Optimization-based Agent Simulations for Evaluating the SPEYES$^1$ System

Candra Meirina*
Feili Yu*
Sui Ruan*
Georgiy M. Levchuk (Aptima Inc.)
Prof. Krishna R. Pattipati*
Prof. David L. Kleinman (NPS)
Robert L. Popp

*Dept. of Electrical and Computer Engineering
University of Connecticut
Contact: krishna@engr.uconn.edu (860) 486-2890

10th International Command and Control Research and Technology Symposium
June 13 - 16, 2005

$^1$Sensing and Patrolling Enablers Yielding Effective SASO (Stability and Support Operations)
Outline

- Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES
  - Stability and Support Operations – SASO
  - Quantifying SPEYES System

- Simulating SPEYES System
  - Mission Scenario
  - Blue Force Organization and Asset Allocation

- Optimization-based Agent for Distributed Dynamic Decision-making – DDD
  - System Architecture
  - Task Processing Phase

- Simulation Results
  - Calibration of Agent-Human Results
  - Quantifying Force Multiplying Effects of SPEYES System
  - SPEYES Component Technology Benefits

- Summary of Findings
• **Stability and Support Operations – SASO**
  – Military activities during peacetime and post-conflict not involving force-on-force combat

• **Key SASO challenges**
  – Poor situation awareness (SA): low familiarity with mission environment
  – Difficult targets/enemy identification: Combatants intermingled with non-combatants
  – Lethal asymmetric threats: Improvised Explosive Devices (IEDs), Vehicle Borne IEDs, Rocket Propelled Grenades (RPGs), suicide bombers, snipers, …

**SPEYES SASO challenge**
Design and demonstrate an innovative force-multiplying SASO security system that enhances SASO effectiveness ⇒ provide security for forces, local population, and infrastructures

**Utilize three component technology enablers for SASO oriented security system:**

  – **Sensing technologies**: low-cost, easily-emplaced, camouflaged sensors (video, acoustic, Infrared) to provide urban situation awareness
  – **Shaping technologies**: non-lethal, and explosives ordinance disposal (EOD) tools to diffuse adversaries, crowds, and improvised explosive devices …
  – **SA/C² technologies**: planning, dynamic resource management, simulation, mission rehearsal …
Challenge

Evaluate systematically the impact of each SPEYES technology ⇒ Quantify the force multiplying effects
Fundamental issues in SPEYES: resource allocation, deployment, and incidence forecasting
⇒ also fundamental issues in urban operations research
⇒ utilize the Square Root Law to show the improvements in timeliness, efficiency, and effectiveness due to SPEYES technologies

Square Root Law:
- The response-time $T_r$ of $N_0$ patrol units is proportional to the square root of the effective area $A$.

$$E[T_r] \approx E[D] = \frac{c}{v_c} \sqrt{\frac{A}{N_0 (1 - \rho)}}$$

- The effective area of coverage is proportional to the number of idle patrol units.

$$A = \left[ \frac{E[T_r]v_c}{c} \right]^2 N_0 (1 - \rho)$$

For equal response time with and without SPEYES technologies ⇒ the same number of forces with SPEYES technologies can cover a larger area ⇒ reduced size force can cover the same area.

Note:
- $D$ is distance
- $c$ is a constant
- $\rho$ is utilization rate
- $v_c$ is patrol speed
Simulating SPEYES System – 1

Mission Scenario

- Demonstrate force multipliers for Cordon and Search missions through simulation-based approach in DDD environment

- Distributed Dynamic Decision-making (DDD) Simulator
  - Distributed Discrete-Event Decision-Making Simulation tool

- Methodology
  - Calibrate agents’ behaviors to those of human-in-the-loop simulations
  - Utilize Monte Carlo simulation to generate performance measures, sensitivity analyses,...
  - Quantify performance improvements due to SPEYES technologies in terms of timeliness, effectiveness, and efficiency of operations

Mission Scenario

- Cordon and Search at National Training Center in Ft. Irwin, California

- Order: assign a Battalion of 4 Companies to conduct multi-phase operations to maintain security and stability in Tiefort City (TC) ⇒ secure the power plant in TC and suppress an ongoing insurgency

- Companies CHARLIE and BRAVO assigned to cordon, search, and secure operations in TC ⇒ move from Forward Operating Base (FOB) to major entrance of TC ⇒ ready to commence operations
Simulating SPEYES System – 2
Blue Force Organization and Asset Allocation

