Terrain Analysis via Supervised Machine Learning

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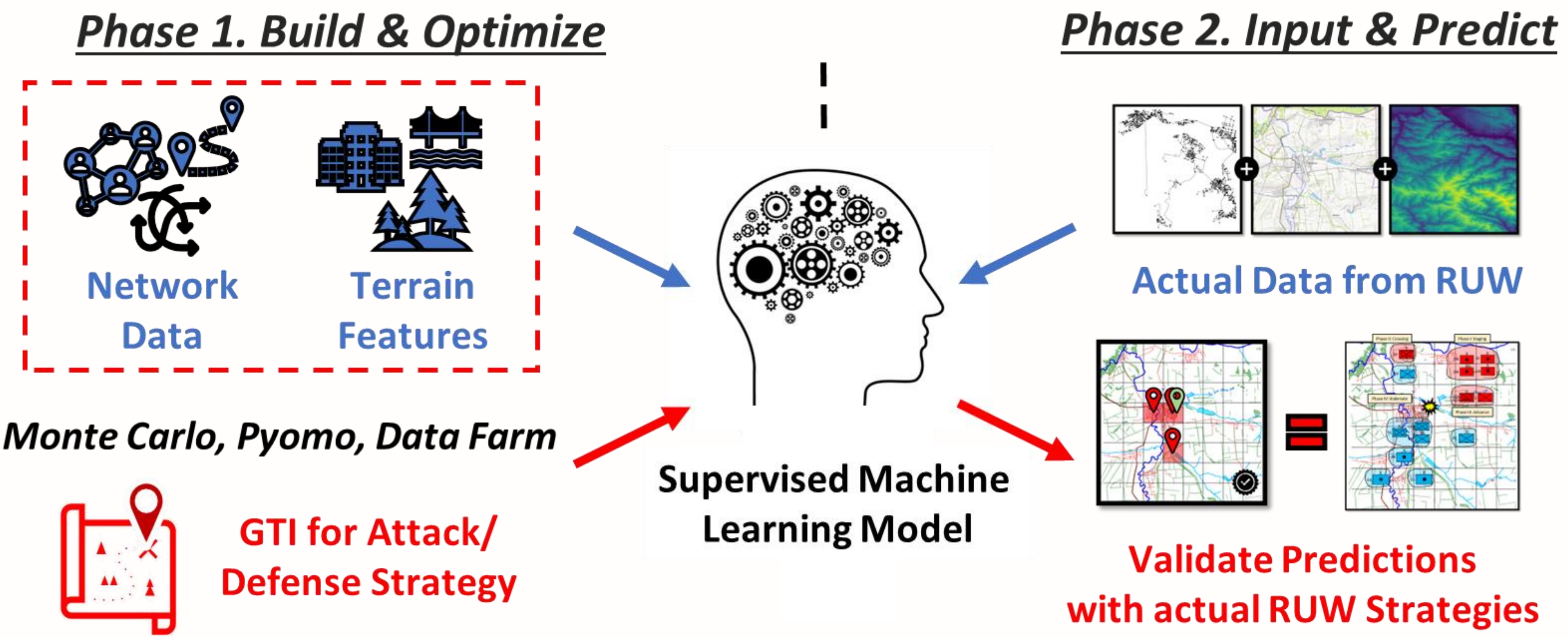
Bottom Line Up Front



Phase 1. Build & Optimize

Network Data

Terrain Features

Monte Carlo, Pyomo, Data Farm

GTI for Attack/ Defense Strategy

Supervised Machine Learning Model

Phase 2. Input & Predict

Actual Data from RUW

Validate Predictions with actual RUW Strategies

Motivation: Traditional terrain analysis depends on manual overlays and heuristics, which are slow, subjective, and hard to scale. Modern conflicts with drones, improvised munitions, and multi-axis threats exploit terrain in ways that make axis bound logic inadequate. **Objectives:** ***This thesis builds a supervised ML framework that transforms GEOINT into terrain intelligence.*** The model evaluated network analysis and terrain data to train a model to predict Ground of Tactical Importance (GTI). Validation against the 2022 Russia–Ukraine War (RUW) shows close alignment with Ukrainian defenses, demonstrating a scalable AI-enabled tool for decision support.

