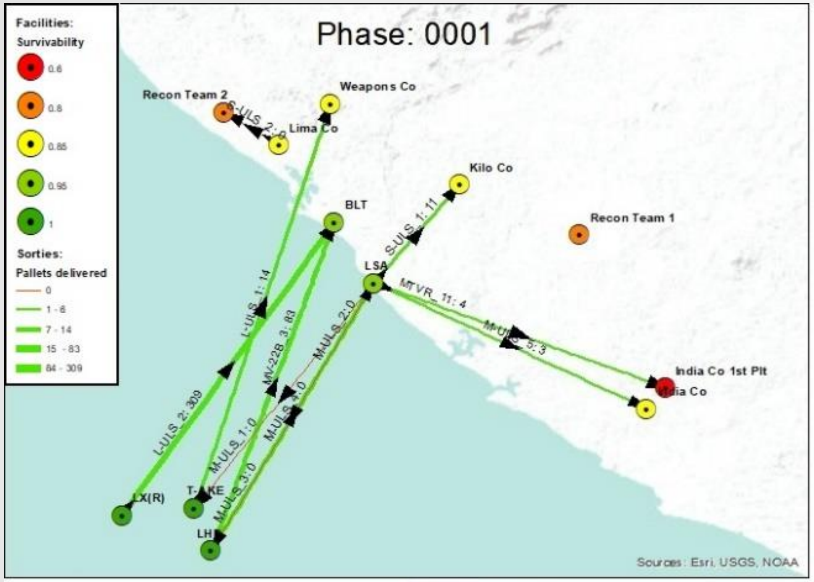
- Unmanned and manned logistics vehicles are assigned based on the MCWL Move 1 Scenario
- Specifications and characteristics of each platform are listed below

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)

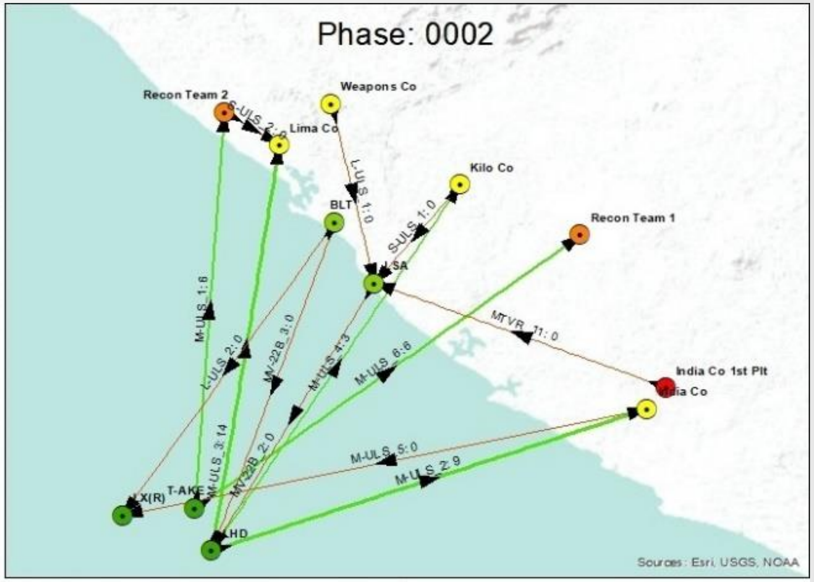
Figure	Platform	Autonomy
	S-ULS	Unmanned
	M-ULS	Unmanned
	L-ULS	Unmanned
	MV-22B	Manned
	CH-53K	Manned
	MTVR	Manned

