Squad Modeling and Simulation for Analysis of Materiel and Personnel Solutions
Elizabeth Mezzacappa, PhD Target Behavioral Response Laboratory
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Distribution Statement A - Approved for Public Release
This presentation proposes development of methods of M&S analysis of materiel and personnel solutions for Squad decisiveness. As part of the ARDEC contribution to the effort, the Target Behavioral Response Laboratory (TBRL) was tasked with development of methods to incorporate laboratory data from human experimentation into the IWARS. This presentation will be on a literature review in support of this effort. The main goals of this literature review are to determine 1) entry-points for data into IWARS, 2) appropriate data for collection under laboratory conditions for entry into IWARS, 3) empirically derived quantitative relationships among leadership, training, and cohesiveness measures and Squad performance that can be entered into IWARS. Results It is possible to use modeling and simulation methods in systems engineering data-based analyses of solutions relevant to Squad performance. The most information for model development and simulation is gained by configuring fine-grained data collection under real operational circumstances, realistic operational training, or under controlled laboratory conditions. Use of archival data for solution effect on Squad performance is not at a high enough resolution for insertion into the IWARS simulation application. Inserting data that has been specifically collected for insertion into IWARS is the most valid approach for seeding simulations (versus use of data collected for other uses). Based on this brief review of the literature, these recommendations can be made. Design of data collection should be performed by behavioral scientists using human experimentation methods in collaboration with computational engineers familiar with IWARS or the simulation program to be used for analysis. Standardized methods and paradigms for laboratory testing of effects of materiel and personnel solutions for Squad performance and insertion into modeling and simulation should be developed. Modeling and simulation in conjunction with empirical behavioral science methods can provide the Army with the much needed tools for analysis in support of the Soldier.
15. SUBJECT TERMS

<table>
<thead>
<tr>
<th>16. SECURITY CLASSIFICATION OF:</th>
<th>17. LIMITATION OF ABSTRACT</th>
<th>18. NUMBER OF PAGES</th>
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<td>a. REPORT</td>
<td>b. ABSTRACT</td>
<td>c. THIS PAGE</td>
<td>Public Release</td>
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<td>unclassified</td>
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
**Advanced Weapons:**
Line of sight/beyond line of sight fire; non line of sight fire; scalable effects; non-lethal; directed energy; autonomous weapons

**Ammunition:**
Small, medium, large caliber; propellants; explosives; pyrotechnics; warheads; insensitive munitions; logistics; packaging; fuzes; environmental technologies and explosive ordnance disposal

**Fire Control:**
Battlefield digitization; embedded system software; aero ballistics and telemetry

ARDEC provides the technology for over 90% of the Army's lethality and a significant amount of support for other services' lethality
• Army has an interest in the Modeling and Simulation of squads in support of acquisition and training decisions
• Leadership, training, and cohesiveness are variables of interest
• An initial review of the literature reveals that archived information is of insufficient granularity to simply “insert” into Modeling and Simulation of squads
• Data collection under controlled conditions is necessary to collect empirically derived quantitative relationships among leadership, training, and cohesiveness measures and squad performance
• An initial proposal for methods and procedures to collect this data is presented
Develop an Integrated decision support layout that maximizes squad capabilities and enhances squad portfolio management across full Doctrine, Training, Leadership, Organizations, Materiel, and Personnel, Facilities (DTLOMP-F):

- Establish squad objective measures that set the conditions to generate command consensus and vision for squad
  - Performance attributes
  - Enabling attributes
  - Measures of formation effectiveness
- Mechanism that recognizes, uses, feeds and builds body of knowledge IRT Leadership, Training, and Materiel for the squad
- Assess potential leadership, training, and products/technologies and measure the payoff for the squad
  - Incorporate an operational context / language for assessments
    - Enables effective communication of resource requirement decisions and priorities across stakeholders community (aka Squad Capability Portfolio Review)
- Establish habitual relationships within the acquisition & operational communities to ensure currency & relevancy for squad

From A. Taylor “Squad Measures of Formation Effectiveness”
Interaction

System

Soldier

Squad

Squad-System
MOE-MOP

Soldier-System
MOE-MOP

Squad-Soldier
MOE-MOP

MOE- Measures of Effectiveness
MOP- Measures of Performance

UNCLASSIFIED
The ARDEC effort in systems engineering and analysis is proposed to be an integral part of analyses of candidate materiel and personnel solutions.