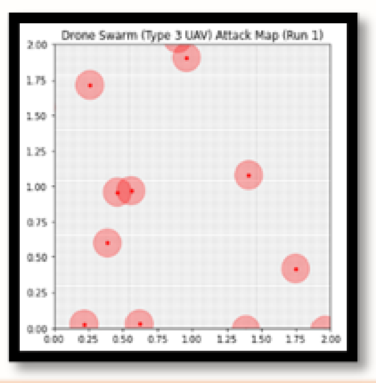
Methodologies

Results

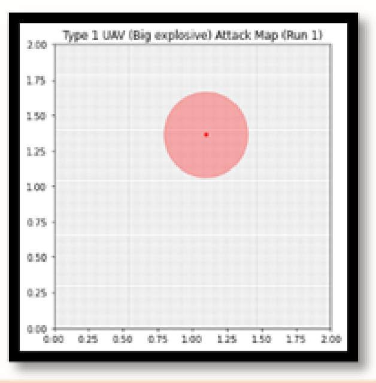
Weapon Effects Simulation

Weapons are defined by four core attack parameters and modeled with Monte Carlo simulation to capture probabilistic effects. Nelson–Swan Group Selection (NSGS) technique is applied to evaluate and rank weapon effectiveness for interdiction.

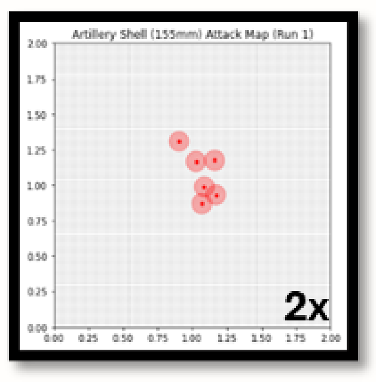
Number of Attacks	Fire count per strike
Dispersion Radius	Mean spread of impact
Targeting Error	Randomness from inaccuracy
Blast Radius	Damaged radius



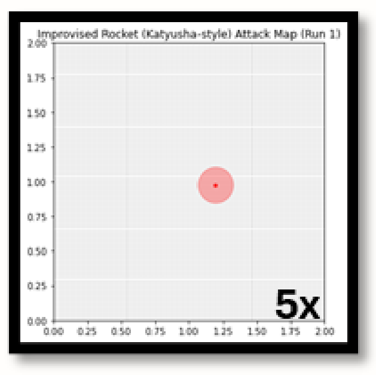
1. Drone Swarm (Type 3 UAV) [50, 1.5, 0.2, 0.1]



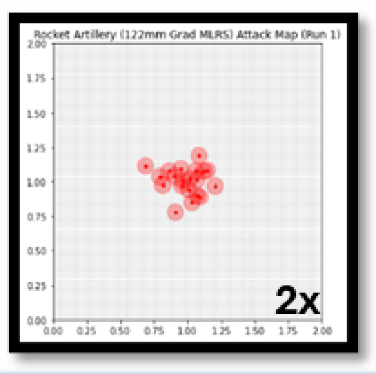
2. Single Big Drone (Type 1 UAV) [1, 0.25, 0.05, 0.3]



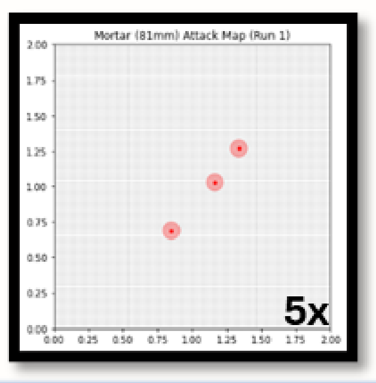
3. 155mm Artillery Shell (M795 HE) [2x6, 0.15, 0.12, 0.07]



