# Unmanned Aerial Vehicle Logistics Modeling and Performance: A Demonstration of Integrative Data Science

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# Partners and Contributors

- Important list of people who have contributed to this effort
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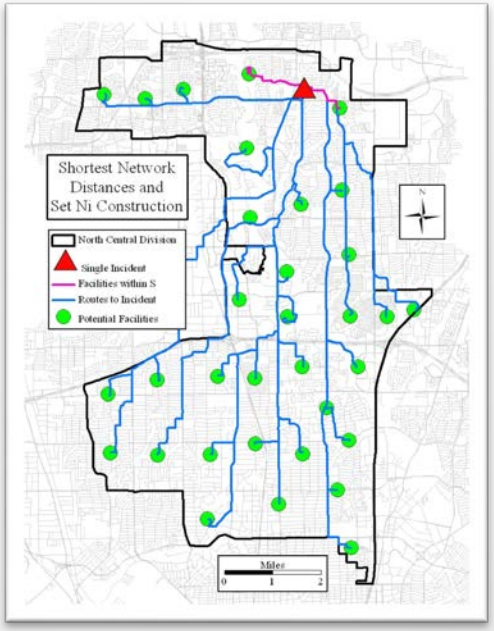
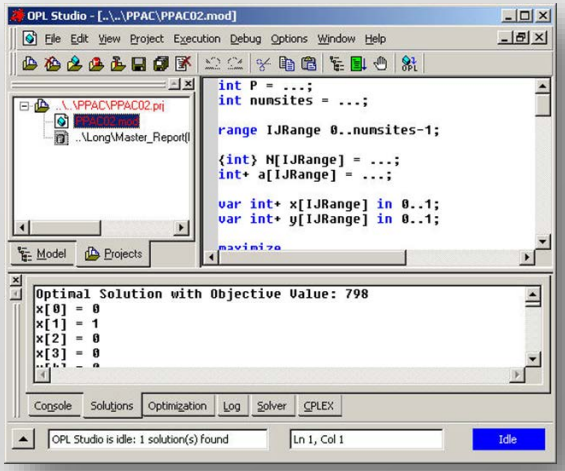
# Integrative Nature of Data Science

- The advance of data science as a discipline
  - Is a recognition that commonalities among scientific approaches, that
  - Offer the most fruitful ground for basic scientific advance
- The motivating mission of the Laboratory for Location Science is to integrate:
  - The theory, methods, tools, and techniques of Spatial Analysis
  - The theory, methods, tools, and techniques of Operations Research
- 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?

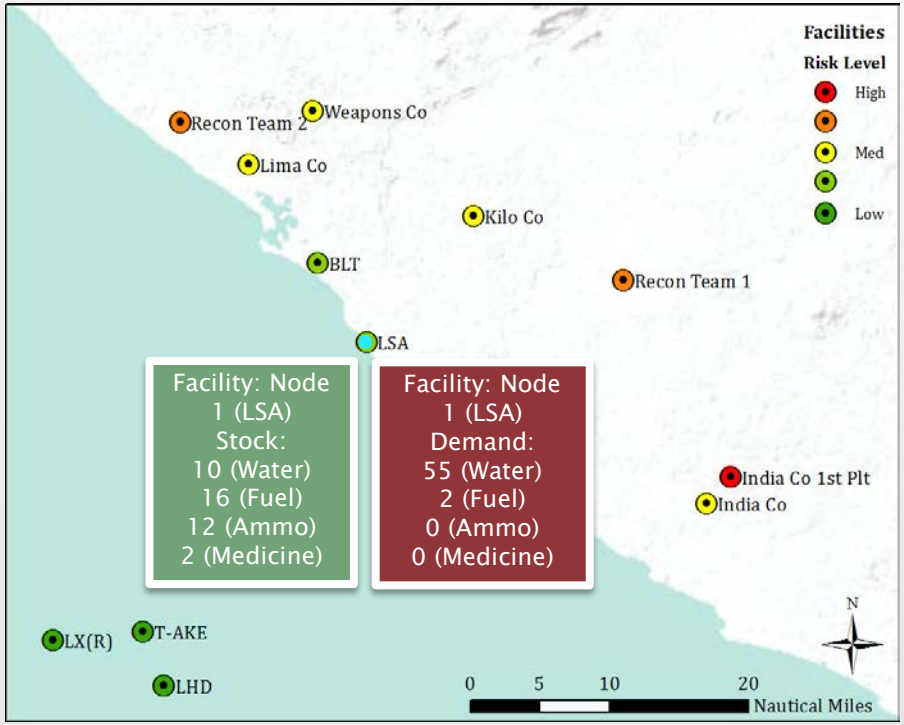
- Marine operations are changing
  - Logistics has to change with them
- Move from:
  - "Storming the beach"
  - Building an "Iron Mountain"
- To:
  - Distributed logistics
  - From a sea base – ships
  - Directly to units inland
- Want to move everything:
  - A Humvee
  - A single packet of food or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