Organizational Assets

- **OPS**: Operations squad (1 Tank + 1 Bradley)
- **AST**: Anti-sniper team (2-3 soldiers)
- **MFT**: Mobile fire team (5 soldiers)
- **ENGR**: Engineer squad (8-10 soldiers)
- **MP**: Military police squad (8-10 policemen)
- **MED**: Medic squad (8-10 medics)
- **IPOL**: Iraqi police squad (8-10 policemen)
- **EOD**: Explosive disposal squad (5-8 soldiers)
- **Q36**: Anti-mortar radar
- **HELO**: Helicopter

SPEYES Technologies

- **CAM**: Camera/sensor cluster
- **UAVS**: SPEYES UAV
- **ASD**: Acoustic sniper detection
- **OPT**: Sniper optics detection
- **DEW**: Directed Energy Force
- **FOAM**: Non-lethal foam calmative dispenser
- **REOD**: Robotic explosive ordinance disposal
- **ACOU**: Acoustic force projection
Optimization-based Agent for DDD – 1
System Architecture

- Flexible mid-fidelity team-in-the-loop simulator
- Scenario controller: dynamic events and data updates, mission tempo & rhythm, execution processing …

- Rules of engagements
- Execution monitoring
- Performance measures

- Maintain situation awareness
- Generate event-based schedule
- Distribute DM-task assignment
- Conduct task processing

DDD Simulator

DDD-State Module

DDD-Local Module

Shared Database

Agent situation awareness

Agent Local Database

Task Processing
Optimization-based Agent for DDD – 1
Task Processing Phase

Task Processing Stages in DDD

Task Appears
- Detect Task
- Measure Task
- Identify Task
- Allocate Assets
- Prosecute
- Execute (Attack)
- Task Completes

Shared Database
Centralized Asset-Task Assignment
Decentralized Task Execution

Agent Local Database

Note: Overall communication delay across the hierarchy is in general 5 mins (15 secs simulation time)
Analysis and Simulation Results – 1
Calibration of Agent-Human Results

Agents’ behaviors are comparable to those of human-in-the-loop simulations

- Agents perform same task sequences as human players
- Consider % performance improvement with SPEYES relative to without SPEYES
- Difference in performance improvements are within 2–19% for individual metrics

One-to-one Comparison of Human and Agent Simulations

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Human</th>
<th>Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W/O SPEYES</td>
<td>With SPEYES</td>
</tr>
<tr>
<td>Mission completion time (hours:min)</td>
<td>11:57</td>
<td>6:24</td>
</tr>
<tr>
<td># MFT Engagements</td>
<td>73</td>
<td>29</td>
</tr>
<tr>
<td>Total Throughput (tasks per hour)</td>
<td>9.4</td>
<td>18.3</td>
</tr>
<tr>
<td># Enemy Attacks (snipers, RPGs, IEDs)</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Troop efficiency (#troops per troop task)</td>
<td>1.07</td>
<td>2.08</td>
</tr>
<tr>
<td># Casualties</td>
<td>41.5</td>
<td>4</td>
</tr>
<tr>
<td>Sniper Detection Rate (of snipers detected/hr)</td>
<td>3.6</td>
<td>10.9</td>
</tr>
</tbody>
</table>
• Integration of sensing, SA/C², and shaping technologies ⇒ significant performance improvements to the force across all measures

• Significant performance improvements (in 4 out of 6 measures) over regular SASO with a full force at 50%-reduced force ⇒ confirming the force multiplier effects of SPEYES technologies
**Relative improvements due to SPEYES**

- Sensing technologies: $\uparrow$ throughput by 11%
- SA/C² technologies: $\uparrow$ throughput by 49%
- Shaping technologies: $\uparrow$ throughput by 12%

**Relative improvements due to SPEYES**

- Sensing technologies: $\downarrow$ casualties by 29%
- SA/C² technologies: $\downarrow$ casualties by 62%
- Shaping technologies: $\downarrow$ casualties by 2%
Summary of Findings

Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES

- Motivation: SASO challenges – poor SA, difficult targets ID, lethal asymmetric threats, ...
- Design an innovative force-multiplying SASO security system to enhance SASO effectiveness – SPEYES
- Need to quantify the force multiplying effects of SPEYES technologies

Evaluating SPEYES System via Agent-based Simulations

- Mission Scenario: Assign Battalion of 4 Companies to conduct Cordon and Search Tiefort City – maintain security and stability, and suppress an ongoing insurgency
- Platform: Distributed discrete-event decision-making simulation tool – DDD Simulator
- Methodology: Calibrate agents' behaviors to human-in-the-loop simulations ⇒ quantify performance improvements in terms of timeliness, effectiveness, and efficiency of operations

