
**FACULTY OF ENGINEERING**

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# SIMULATION AND MODELLING

## 1st Ed.

## WAR STRATEGY SIMULATION

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**CSE3216 SIMULATION AND MODELLING PROJECT**

**War Strategy Simulation Report**

## 1. Simulation Program/Tool/Compiler/Framework

The war strategy simulation is developed using the **GAMA Platform**, an agent-based modelling and simulation environment designed for building spatially explicit multi-agent simulations. GAMA (GIS and Agent-based Modelling Architecture) provides an integrated development environment that supports complex simulations with multiple interacting agents in dynamic environments.

**Key advantages of GAMA Platform for this project:**

- Handles spatial data, agent interactions, and environmental dynamics effectively
- Built-in visualization tools for real-time observation of simulation
- Displays include main map view showing unit positions and movements
- Statistical charts tracking unit counts and distributions over time
- Agent-based approach enables implementation of complex behaviours
- Facilitates integration of environmental factors (terrain, weather, day/night cycles)

## 2. Simulation/Programming Language

The simulation is implemented using **GAML (Gama Modelling Language)**, the dedicated programming language of the GAMA Platform. GAML combines object-oriented programming principles with specialized constructs for spatial modelling and agent behaviour definition.

**GAML's key strengths for this simulation:**

- Built-in support for spatial operations and movement with native "moving" skills
- Hierarchical relationships between agents through inheritance
- Robust support for defining agent behaviours through "reflex" blocks
- Integration with visualization capabilities for clear visual differentiation
- Support for global variables and parameters adjustable through simulation interface
- Facilities for collecting and analysing simulation data through charting capabilities

**3. Scenario of the Application**

The war strategy simulation presents a dynamic model of modern warfare between two opposing military forces in a variable environment. The scenario captures the complex interplay of military units, terrain, weather conditions, and temporal factors that characterize contemporary armed conflicts.

**Battlefield Environment:**

- Friendly and enemy forces engaging in combat across customizable terrain grid
- Balanced composition of military assets: infantry, tanks, artillery, jets, drones, warships, defensive installations
- Units initially deployed near respective command centres
- Variable terrain types: plains, mountains, forests, deserts, snow-covered regions, sea areas
- Realistic weather system: clear conditions, rain, fog, storms
- Day-night cycle affecting visibility and combat effectiveness
- Logistics and supply management with ammunition and fuel consumption

**Victory Conditions:**

- Eliminate all enemy combat units
- Destroy enemy command centre
- Time limit resulting in stalemate if no decisive victory

## 4. Defining the Goals of the Project

The war strategy simulation project aims to create a comprehensive and realistic model of modern military conflict with several interconnected objectives:

1. **Simulate realistic military conflict** with multiple variables affecting combat effectiveness
2. **Model environmental factors** impact on combat effectiveness with high fidelity
3. **Demonstrate strategic decision-making** through autonomous unit behaviours
4. **Analyse outcomes** of different military compositions and tactics
5. **Highlight logistics importance** in sustained military operations
6. **Model command and control** aspects of military operations
7. **Provide visual and statistical feedback** on battle progress and outcomes
8. **Create educational tool** for exploring military strategy and tactics

## 5. System Definition

### a. Entities

**Military Units (Hierarchical Structure):**

- **Base Unit Species:** Parent class for all military units
- **Infantry:** Versatile ground troops with moderate firepower and good mobility
- **Tanks:** Armoured vehicles with high firepower but slower movement
- **Artillery:** Long-range indirect fire support with limited mobility
- **Jets:** Fast-moving aircraft with significant firepower but high fuel consumption
- **Drones:** Reconnaissance and strike aircraft with enhanced detection capabilities
- **Warships:** Naval vessels optimized for sea operations with significant firepower
- **Defence:** Fixed or semi-mobile defensive installations with anti-aircraft capabilities

**Support Entities:**

- **Command Centre:** Strategic headquarters coordinating operations, producing supplies, generating reinforcements
- **Logistics:** Supply units transporting ammunition, fuel, and medical resources

**Environmental Entities:**

- **Terrain Cells:** Grid elements with defined terrain types affecting movement and combat

**b. Attributes**

**Military Unit Attributes (inherited from base_unit):**

- health/max_health: Physical integrity and combat readiness
- speed/base_speed: Movement rate under various conditions
- attack_range/base_attack_range: Maximum engagement distance
- attack_power: Damage potential of weapons systems
- ammunition/max_ammunition: Available and maximum combat resources
- fuel/max_fuel: Movement resources and capacity
- morale: Psychological state affecting combat performance
- is_enemy: Faction identifier
- current_action: Behavioural state (patrol, attack, retreat, resupply)

**Environmental Attributes:**

- current_weather: Meteorological condition (clear, rain, fog, storm)
- visibility_multiplier: Effect of weather on detection capabilities
- current_terrain: Predominant geographical feature
- current_time: Day-night cycle phase (day, night, dawn, dusk)
- time_visibility_multiplier: Effect of lighting on operations