# What Platforms are in the Mix?

- 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 Building/Visualization
- Computation of parameters necessary for the optimization process, e.g.
    - OD matrices
    - Network connectivity based on mode
- Means of Transfer to the OR side



# 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

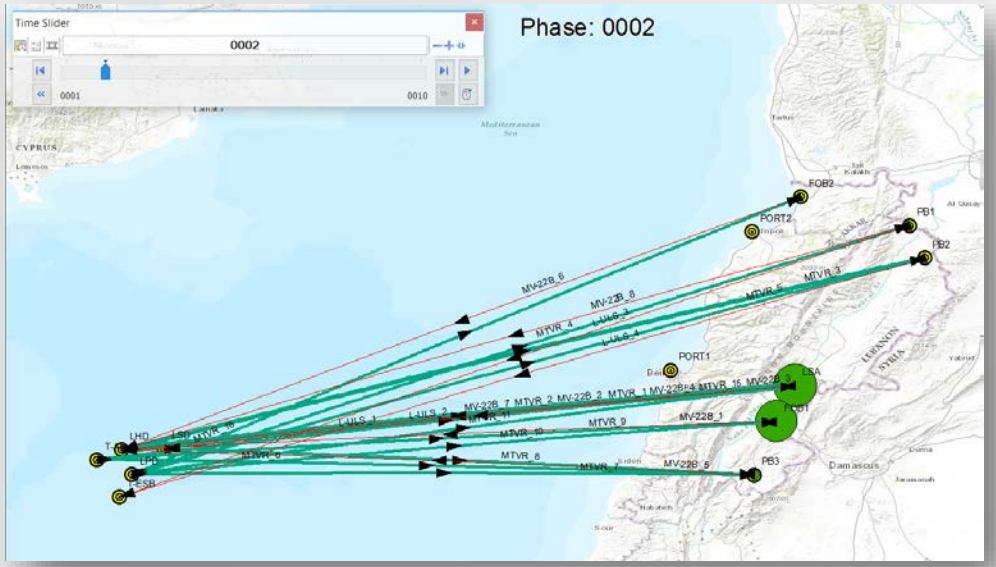
$$Min\ z = \sum_{(t,t')\in timeArcs} \sum_{(n,n')\in nodeArcs} \sum_v crew_v nodeRisk_{v,n} link_{v,n,n',t,t'}$$

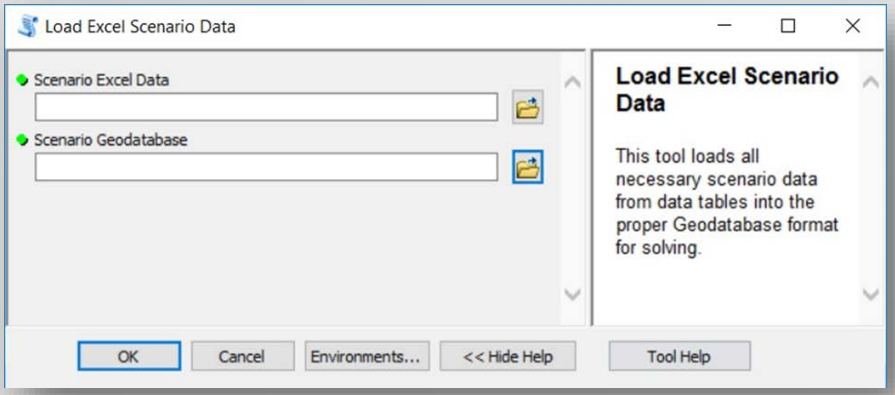
**Obj 3.** Minimize discounted, operating costs