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

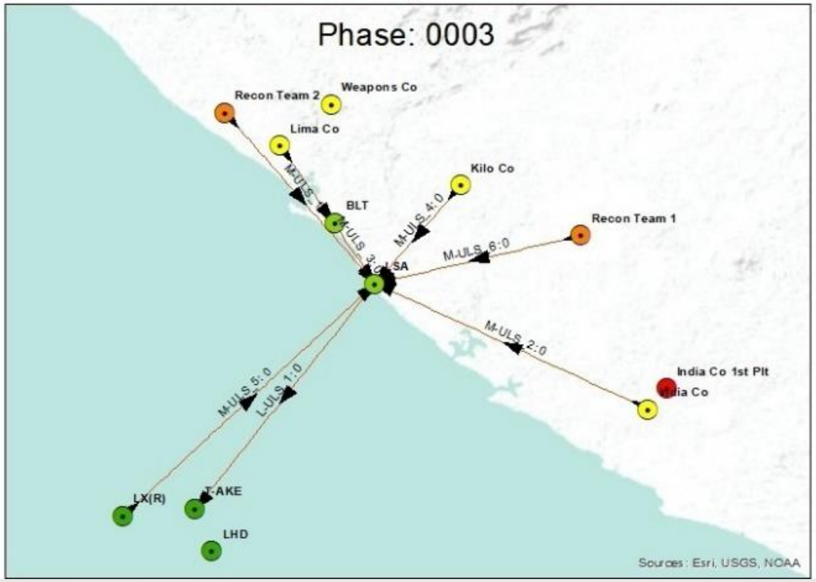
MCWL Maps



Phase: 0001
Facilities:
Survivability
0.6
0.8
0.85
0.95
1
Sorties:
Pallets delivered
0
1 - 6
7 - 14
15 - 83
84 - 309
Recon Team 2
Weapons Co
Lima Co
Kilo Co
BLT
Recon Team 1
LSA
India Co 1st Plt
India Co
LX(R)
T-AKE
LHD
Sources: Esri, USGS, NOAA



Phase: 0002
Recon Team 2
Weapons Co
Lima Co
Kilo Co
BLT
Recon Team 1
LSA
India Co 1st Plt
India Co
LX(R)
T-AKE
LHD
Sources: Esri, USGS, NOAA



Phase: 0003
Recon Team 2
Weapons Co
Lima Co
Kilo Co
BLT
Recon Team 1
LSA
India Co 1st Plt
India Co
LX(R)
T-AKE
LHD
Sources: Esri, USGS, NOAA

“Swarm” Scenario

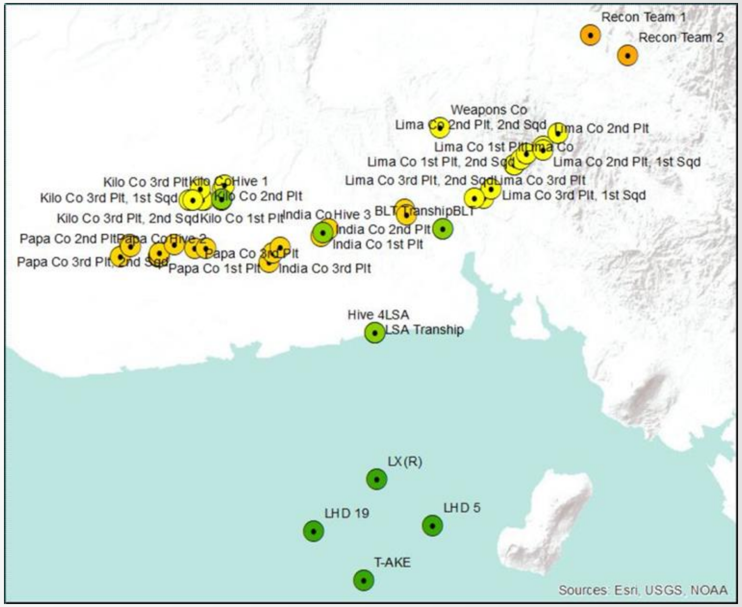
- Model unmanned logistics viability based on 2016 wargame
  - Many “small” UAVs
- Much larger and more detailed than all previous scenarios:
  - 55 Facilities (vs. 14): Company, 1st 2nd Platoon, 1st 2nd Squad, Hives
  - 67 Vehicles (vs. 31): added XS-ULS and G-ULS
  - 7 Commodities (vs. 4): added Ammo 2, Construction, Rations
- VASTLY larger optimization problem



Name	Speed (nm/hr)	Capacity (lbs)	Range (nm)	Acquisition Cost	Cost Per Hour	Cost Per Nautical Mile	Prob of Fail	Crew	Mode	Class
XS-ULS	**32**	**25**	**13**	**25000**	**40**	**1**	**0.15**	0	**Air**	**S**
S-ULS	32	50	13	90000	100	3	0.15	0	Air	S
M-ULS	64	500	54	650000	300	5	0.1	0	Air	M
L-ULS	230	5000	350	7500000	1550	8	0.075	0	Air	L
MV-22B	248	20000	428	72614579	11000	44	0.025	3	Air	L
CH-53K	156	27000	110	92796000	10000	64	0.025	4	Air	L
G-ULS	**15**	**15**	**260**	**20000**	**40**	**3**	**0.05**	0	**Land**	**S**
MTVR	52	30000	260	195271	4000	77	0.05	3	Land	M