Because of its focus on small unit modeling and simulation, the Infantry Warrior Simulation (IWARS) software application was selected as the software platform to conduct these systems analyses.

The intent is to demonstrate the utility of M&S, in particular, IWARS in analysis of candidate solutions, especially in the area of determining effectiveness and realizing cost savings.

As part of the ARDEC contribution to the effort, the Target Behavioral Response Laboratory (TBRL) was tasked with the development of methods to incorporate laboratory data from human experimentation into the IWARS.
Leadership, Training, and Cohesiveness Factors

- Leadership, Training, and Cohesiveness Factors are particularly problematic
- TBLR Effort = Two Approaches
  - Review of the literature for previous work on how these factors relate to squad performance
  - Empirical approaches for gathering data
- Analysis of how these factors could be incorporated into modeling and simulation of squads
A constructive, force-on-force, combat simulation

Used to model individual Soldier, team, and small-unit combat operations in complex environments, including Military Operations on Urban Terrain (MOUT), to support analysis of warrior systems

Key measures of interest for analyses performed using IWARS include survivability, lethality, command and control, situation awareness, mobility, and sustainability
The primary IWARS simulation objects are intelligent agents that are semi-autonomous, which allows realistic modeling of soldier and unit behaviors.

The behavior engine uses goal-driven behaviors that can be interrupted and adapted as the combatant’s needs and goals change over the course of a scenario.

Agents can also interact with each other, which could potentially affect decision-making activities.

IWARS agents have the ability to perform operational tasks related to:

- movement
- engagement
- communication
- perception
- decision-making

from IWARS 4.0 User Guide
• Skills are the most basic behaviors available to agents
• When a skill is added to a mission, it becomes an activity that can be renamed and modified
• IWARS skills include:

<table>
<thead>
<tr>
<th>IWARS Skills</th>
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</thead>
<tbody>
<tr>
<td>Activate Motion</td>
</tr>
<tr>
<td>Change Posture</td>
</tr>
<tr>
<td>Communicate</td>
</tr>
<tr>
<td>Drive Vehicle</td>
</tr>
<tr>
<td>Look for Shield</td>
</tr>
<tr>
<td>Reload</td>
</tr>
<tr>
<td>Set Behavior</td>
</tr>
<tr>
<td>Set UDOP Profile</td>
</tr>
<tr>
<td>Throw Grenade</td>
</tr>
<tr>
<td>Wait</td>
</tr>
<tr>
<td>Change Agent Facing</td>
</tr>
<tr>
<td>Change Vehicle Facing</td>
</tr>
<tr>
<td>Configure COP Access Point</td>
</tr>
<tr>
<td>Follow</td>
</tr>
<tr>
<td>Mount Vehicle</td>
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<tr>
<td>Remove Message</td>
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<tr>
<td>Set Formation</td>
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<tr>
<td>Shoot</td>
</tr>
<tr>
<td>Use Shield</td>
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<tr>
<td>Change Field of</td>
</tr>
<tr>
<td>Change Visual</td>
</tr>
<tr>
<td>Dismount Vehicle</td>
</tr>
<tr>
<td>Light Flare</td>
</tr>
<tr>
<td>Move</td>
</tr>
<tr>
<td>Select Weapon</td>
</tr>
<tr>
<td>Set Path</td>
</tr>
<tr>
<td>Take Over a Slot</td>
</tr>
<tr>
<td>Use UDOP Device</td>
</tr>
</tbody>
</table>