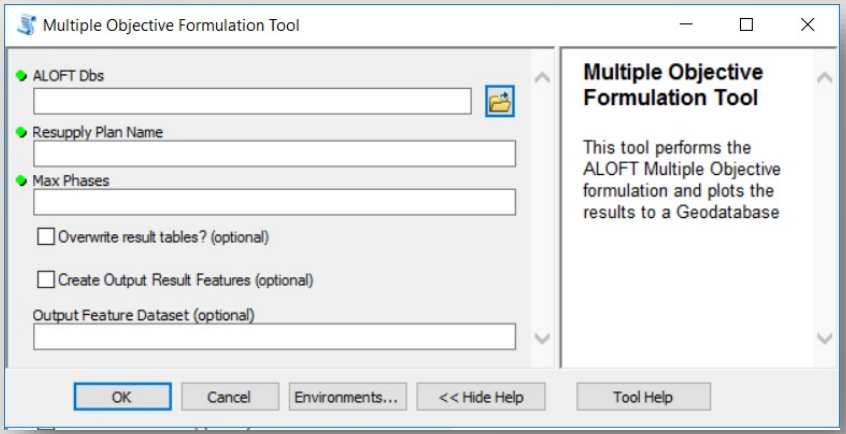
$$Min\ z = \sum_{(t,t')\in timeArcs} discount_t \sum_{(n,n')\in nodeArcs} \sum_v operatingCostPerDistanceUnit_v ranges_{n,n'} link_{v,n,n',t,t'}$$

