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

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- Alec Barker
- Diana (Pat) Guillen-Piazza
- Mike Cosgrove
The ALOFT Project

- Autonomous Logistics Operations Family of Tools
  - 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 desirable 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)
Unmanned and manned logistics vehicles are assigned based on the MCWL Move 1 Scenario.

Specifications and characteristics of each platform are listed below:

<table>
<thead>
<tr>
<th>Node</th>
<th>Name</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LSA</td>
<td>1 (S–ULS) 6 (M–ULS) 12 (MTVR)</td>
</tr>
<tr>
<td>4</td>
<td>Lima Co</td>
<td>2 (S–ULS)</td>
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<td>6</td>
<td>India Co</td>
<td>3 (S–ULS)</td>
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<tr>
<td>10</td>
<td>LX(R)</td>
<td>1 (L–ULS)</td>
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<td>11</td>
<td>T–AKE</td>
<td>1 (L–ULS)</td>
</tr>
<tr>
<td>12</td>
<td>LHD</td>
<td>3 (MV–22B) 2 (CH–53K)</td>
</tr>
</tbody>
</table>

### Platforms

- **S–ULS**: Unmanned
- **M–ULS**: Unmanned
- **L–ULS**: Unmanned
- **MV–22B**: Manned
- **CH–53K**: Manned
- **MTVR**: Manned

### Specifications and Characteristics

<table>
<thead>
<tr>
<th>Name</th>
<th>Speed (nm/hr)</th>
<th>Capacity (lbs)</th>
<th>Range (nm)</th>
<th>Acquisition Cost</th>
<th>Cost Per Hour</th>
<th>Cost Per Nautical Mile</th>
<th>Prob of Fail</th>
<th>Crew</th>
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<tbody>
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<td>S–ULS</td>
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</table>
MCWL Maps
### “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, 1\(^{st}\) 2\(^{nd}\) Platoon, 1\(^{st}\) 2\(^{nd}\) 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

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<td>0.05</td>
<td>3</td>
<td>Land</td>
<td>M</td>
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</tbody>
</table>
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
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

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Standard error</th>
<th>Wald Chi-Square</th>
<th>Pr &gt; Chi²</th>
<th>Lower bound</th>
<th>Upper bound</th>
<th>Odds ratio</th>
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<td>-4.271</td>
<td>-1.372</td>
<td>0.060</td>
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</tbody>
</table>
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

Load Excel Scenario Data
Scenario Excel Data
Scenario Geodatabase

Load Excel Scenario Data
This tool loads all necessary scenario data from data tables into the proper Geodatabase format for solving.

Query and Feature Builder
Working Geodatabase
Resupply Plan
Queries list
Platform Assignments
Output query table Name
Output Dataset (needed if creating Features) (optional)

Query and Feature Builder
Perform queries on Geodatabase tables and create corresponding point or line features. Test

Multiple Objective Formulation Tool_Weighted
ALOFT Dbs
Resupply Plan Name
Max Phases

Multiple Objective Formulation Tool_Weighted
Minimize Shored Demand (optional)
MSD Weight (optional)
Minimize Crew Loss (optional)
MCL Weight (optional)
Minimize Travel Cost (optional)
MTC Weight (optional)

Multiple Objective Formulation Tool
Overwrite result tables? (optional)
Create Output Result Features (optional)
Output Feature Dataset (optional)

Multiple Objective Formulation Tool
ALOFT Dbs
Resupply Plan Name
Max Phases

Multiple Objective Formulation Tool
Overwrite result tables? (optional)
Create Output Result Features (optional)
Output Feature Dataset (optional)
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