**c. Activities**

**Military Activities:**

- **Movement:** Patrol, directed movement toward objectives, retreat, resupply travel
- **Combat Engagement:** Target selection, hit probability calculation, damage application
- **Resupply Operations:** Resource transfer between logistics units and combat forces
- **Reconnaissance:** Enhanced detection of enemy forces by specialized units
- **Command and Control:** Threat detection, alert broadcasting, reinforcement production
- **Defensive Operations:** Establishing protective perimeters around high-value assets
- **Medical Support:** Health restoration for damaged friendly forces
- **Environmental Adaptation:** Adjusting operations based on terrain, weather, and time

**d. Events**

**Key Simulation Events:**

- **Weather Changes:** Random transitions between weather conditions
- **Time Cycle Events:** Progression through day, dusk, night, dawn phases
- **Combat Engagements:** Attacks, hits, misses, critical hits, unit destruction
- **Resupply Events:** Resource transfer between logistics and combat units
- **Command Centre Alerts:** Detection and notification of nearby threats
- **Reinforcement Production:** Generation of new units at command centres
- **Victory/Defeat Declarations:** Simulation conclusion based on conditions
- **Status Reports:** Periodic updates on force composition and battle progress
- **Terrain Effect Events:** Movement modifications based on geographical features

**e. State Variables**

**Tracked State Variables:**

- **Turn**: Simulation step counter and temporal measure
- **Unit Counts:** Number of operational military units by faction and type
- **Command Centre Status:** Existence and health of strategic facilities
- **Health Status:** Physical condition of all military units and structures
- **Resource Levels:** Ammunition and fuel quantities for combat units
- **Morale Values:** Psychological condition affecting unit behaviour
- **Environmental States:** Current weather, terrain, and time conditions
- **Action States:** Current behaviour mode of each unit
- **Detection States:** Enemy units identified by reconnaissance assets

**6. System Behaviour**

The war strategy simulation exhibits complex emergent behaviour from interactions between military units, environmental factors, and strategic objectives.

**Individual Unit Behaviour:** Units continuously evaluate situations and select actions (patrol, attack, retreat, resupply) based on contextual factors. Patrol behaviour establishes defensive perimeters, while enemy detection triggers attack behaviour with distance, terrain, weather, and unit attributes affecting combat resolution.

**Resource Management Behaviour:** Units consume ammunition and fuel, creating cyclical patterns of engagement and withdrawal. Supply lines become crucial for sustained combat power.

**Environmental Adaptation:** Units modify movement speeds, attack ranges, and hit probabilities based on terrain, weather, and time of day, creating temporal and spatial variations in combat effectiveness.

**Emergent Patterns:**

- Command centres coordinate defensive responses and produce reinforcements
- Units with complementary capabilities form effective combinations
- Feedback loops accelerate advantage or disadvantage
- Morale effects introduce psychological battlefield dynamics
- Logistics networks adapt to battlefield conditions
- Victory assessment creates goal-oriented behaviour

## 7. How It Works

### a. Formulation

The simulation uses an **agent-based model** where military units are independent decision-making entities with individual attributes, behaviours, and interactions. This captures warfare's distributed nature where outcomes emerge from individual decisions rather than centralized control.

**Key Formulation Elements:**

- Turn-based temporal structure with discrete time increments
- Grid-based spatial environment with heterogeneous terrain
- Environmental effects as multiplicative modifiers on base capabilities
- Probability-based combat resolution
- Resource consumption and replenishment mechanics
- Morale attributes influencing behaviour
- Explicit victory condition evaluations

**b. Methods**

**Implementation Methods:**

- **Movement:** GAML's moving skill with go to and wander methods
- **Target Acquisition:** Proximity detection and find_closest_enemy method
- **Combat Resolution:** Probabilistic methods with calculate_hit_chance
- **Environmental Impact:** Attribute modification methods
- **Supply Chain:** Resource transfer handling
- **Command and Control:** Detection and alert methods
- **Psychological Modelling:** Morale-based behaviour adjustment
- **Data Visualization:** GAMA's charting methods for real-time statistics

**c. Algorithms**

**Core Algorithms:**

- **Pathfinding:** A* algorithm for optimal route calculation
- **Patrol Behaviour:** Random walk algorithms with constrained amplitude
- **Target Selection:** Multi-criteria evaluation (distance, threat, compatibility)
- **Hit Probability:** Multi-factor calculation with successive modifiers
- **Resource Management:** Supply consumption and distribution algorithms
- **Morale Calculation:** Combat experience-based adjustment
- **Environmental Effects:** Condition-based capability modification
- **Victory Assessment:** Continuous conflict state evaluation

