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Revised title:

Presented in: WG(s) #, 29 , CG , Special Session , Demonstration , Tutorial , or Focus Session #

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**Modeling chemical Environment on Mobile Forces Using and Agent-Based Simulation**

Air Force Research Lab Monterey, Canada 93940

 Approved for public release, distribution unlimited

See also ADM202526. Military Operations Research Society Symposium (75th) Held in Annapolis, Maryland on June 12-14, 2007., The original document contains color images.
Modeling Chemical Environments and Effects on Mobile Forces Using an Agent-based Simulation

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Mr Vic Middleton
MAJ Jon Alt
Agenda

• Research questions
• Scenario review
• DOE
• Findings
• Future work
Gas Tanker Blast Kills Nine in Iraq

Bomb Rips Through Tanker Carrying Chlorine Gas, Killing Nine, Filling Hospital Beds in Iraq

A car bomb and a suicide attacker killed at least 11 people across Baghdad Tuesday, Feb. 20, 2007 as militants show increasing defiance to a major security operation.

By BRIAN MURPHY Associated Press Writer

BAGHDAD, Iraq Feb 21, 2007 (AP)
Primary Research Question: How does the level of chemical SA impact combat effectiveness of a Future Force Warrior (FFW) platoon?

Supporting Questions:
• How to model chemical agents?
• How to model chemical detection, protection, and effects on soldiers?
• How to represent chemical SA?
• Is Pythagoras a viable tool in modeling a chemical environment?
Model Assumptions & Constraints

• Assumptions
  – Mask provides 100% protection from chemical
  – Chemical SA affected by detector distribution and intelligence estimates

• Constraints
  – The only protective gear modeled is mask
  – No civilians modeled
  – Enemy not affected by chemical
Battlespace

*not to scale*
Measures of Performance

• Detection
  – Self-detection after 2 min exposure\(^1\)
  – Mechanical JCAD detection varied from 2 – 14 sec exposure\(^2\)

• Protection
  – State change sets vulnerability to zero (100% protection)
  – Easily varied for future studies using this model

• Performance effects
  – Donning mask degrades speed 20%, marksmanship 20%, and field of view 40%\(^3\)

\(^1\) Medical Aspects of Chemical and Biological Warfare
\(^2\) JCAD Operational Requirements Document
\(^3\) Military Psychology, 9(4) & CANE Study
Measures of Effectiveness

- Percent blue kinetic (hostile fire) casualties
- Percent soldiers lethally dosed
- Percent soldiers incapacitated
Design of Experiment

Traditional Approach:
• Limit number of factors or scenario alternatives
• “Fix” all other factors in the simulation to specified values
  – Isolate factors
• Limit number of replications for each design point
  – “$2^{100}$ is forever”, Gen J. Welch

Emergent Analysis:
• Examine multiple factors simultaneously
  – Identify significant factors and interactions
• Technique: NOLH design
  – Use relatively few design points with space filling properties
  – Achieve (nearly) orthogonal design points
• Apply distillation simulations
  – Low resolution, agent-based

Robust Quick Turn Analysis

Kleijnen, Sanchez, Lucas & Cioppa 2005
## Factors

### 8 design factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Settings</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Speed</td>
<td>1.2 – 4.15</td>
<td>Ground speed of blue forces (km/hr)</td>
</tr>
<tr>
<td>Obedience in Mask</td>
<td>0.2 - 0.9</td>
<td>Probability of soldiers to follow orders after masking</td>
</tr>
<tr>
<td>Number UAVs</td>
<td>0 - 2</td>
<td>Number of UAVs available</td>
</tr>
<tr>
<td>Number of UGVs</td>
<td>0 - 4</td>
<td>Number of armed unmanned ground vehicles available</td>
</tr>
<tr>
<td>JCAD sensitivity</td>
<td>2 - 14</td>
<td>Time until JCAD detects (sec)</td>
</tr>
<tr>
<td>Mask marksmanship</td>
<td>0.4 - 0.8</td>
<td>Marksmanship of blue forces after they mask</td>
</tr>
<tr>
<td>Internal communications</td>
<td>0.5 - 1.0</td>
<td>Internal communications effectiveness</td>
</tr>
<tr>
<td>External communications</td>
<td>0.5 - 1.0</td>
<td>External communications effectiveness</td>
</tr>
</tbody>
</table>
Experiment