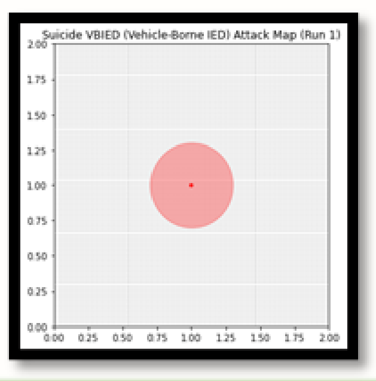
6. Improvised Rocket System [5x1, 0.07, 0.18, 0.13]



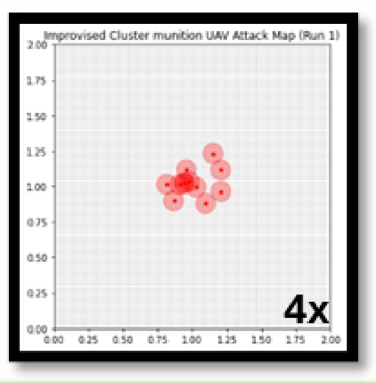
4. BM-21 Grad (122mm MLRS) [2x20, 0.1, 0.1, 0.06]



5. M252 81mm Mortar [5x3, 0.15, 0.12, 0.06]

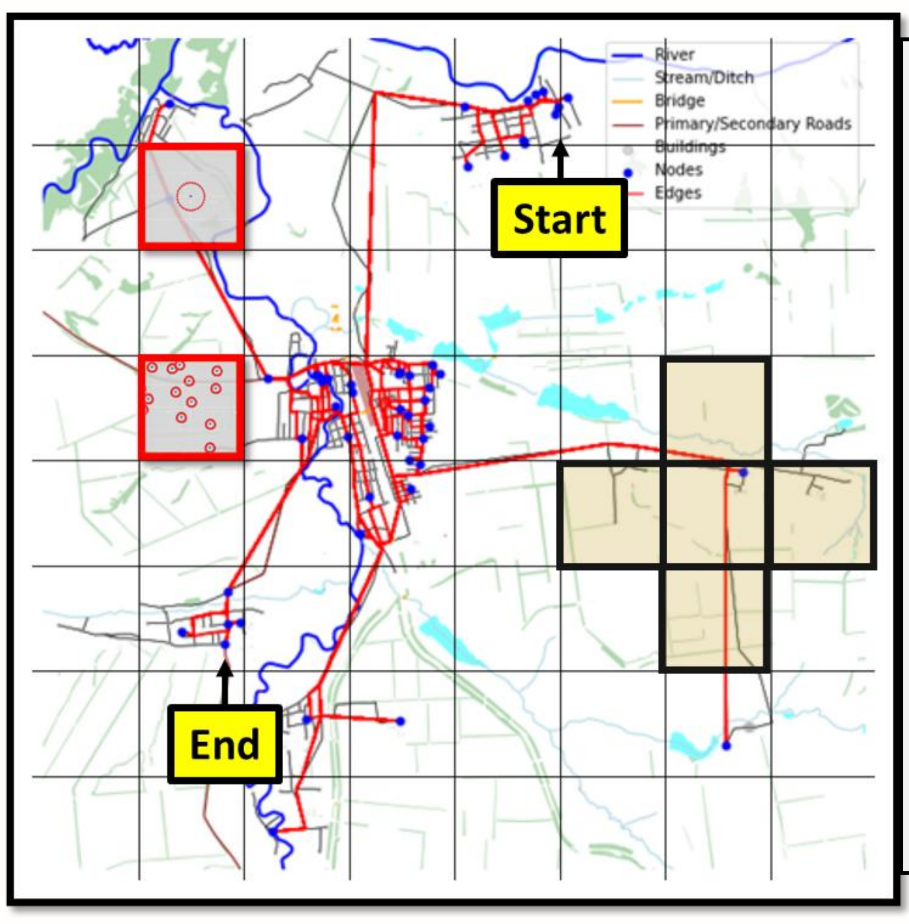


7. VBIED (Vehicle-Borne IED) [1, 0, 0, 0.3]



8. UAV-Borne Cluster Munitions [4x12, 0.1, 0.05, 0.05]

Networks Interdiction & Supervised Machine Learning



Each map contains:

1264 x Predictors:

- 640 x Network Data
- 640 x Terrain Feature
- 64 x Elevation Data

1 x Label:

- 1 of 64 Possible Grids from 8 x 8 Map

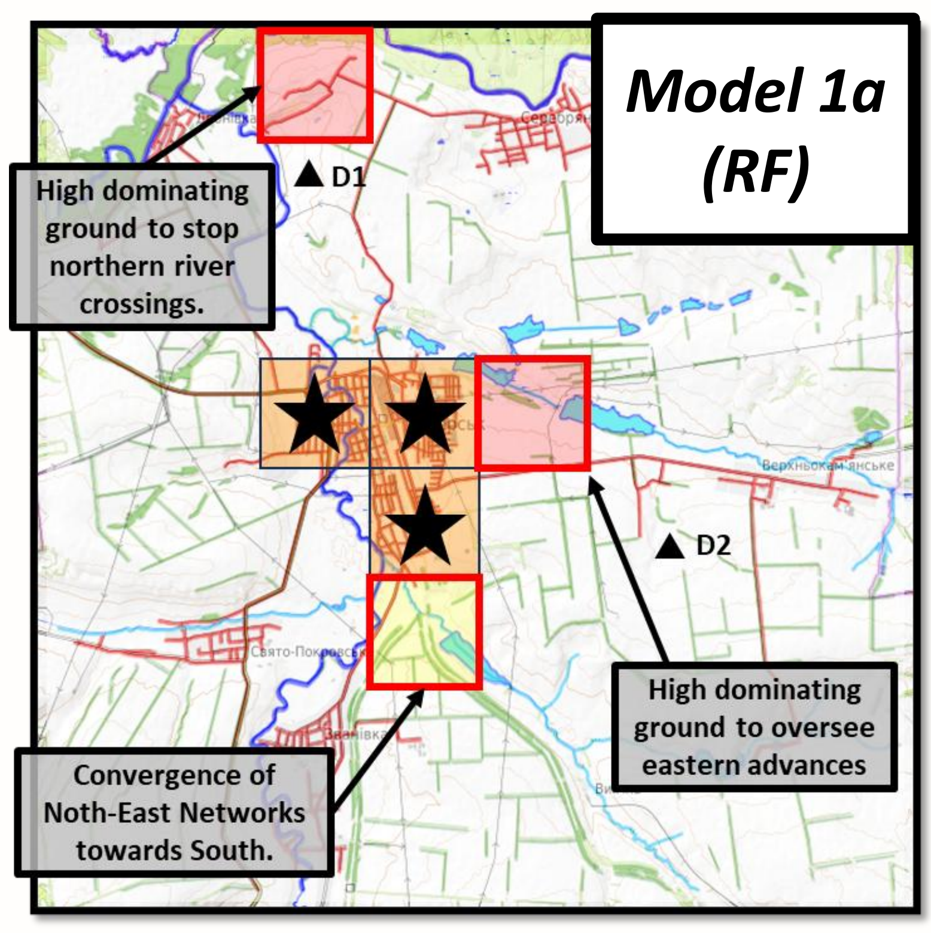
Predictors were extracted from OSMnx (road/terrain features) and USGS DEM (elevation).

Labels were generated by combining:

- **Network Disruption:** Simulate weapon effects, compute shortest path via Bender's decomposition, and evaluate max-min operational cost.
- **Terrain Advantage:** Weighted score of rivers, bridges, roads, urban areas, and elevation.

Both scores were normalized into an objective label.

The model was applied to Siversk in the 2022 RUW to test prediction fidelity.