Swarm Scenario Problems/Approaches

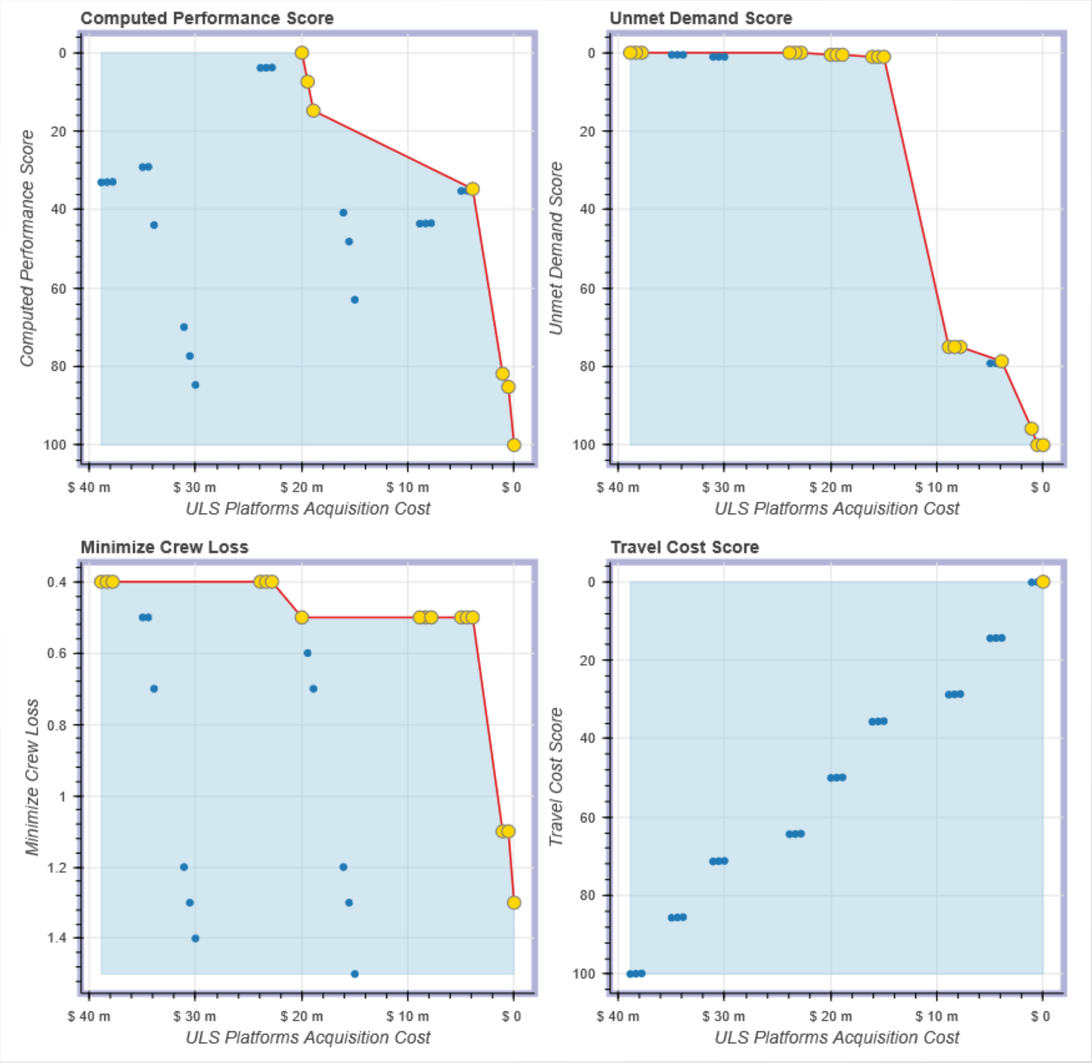
- The Swarm scenario with our existing formulation was intractable
  - Code refactoring for performance
  - Revising the formulation
  - Changing the pre-processing of problem
- We are just beginning to consider heuristic solution procedures
  - Won't guarantee an optimal solution
  - Should give a good solution to larger scenarios like Swarm
  - We knew the day would come where we would need to develop these, and it was Swarm that brought us to the bound of tractability



Platform Mix Analysis

Platform Mix Analysis

- Generate Pareto Trade-Off curves for each scenario
  - Solve over a range of mixes
  - Compare performance to cost
- What does the Pareto Trade-off offer?
  - Ability to visually examine which mixes in a scenario are non-dominated
  - Allow to make decisions amongst non-dominated solutions
    - Look for "elbows" in the graph



Platform Mix Analysis Contd.