from IWARS 4.0 User Guide
## Warrior Battle Drills 2011

### Subject Area 16: (Battle Drills) React to Contact:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Title</th>
<th>Training Location</th>
<th>Sustainment Training Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>071-410-0002</td>
<td>React to Direct Fire While Mounted (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-326-0513</td>
<td>Select Temporary Fighting Positions (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-100-0030</td>
<td>Engage Targets with an M16-Series Rifle/ M4 Series Carbine (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-326-0608</td>
<td>Use Visual Signaling Techniques (Repeat)</td>
<td>BCT/OSUT</td>
<td>AN</td>
</tr>
<tr>
<td>071-326-0502</td>
<td>Move under Direct Fire (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-326-0503</td>
<td>Move Over, Through, or Around Obstacles (Except Minefields) (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-326-0510</td>
<td>React to Indirect Fire While Dismounted (If Applicable) (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-326-3002</td>
<td>React to Indirect Fire While Mounted (If Applicable) (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>113-571-1022</td>
<td>Perform Voice Communications (Repeat)</td>
<td>BCT/OSUT</td>
<td>AN</td>
</tr>
<tr>
<td>071-326-0501</td>
<td>Move as a member of a Fire Team (Repeat)</td>
<td>BCT/OSUT</td>
<td>SA</td>
</tr>
<tr>
<td>071-325-4407</td>
<td>Employ Hand Grenades (Repeat)</td>
<td>BCT/OSUT</td>
<td>AN</td>
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</table>
- Real individual Soldier behavior vs IWARS Soldier behavior

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<tr>
<td><strong>Wait</strong></td>
<td></td>
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</tbody>
</table>
Proposed Methods

- Construct Scenario
- Record *Individual* Soldier Behavior Metrics of *Individual* Skills:
  - Frequency
  - Speed
  - Probability
  - Accuracy
- Record *Squad* Performance
- Seed IWARS agents with recorded Soldier recorded values of metrics of *individual* skills
- Run simulations
- Generate forecasts
- Data-Seeded Forecasted Measures of Squad Performance
- Default Seeds
- Run simulations
- Generate forecasts
- Default Seeded Squad Performance
Construct Scenario Candidate **Solution A**

Record *Individual* Soldier Behavior
Metrics of *Individual* Skills:
- Frequency
- Speed
- Probability
- Accuracy

Seed IWARS agents with recorded Soldier recorded values of metrics of *individual* skills

Run simulations

Record Squad Performance

Generate forecast Candidate Solution A

Observed Measures of Squad Performance with Candidate Solution A
Solution Analyses

Construct Scenario Candidate **Solution B**

Record *Individual* Soldier Behavior

Metrics of *Individual* Skills:
- Frequency
- Speed
- Probability
- Accuracy

Run simulations

Seed IWARS agents with recorded Soldier recorded values of metrics of *individual* skills

Record Squad Performance

Generate forecast Candidate Solution B

Observed Measures of Squad Performance with Candidate Solution B
• Each skill/activity has associated parameters that are to be set by the user prior to running the simulation
• These parameters function as the “insert” for Leadership, Training, and Cohesiveness
• Requires information about the association between these variables and squad performance
• Requires information about these variables and Soldier and squad level parameters of behaviors
• The terms Leadership, Cohesiveness, and Training were used to search databases
  – The Army Research Institute for Behavioral and Social Science (ARI) online archives
  – Military Psychology
  – Defense Technology Information Center (DTIC)
  – PsychInfo
• Studies of military groups were specifically targeted
• Articles that contained metric values that could be in some way inserted into the IWARs were targeted
Quantitative metrics of effect of leadership on performance

- Task-focused leadership was positively correlated with perceived team effectiveness and team productivity ($r = .333$ and $r = .203$) (Burke, 2006)
- Leader effectiveness was positively correlated with group performance measures ($r = .39$, $r = .43$) (Vogelaar, 1997)
- Leadership cohesion (cohesive bonds among platoon leaders) was found positively associated with ratings of their unit’s performance by outside observers ($r = .52$). (Mael, 1993)
- Finally, toxic leadership was negatively associated with confidence to follow the toxic leader in life-or-death situations ($r = -55$) (Stelle, 2011)
• No articles addressing effects of specific military skills training on specific task performance were found
• In contrast team training/team process training effects studies were numerous
• Team process was positively correlated with number of targets destroyed (r=.30) (Stout, 1994)
Quantitative metrics of effect of cohesiveness on performance

• Using a well-validated measure of military group cohesiveness, horizontal cohesion among Soldiers was positively correlated with mission performance ($r=.52$) (Siebold G., The evolution of the measurement of cohesion, 1999)

• Meta-analytic studies also show a consistent moderate correlation with performance (around $r=.4$) (Siebold G., Key questions and challenges to the standard model of military group cohesion, 2011)(Oliver, 1999)
The literature reveals moderate correlations between these psychosocial variables and collective (squad, platoon, and team) performance.

