Autonomous Logistics Operations Family of Tools (ALOFT)

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Partners and Contributors

- Important list of people who have contributed to this effort
  - Alec Barker
  - Mike Resig
  - Fred Woodaman
  - Jin Lee
  - Pat Guillen-Piazza
  - Pete Revay
  - Susan Lyon
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?
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
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.

<table>
<thead>
<tr>
<th>Node</th>
<th>Name</th>
<th>Mode</th>
<th>X</th>
<th>Y</th>
<th>Platform</th>
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### 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

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<thead>
<tr>
<th>Node</th>
<th>Name</th>
<th>Platform</th>
<th>Figure</th>
<th>Platform</th>
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<td>4</td>
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<td>2 (S–ULS)</td>
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<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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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:

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<td>Ammo: 3</td>
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<td></td>
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<td>-</td>
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<td>T-AKE</td>
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<td>Fuel: 2,000</td>
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<td>Medicine: 4</td>
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</tbody>
</table>

Facilities - Platforms - Supplies and Demands - Map - Optimal Solution
MCWL Overview – Map

Facility: Node 1 (LSA)
Demand:
- Water: 55
- Fuel: 2
- Ammo: 0
- Medicine: 0

Stock:
- Water: 10
- Fuel: 16
- Ammo: 12
- Medicine: 2

Facility: Node 1 (LSA)
- Demand:
  - Water: 55
  - Fuel: 2
  - Ammo: 0
  - Medicine: 0

Facilities:
- Risk Level:
  - High
  - Med
  - Low

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)

Platforms:
- Recon Team 2
- Weapons Co
- Lima Co
- Kilo Co
- BLT
- Recon Team 1
- India Co 1st Plt
- India Co

Supplies and Demands:
- Node 6 (India Co)
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
\[
\min z = \sum_t \text{discount}_t \sum_i \sum_n utility_{n,i} \text{SHORTE}_{n,i,t}
\]

Obj 2. Minimize crew risk
\[
\min z = \sum_{(t,t')} \text{timeArcs} \sum_{(n,n')} \text{nodeArcs} \sum_v \text{crew}_{n,n'} \text{nodeRisk}_{v,n,n',t,t'}
\]

Obj 3. Minimize discounted, operating costs
\[
\min z = \sum_{(t,t')} \text{timeArcs} \text{discount}_t \sum_{(n,n')} \text{nodeArcs} \sum_v \text{operatingCostPerDistanceUnit}_{v,n,n',t,t'}
\]
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
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
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?