- Which variable values (platform sizes) are driving the change?
  - Logistic regression
  - A negative value of the coefficient means that the presence of the component in the context of the full model is associated with a smaller likelihood of being on the Pareto Frontier
  - S1, S2, L1, L2 platform sizes are strongly significant in lowering the likelihood of being on the Pareto Frontier
    - Consistent with descriptive stats and other findings

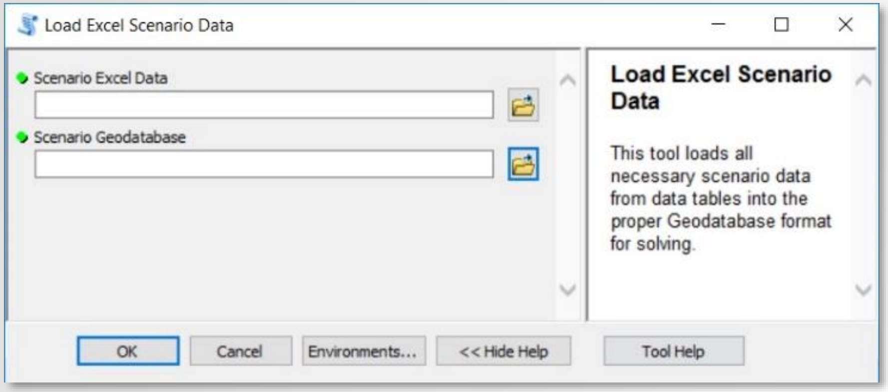
Model parameters (Variable Non-Dominated):							
Source	Value	Standard error	Wald Chi-Square	Pr > Chi²	Lower bound	Upper bound (	Odds ratio
Intercept	1.227	0.594	4.266	0.039	0.063	2.391	
Small-S0	0.000	0.000					
Small-S1	-2.171	0.646	11.315	0.001	-3.437	-0.906	0.114
Small-S2	-2.448	0.686	12.724	0.000	-3.793	-1.103	0.086
Medium-M0	0.000	0.000					
Medium-M1	0.000	0.578	0.000	1.000	-1.132	1.132	1.000
Medium-M2	-1.018	0.660	2.375	0.123	-2.312	0.276	0.361
Large-L0	0.000	0.000					
Large-L1	-2.212	0.636	12.088	0.001	-3.459	-0.965	0.109
Large-L2	-2.822	0.740	14.557	0.000	-4.271	-1.372	0.060