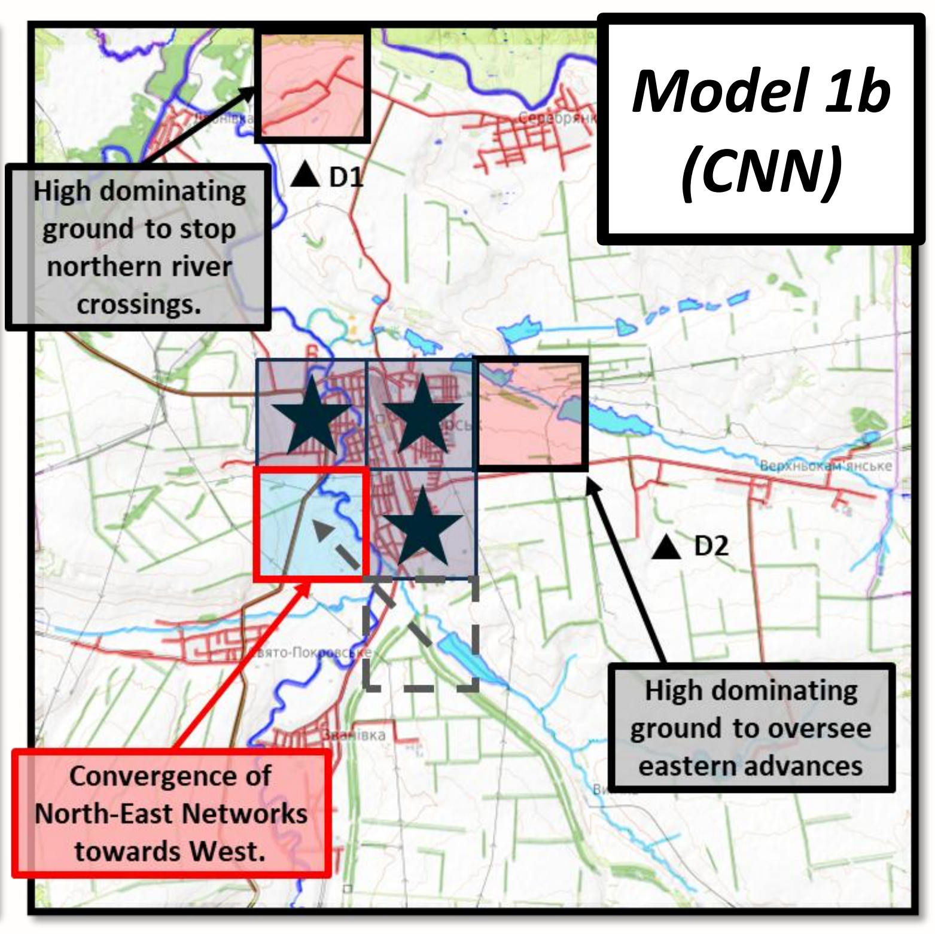


Model 1a (RF)

High dominating ground to stop northern river crossings.

Convergence of Noth-East Networks towards South.