- Applied 8 factors to Nearly Orthogonal Latin Hypercube – 65 design points
- Crossed 65 design points with 2 categorical factors each at 2 levels:
  - Chemical intelligence estimate (none or near perfect)
  - Distribution of JCAD (UGV with JCAD or without JCAD)
- 65 design points x 4 scenarios = 260 total design points.
- 260 design points x 30 replications each = 7,800 computational runs

60 hours total run time

Full factorial = 5.3 years!
Data Analysis

Methodology

- Step-wise regression against means by MOE
  - Identify interactions & higher order effects
- ANOVA on dominating factors
- Regression tree
  - Identifies the factor that explains most variation in MOE
  - Useful finding most ‘important’ factors
MOE: Percent Blue Kinetic Casualties

Kinetic casualties decrease when number of ARV increase

By Number of ARV

Masking sooner increases kinetic casualties

By Level of Chemical Intelligence
## MOE: Percent Blue Kinetic Casualties

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<thead>
<tr>
<th>Category</th>
<th>Count</th>
<th>Mean</th>
<th>Std Dev</th>
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<tbody>
<tr>
<td>All Rows</td>
<td>260</td>
<td>43.059412</td>
<td>21.666756</td>
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<tr>
<td>ARV&gt;=2</td>
<td>164</td>
<td>32.566519</td>
<td>15.995720</td>
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<td>ARV&lt;3</td>
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<td>39.417614</td>
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<tr>
<td>Initial Intell?&lt;1</td>
<td>32</td>
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<td>96</td>
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</table>

**Increasing number of ARV decreases kinetic casualties 15%**

**Significant decrease in kinetic casualties when ARVs>=2.**

**No chemical intelligence produced lower kinetic casualties**

**Decrease in kinetic casualties when ARVs>=2.**

**Internal communications becomes more important with fewer ARV**

**Reality: 1 ARV organic to platoon**
Findings (1 of 3)

• **Finding**: Prior intelligence of chemical threat reduced chemical casualties but not overall casualties.

• **Interpretation**: Degraded functionality while masked contributed to increased kinetic casualties. *Methodology of applying simple behaviors to agents produced complex results.*

• **Recommendation**: Consider greater risk against non-persistent agent.
MOE: Percent Soldiers Lethally Dosed

Prior intelligence reduces chemical fatalities

Reality: imperfect intelligence is normal

Slow foot speed (< 3.2 km/hr)

JCAD detection supports less chemical fatalities

Zero ARVs reduce lethal exposure!
• **Finding:** No ARVs in scenario resulted in lower chemical casualties (not intuitive).

• **Interpretation:** Unclear...but places to start include model artifacts, tactics, employment. *Methodology supports quick ‘what if’ analysis.*

• **Recommendation:** Explore the ‘what if’ questions.
MOE: Percent Soldiers Incapacitated

Prior intelligence reduces chemical exposure

Further examine ARV/UAV tactics

Instantaneous detection requirement

Reality: imperfect intelligence is normal

Further examine ARV/UAV tactics

Instantaneous detection requirement
• **Finding**: While quicker JCAD detections uniformly reduced chemical casualties, detection thresholds between 6-8 seconds showed appreciably reduced casualties.

• **Interpretation**: What is impact of achieving instantaneous JCAD requirement? Are alternate thresholds reasonable requirements? *Methodology enables rapid ‘what if’ analysis and examination of factors at multiple levels.*

• **Recommendation**: Conduct further research on JCAD sensitivity.
Conclusions

• Pythagoras provides a framework that is easily adapted to modeling efforts and low resolution effects in the CBRN realm
• DOE research at NPS provides ground-breaking methods to experimental design
• Recommend future work:
  – Review employment tactics of ARVs and UGVs
  – Introduce civilians to the battlefield
  – Examine physiological/psychological effects of extended operations in MOPP
  – Introduce false alarms into current model
Questions