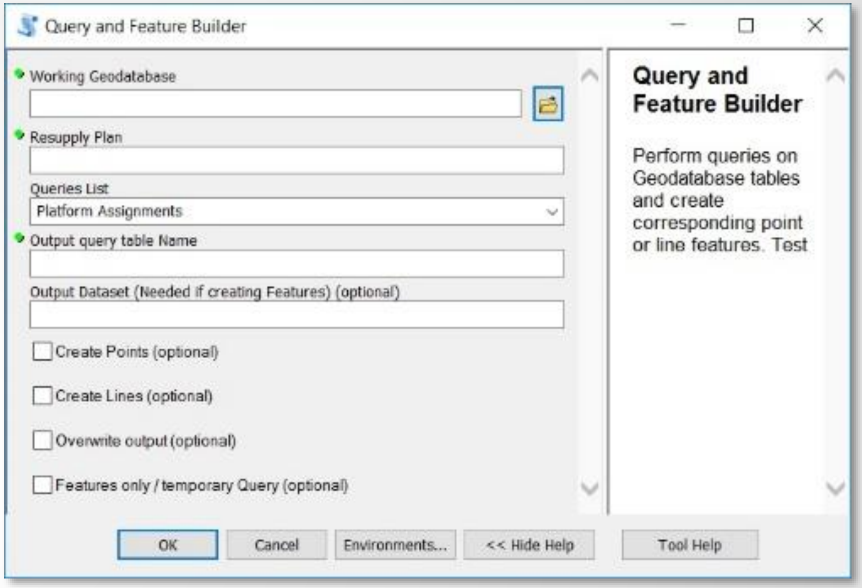
ALOFT Application Development

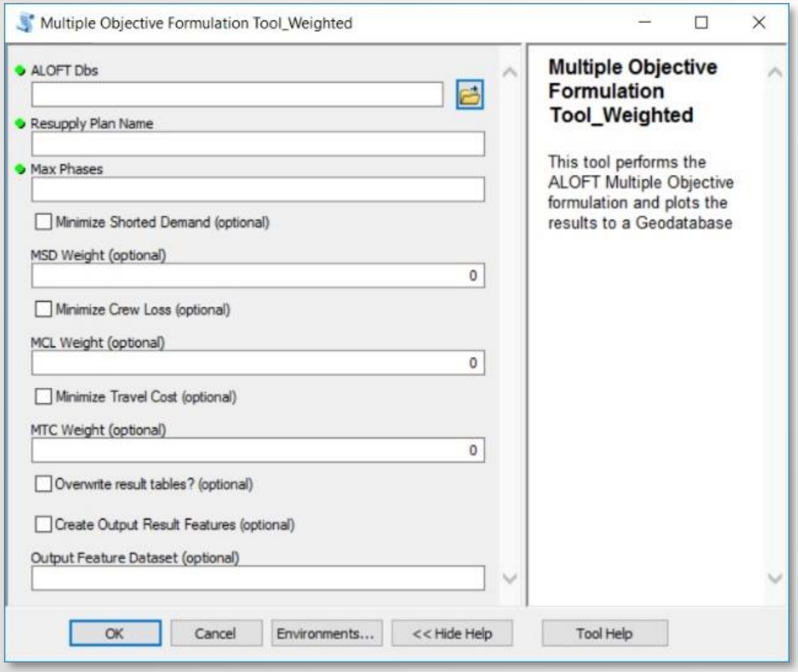
Software Platform/Integration

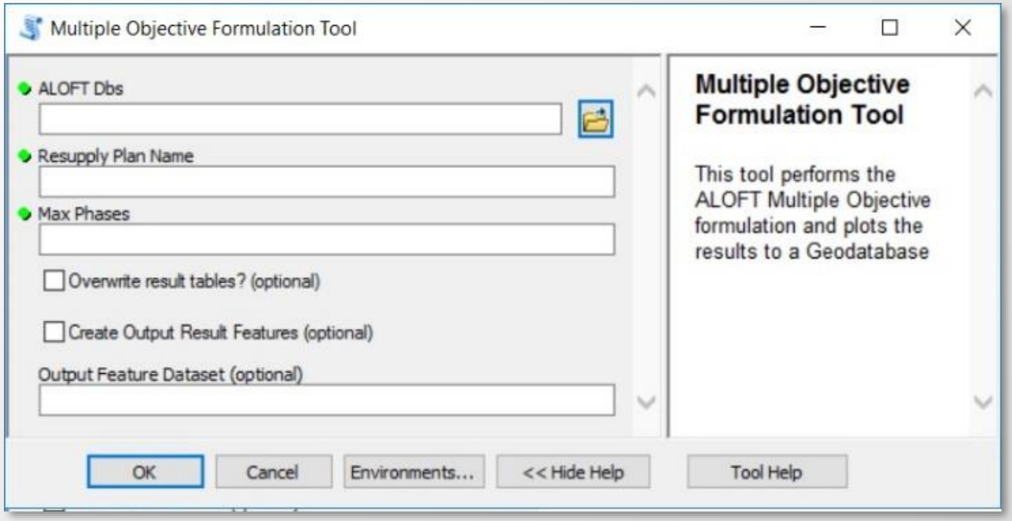
- ALOFT provides a set of custom tools designed to be run from ArcGIS
  - Users can set up their data and model input in ArcGIS
  - Users can view output in ArcGIS
  - Minimal to no need for users to interact with other software
- Integrated with a linear programming solver backend
  - Solvers are specialty applications designed to solve computationally complex optimization problems
  - ALOFT built with a Gurobi backend, a commercial solver ($$$)
    - Compatible with other solvers (i.e. CPLEX, COIN-OR)
  - Integration via PuLP (Python for Linear Programming | https://github.com/coin-or/pulp)

ArcGIS User Interface









Questions?

Formulation Overview

- Ships and unit locations are treated as nodes in a time/space network
- Nodes either hold stock or demand resupply
- Nodes have different risk of loss for vehicles visiting at the node
- Vehicles (manned or unmanned) carry cargo between nodes, picking up shipments and making deliveries to meet demand in supply classes
- Vehicles come in types - with different speed, capacity, class, and range
- Time advances in discrete time steps (size chosen by user)
- Must meet all demand by a given time deadline
- Multiple Objectives - in priority order:
  - Minimize discounted, prioritized unmet demand
  - Minimize risk exposure of manned aircraft
  - Minimize discounted operating costs

Output: optimal multi-sortie resupply plan

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

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