High dominating ground to oversee eastern advances

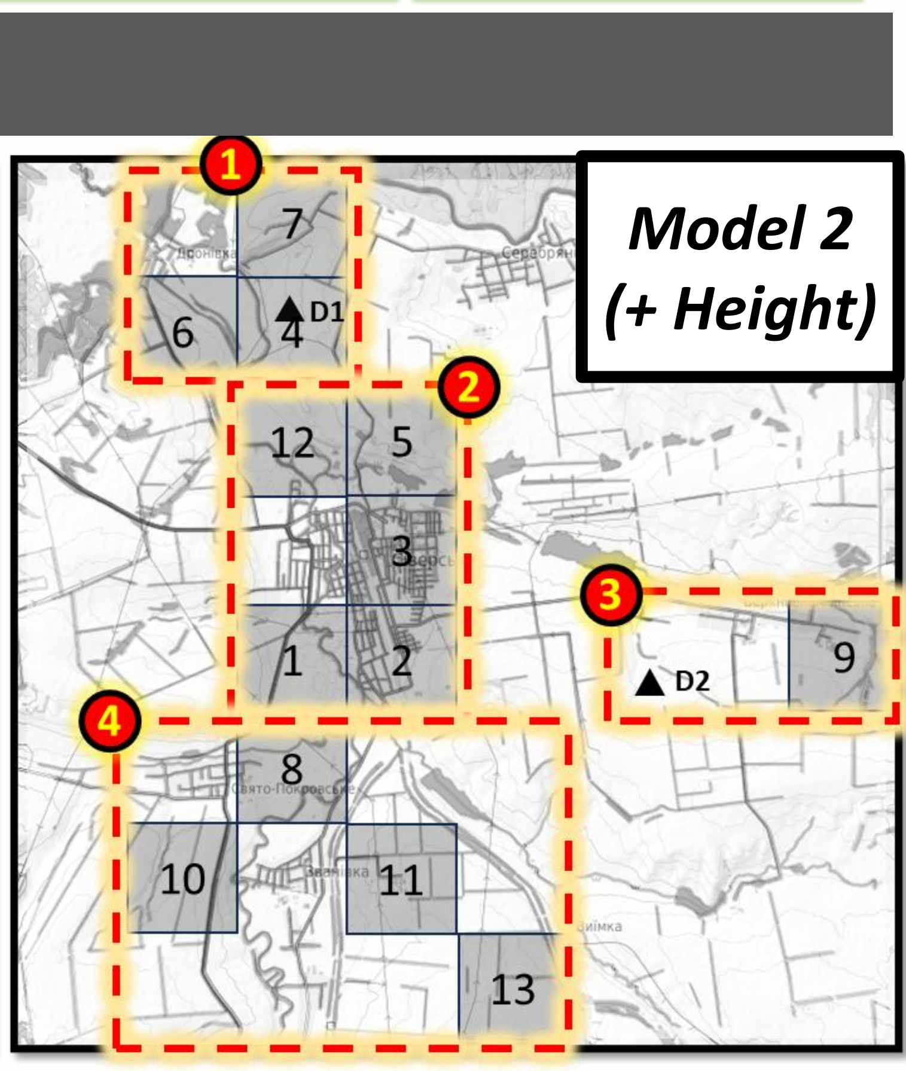


Model 1b (CNN)

High dominating ground to stop northern river crossings.

Convergence of North-East Networks towards West.

High dominating ground to oversee eastern advances



Model 2 (+ Height)

🟥	Actual Engagement Zone
🟦	CNN Prediction
🟨	RF Prediction
★	Overlap
▲	Dominating Gound
⬚	Effects of Terrain

The optimized model achieves **<u>Classification Accuracy of Top-3: 61.7%; Top-6: 82.3%.</u>**

- **<u>Model 1a/1b:</u>** RF and CNN models predicted similar GTIs with one different grid based on alternate constriction points, confirming similar terrain-analysis logic.
- **<u>Model 2:</u>** Adding elevation improved predictions, aligning it more closely with actual Ukrainian defenses (urban strongpoints, high ground, chokepoints).

(1) Dominating Ground D1 *overlooks Siverskyi Donets River, offering observation and fields of fire, <u>allows defenders to delay or block River Crossing Operations.</u>*

(2) Settlements in Siversk *contain dense urban terrain that provides cover and concealment, <u>allows defenders to use it as a strong defensive position.</u>*

(3) Dominating Ground D2 *oversees a Type X route from East that supports speedy projection of forces, <u>allows defenders to observe and interdict enemy maneuver.</u>*

(4) Constriction Points *where the roads lead into the depth of Ukraine from the East and West, <u>allow defenders to observe and interdict enemy maneuver.</u>*

Future Work

1. **<u>Predictors:</u>** Transform military GEOINT archives into actionable terrain features.
2. **<u>Labels:</u>** Derive CONOPS-based information from Operational Plans to train the Supervised Model with Military CONOPS Logic.