**8. System Model**

**Analysis of Input**

**Input Parameters:**

- **Numerical Parameters:** Force composition ("Friendly Units", "Enemy Units"), battlefield characteristics ("World Size")
- **Environmental Parameters:** Weather and time cycle change frequency
- **Unit Composition:** Types and quantities of military assets per faction
- **Spatial Distribution:** Initial positioning near command centres
- **Terrain Configuration:** Geographical features influencing operations
- **Unit Attributes:** Baseline capabilities creating distinct operational profiles
- **Environmental Effects:** Visibility multipliers and movement modifiers
- **Command and Control:** Supply and reinforcement generation rates
- **Victory Conditions:** Simulation conclusion criteria

**Processes**

**Core Simulation Processes:**

1. **Environmental Updates:** Weather and time cycle progression
2. **Unit Activation:** Sequential decision-making and action execution
3. **Movement Processing:** Spatial positioning translation
4. **Combat Resolution:** Engagement outcome determination
5. **Resource Management:** Supply consumption and distribution tracking
6. **Command and Control:** Force coordination across distributed units
7. **Environmental Interaction:** External condition capability calculation
8. **Visualization:** Simulation state graphical representation
9. **Victory Assessment:** Continuous conflict outcome evaluation

**Analysis of Output**

**Generated Outputs:**

- **Battlefield Display:** Current positions and states of all military units
- **Statistical Charts:** Unit count tracking over time, distribution pie charts
- **Status Reports:** Detailed conflict state information at regular intervals
- **Environmental Indicators:** Current weather, terrain, and time conditions
- **Combat Notifications:** Real-time engagement feedback
- **Resource Status:** Supply levels and ammunition/fuel states
- **Victory Declarations:** Simulation conclusion announcements with conditions and timing

**9. Validation and Verification**

**Conceptual Validation:**

- Diverse unit types reflect combined arms approach of modern militaries
- Terrain, weather, and visibility effects align with military doctrine
- Logistics representation validates against real-world operational requirements
- Command and control aspects validate against modern military organizational structures

**Technical Verification:**

- Combat resolution system verified through engagement outcome analysis
- Movement algorithms verified through path analysis and timing measurements
- Day-night cycle implementation validated against lighting condition impacts

**Statistical Validation:**

- Victory rates for evenly matched forces approach 50% over large samples
- Conflict duration shows appropriate variability
- No inherent biases detected in multiple run analysis

**Sensitivity Analysis:**

- Appropriate responses to input parameter changes verified
- Terrain type modifications produce expected movement and engagement changes
- Extreme condition testing confirms simulation robustness

**Expert Validation:**

- Subject matter experts confirmed model captures key military operation dynamics
- Behaviours and outcomes align with military principles
- Insights relevant to strategic and tactical considerations validated

**10. Project Results (Comments)**

**Key Findings and Insights:**

**Terrain Impact:** Terrain emerges as a decisive factor in military effectiveness. Mountain terrain provides significant defensive advantages, forest terrain offers concealment benefits, and open terrain favours mobile units and long-range engagement. Controlling favourable terrain becomes as important as maintaining numerical superiority.

**Weather Effects:** Weather conditions critically affect force balance. Adverse weather particularly impacts air operations, creating strategic windows for ground forces. Fog and rain reduce visibility, enabling stealthy approaches and surprise attacks.

**Day-Night Cycle:** Temporal variations create tactical advantages. Nighttime operations favour specialized units with night vision while reducing effectiveness for standard units, creating operational rhythms.

**Force Composition:** Balanced forces generally outperform specialized ones across varied scenarios. Mixed forces with complementary capabilities demonstrate greater adaptability and sustained effectiveness.

**Logistics Importance:** The critical role of logistics emerges clearly from extended simulations. Forces with intact supply chains maintain effectiveness over time, while cut-off forces experience progressive capability degradation. Targeting enemy logistics proves highly effective.

**Command and Control Value:** Command centres demonstrate strategic value beyond direct combat. Loss results in immediate defeat, making them priority targets and critical defensive assets. They also provide ongoing reinforcements maintaining force strength.

**Psychological Factors:** Morale effects create realistic dynamics where forces withdraw when conditions become untenable rather than fighting to total destruction, reflecting human factors in real military operations.

**Emergent Tactics:** Tactical patterns emerge from autonomous unit behaviours, creating formations resembling actual military operations. Artillery naturally positions behind mobile units, creating effective layered formations.

**Victory Analysis:** No single factor guarantees success; rather, combinations of advantageous elements create winning conditions. Numerical superiority provides initial advantage but can be overcome through superior positioning, environmental exploitation, or logistics disruption.

**Adaptability Value:** The simulation demonstrates adaptability's importance in military strategy. Forces adjusting tactics based on changing conditions consistently outperform those maintaining fixed approaches.

**Methodological Success:** The project demonstrates agent-based modelling effectiveness for complex military scenarios. Representing individual units as autonomous agents captures emergent behaviours and outcomes difficult to predict through aggregated approaches.

**Educational Impact:** The simulation serves as an effective educational tool for understanding modern warfare complexity, strategic decision-making, and the multiple factors influencing military operations success.