# The ALOFT 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

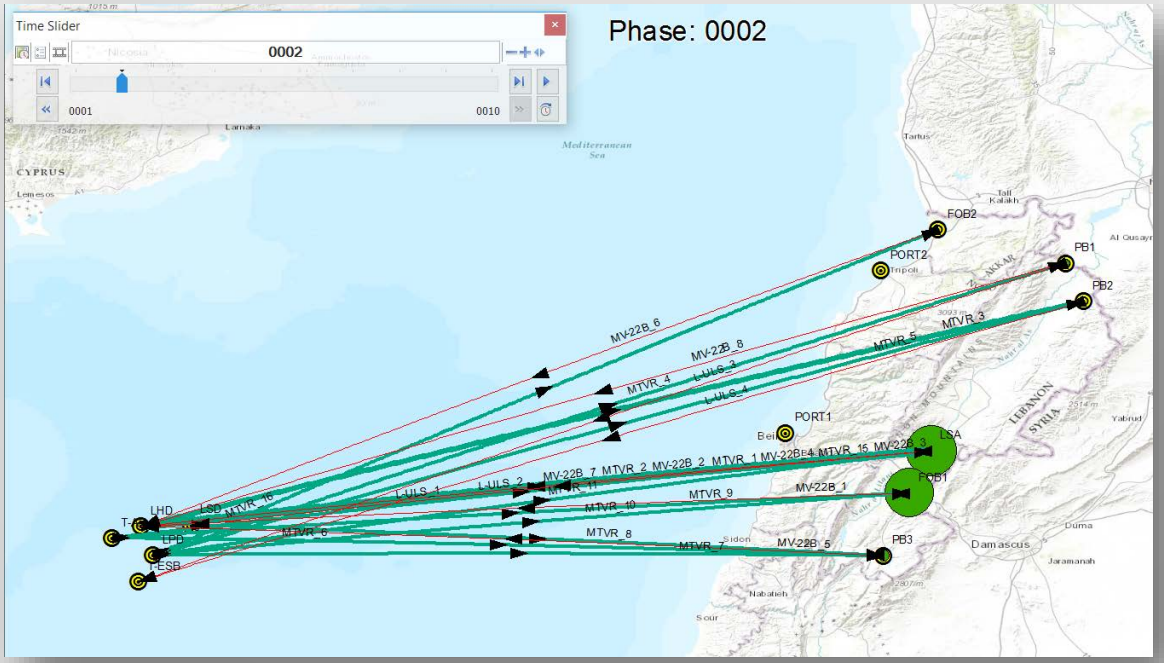


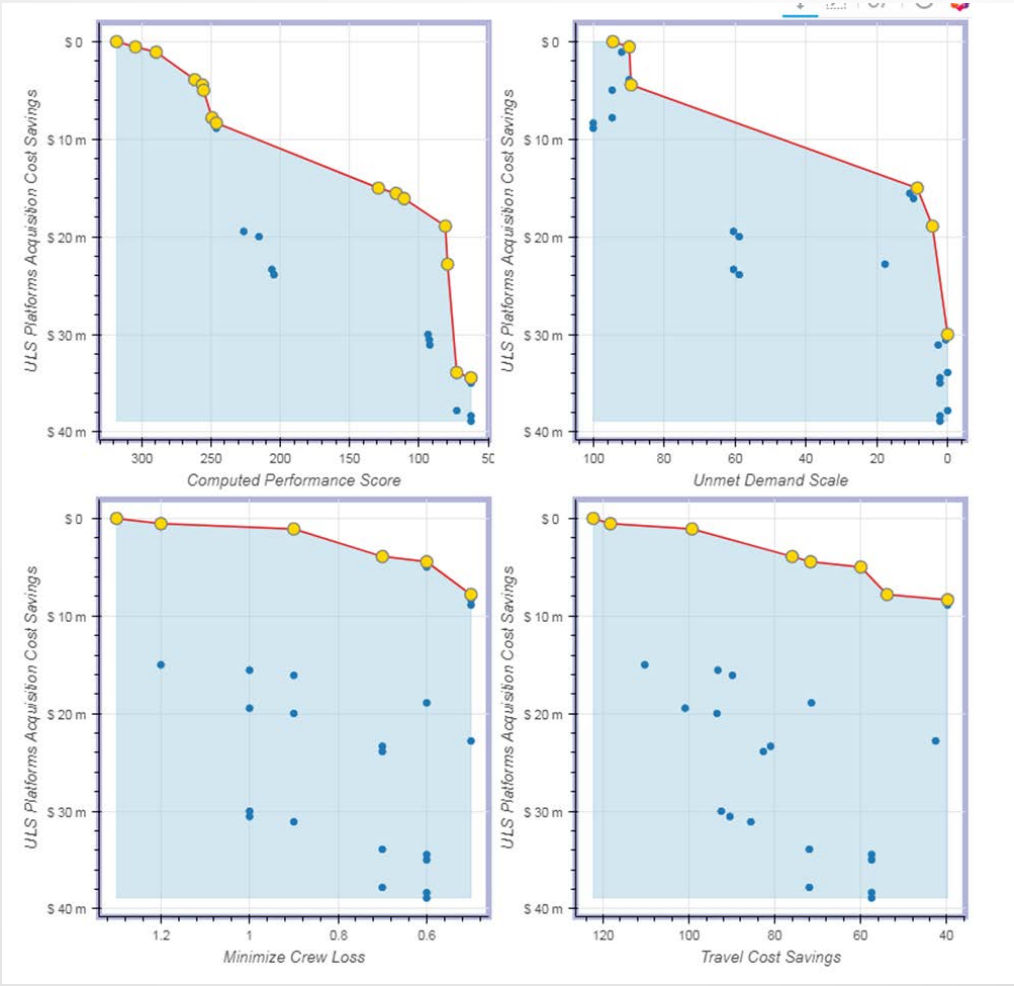
# What Does the Integration Buy Us?