Analysis and Simulation Results

- Agent Calibration: Agents' behaviors are comparable to those of human-in-the-loop simulations
- Force Multiplying Effects: Significant performance improvements to the force
  - Better sensing & shaping technologies ⇒ increase detection of enemies ⇒ decrease the # of attacks ⇒ reduce casualties ⇒ improve throughput and troop efficiency
  - Improve (in 4 out of 6 measures) over regular SASO with a full force, at 50%-reduced force with SPEYES
- SPEYES Component Technology Benefits
  - Throughput improvements: Sensing 11% – SA/C2 49% – Shaping 12%
  - Casualty reduction: Sensing 29% – SA/C2 62% – Shaping 2%

Future: DARPA is planning to build a physical SPEYES System
<table>
<thead>
<tr>
<th>Class</th>
<th>Technology</th>
<th>Performance Profile</th>
<th>Application Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing</td>
<td>Video</td>
<td>360 degree rotation. Auto-focus up to 600 m</td>
<td>Place a grid of 3 cameras in position on watch tower for persistent surveillance instead of 6 soldiers.</td>
</tr>
<tr>
<td></td>
<td>Acoustic</td>
<td>Locate source of weapon discharge from a distance of 100s meters.</td>
<td>Faster neutralization of snipers; decrease in casualties</td>
</tr>
<tr>
<td></td>
<td>Explosive sniffers grid</td>
<td>Grid detecting IEDs, VBIEDs at 10-20 meters</td>
<td>Increased throughput at checkpoints; decreased casualties &amp; asset damage decrease</td>
</tr>
<tr>
<td>SA/C2</td>
<td>Sensor placement</td>
<td>Optimized grid-based placement every 100 m</td>
<td>Faster hot-spot detection and increased throughput</td>
</tr>
<tr>
<td></td>
<td>Distributed planning &amp; resource mgnt</td>
<td>High-bandwidth one-to-one communication</td>
<td>Reduce manning for patrol due to mutual support</td>
</tr>
<tr>
<td></td>
<td>Data fusion</td>
<td>Predictive threat dynamics models</td>
<td>Acoustic and video data fusion estimates crowd size, hostility, and predicts dynamics</td>
</tr>
<tr>
<td></td>
<td>NL-foam</td>
<td>Non-toxic. Hard to remove. Easily transportable. Short curing time.</td>
<td>Use foam to secure buildings (e.g. weapons cache) instead of leaving 5-10 soldiers</td>
</tr>
<tr>
<td>Shaping</td>
<td>REOD</td>
<td>Clear IEDs remotely from a distance of up to 600 meters.</td>
<td>Send REOD to neutralize IEDs instead of human EOD squad; reduce casualties, increase throughput</td>
</tr>
<tr>
<td></td>
<td>Non-lethal High-power Micro Wave</td>
<td>Disrupts electronics at range in 10s of meters.</td>
<td>Stop suspect vehicles to search; reduce friendly and civilian casualties; reduce manning at checkpoint</td>
</tr>
<tr>
<td></td>
<td>Smart patrols</td>
<td>Threat prediction &amp; optimal path planning for 1000 km²</td>
<td>Decreased response time. Threat avoidance reduces casualties</td>
</tr>
</tbody>
</table>
Organizational Assets

- **OPS**: operations squad (1 Tank + 1 Bradley)
- **AST**: anti-sniper team (2-3 soldiers)
- **MFT**: mobile fire team (5 soldiers)
- **ENGR**: engineer squad (8-10 soldiers)
- **MP**: military police squad (8-10 policemen)
- **MED**: medics squad (8-10 medics)
- **IPOL**: Iraqi police squad (8-10 policemen)
- **EOD**: explosive disposal squad (5-8 soldiers)
- **Q36**: anti-mortar radar
- **HELO**: helicopter

SPEYES Technologies

- **HSMAP**: sensor placement, hot-spot mapping
- **DPLAN**: distributed planning & resource management
- **SFUSE**: sensor and data fusion models
- **CAM**: camera/sensor cluster
- **UAVS**: SPEYES UAV
- **DEW**: directed energy force
- **FOAM**: non-lethal foam
- **CLM**: calmateive dispenser
- **CBSM**: crowd detection and size
- **REOD**: robotic explosives disposal
- **ASD**: acoustic sniper detection
- **ACOU**: acoustic force projection
- **OPT**: sniper optics detection