- Logistics decision makers can build and modify spatially aware scenarios that they couldn't have with OR tools
- Optimal solution can be found with the LP solver which GIS can not provide
- Ability to visualize the solution provided valuable insight



# Platform Mix Analysis

- In order to analyze platform mix we must change platform mix
  - Solve over a range of mixes
    - Multiplies the results
    - Dozens of scenarios
    - Dozens of platform mixes
  - Again a data science problem
- One way to begin is Pareto tradeoff analysis
  - Compare performance to cost
  - Pareto optimal boundaries
  - Determine non-dominated solutions

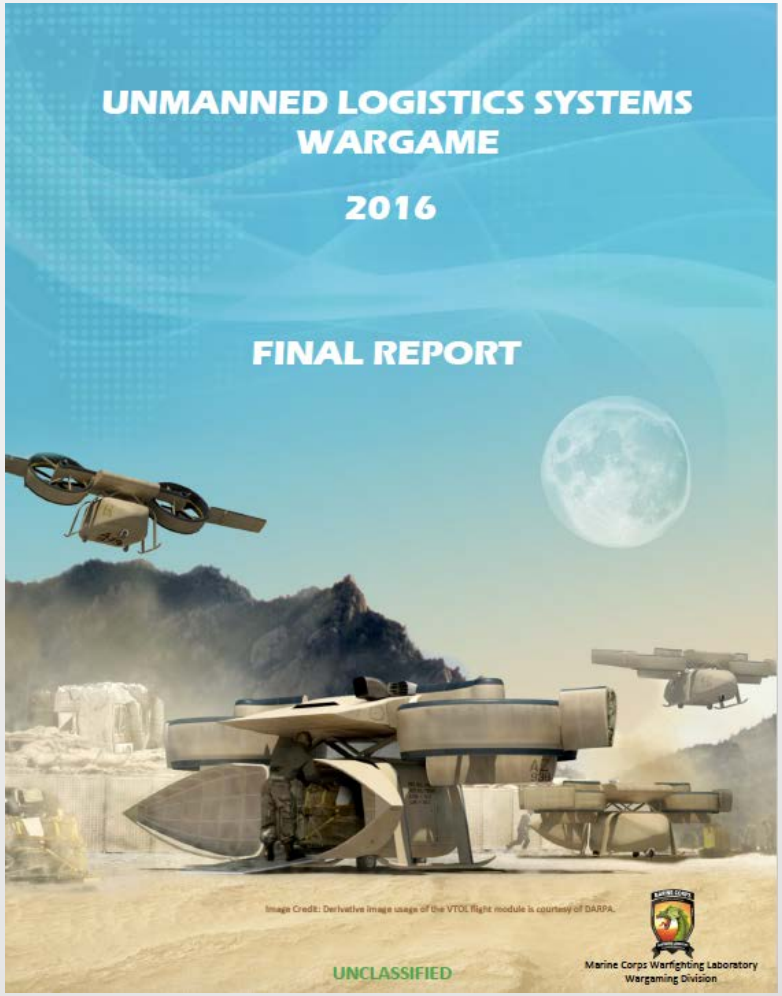


# Conclusion and Paths Forward

- We believe we have demonstrated
  - The value of integrating GISci and Location Science/OR
- We know that we can:
  - Model logistics scenarios
  - Solve them optimally
  - Interpret the results, including performance measures
- What is next?
  - Extending scenarios, Random scenarios
  - Sensitivity of solutions
  - Find the bounds of tractability
  - Additional models where facility location changes but mix stays the same
  - Add statistical tests of significance to the Pareto Performance Analysis
- Questions?

# 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)<br>6 (M-ULS)<br>12 (MTVR) |
| 2 | BLT | 12 | -9.520849 | 5.413603 | - |
| 3 | Kilo Co | 12 | [illegible] | 5.469172 | - |
| 4 | Lima Co | 12 | [illegible] | 5.528302 | 2 (S-ULS) |
| 5 | Weapons Co | 12 | -9.527214 | 5.589981 | - |
| 6 | India Co | 12 | [illegible] | 5.135118 | 3 (S-ULS) |
| 7 | India Co 1st Plt | 12 | -9.026156 | 5.1661 | - |
| 8 | Recon Team 1 | 12 | [illegible] | 5.394503 | - |
| 9 | Recon Team 2 | 12 | [illegible] | 5.577157 | - |
| 10 | LX(R) | 8 | [illegible] | 4.976472 | 1 (L-ULS) |
| 11 | T-AKE | 8 | [illegible] | 4.986402 | 1 (L-ULS) |
| 12 | LHD | 10 | [illegible] | 4.923426 | 3 (MV-22B)<br>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)<br>6 (M-ULS)<br>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)<br>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)