While there exist numerical values representing the relationship between psychosocial variables and team performance, the questions revolve around the appropriate methods for inserting these data into IWARS or other modeling and simulation programs.
Possible Insertion Methods

• Locate Army standards or normative data on leadership, training, and cohesiveness measures (Siebold G., The evolution of the measurement of cohesion, 1999) (Oliver, 1999) and Squad performance in the react to contact battle drill, if they exist.

• Simulation experiments examining the effects of varying degrees of leadership, training, or cohesiveness solutions on squad performance can create input data seeds to IWARS by derivations using standards/norms multiplied by the correlational factors reported in the previous section.

• A similar method is to designate seed data as representing squads that are categorized at different points on the spectrum for these variables (High, Med, and Low), again with relative values inputted based on the correlational factors, and anchored at one of these points based on standard or normative data.
• Difficulty in locating standard or normative data (?)
• Heterogeneity of leadership, training, and cohesiveness, as well as performance measures may also present problems
• Static vs Dynamic Issues
  – Archives are static measures, M&S is a dynamic scenario.
• Granularity Issues
  – Archives are overall relationship, M&S requires relation to specific behaviors
Generation of Baseline Empirical Data

- Data collection in the laboratory should then focus on recording execution of these component performance skills
  - Test bed set up must allow for observation or recording of these skills
    - motion capture methods and video recording methods
- Data are processed to yield numerical values indicating Soldier and squad behavior
  - distance between Soldiers, time between commands given and commands executed, frequency of Soldiers going prone, number of trigger pulls, and speed of movements
  - numerical indices of overall squad performance
- These numerical values are then used to configure parameters of the skills and activities in IWARS
  - options and parameters controlling the agents’ activities are set to match those recorded in the lab
<table>
<thead>
<tr>
<th>Doctrinal Performance Step</th>
<th>Type of Laboratory Data Collected</th>
<th>Data Processing for Quantitative Metrics</th>
<th>Skill Configuration in IWARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assume your position in the fire team's current formation...d. Assume your position within the fire team file formation.</td>
<td>Motion Capture</td>
<td>Distance between Soldiers, Leading Edge/Trailing Edge Dispersion</td>
<td>Activate Motion, Set Formation</td>
</tr>
<tr>
<td>NOTE: The normal distance between Soldiers is 10 meters.</td>
<td>Motion Capture</td>
<td>Distance between Soldiers, Leading Edge/Trailing Edge Dispersion</td>
<td>Activate Motion, Set Formation</td>
</tr>
<tr>
<td>NOTE: When the fire team leader moves left, you move to the left. When the fire team leader gets down, you get down.</td>
<td>Motion</td>
<td>Latency between Fire Team Lead and Soldier Behaviors</td>
<td>Move, Wait, Change Agent Facing, Communicate, Follow</td>
</tr>
</tbody>
</table>
Baseline Data Input and Validation of Model

- Data on Performance of Warrior Skills
- Data on Squad Performance
- Agent/Script Configuration Based on Observed Soldier Behaviors
- Running Simulation
- Forecasted Squad Performance

Output from IWARS can be Compared with data on Squad Level Measures of Effectiveness

Data on Soldier behaviors are inputted into IWARS
Comparisons of Candidate Solutions

Statistical analyses comparing Soldier and Squad performance using candidate solutions can be done on data recorded in the lab. Statistical analyses comparing Soldier and Squad forecasted performance using candidate solutions can be done on outputs from IWARS.

Candidate Solutions → Observed Effects on Warrior Skills → Observed Effects on Squad Performance → Agent/Script Configuration Based on Observed Effects on Soldier Behaviors → Running Simulation → Forecasted Squad Performance
Insertion of Leadership, Training, and Cohesiveness Factors into IWARS

Soldier’s and Squad’s Differing Levels of Leadership, Training, and Cohesiveness are run in the laboratory.

Soldier’s and Squad’s Differing Levels of Leadership, Training, and Cohesiveness are run in the laboratory.

Observed Effects on Warrior Skills

Observed Effects on Squad Performance

Agent/Script Configuration Based on Observed Effects on Soldier Behaviors
Outdoor Test Bed

Motion Capture Camera mounted on pole.

Portion of the outdoor test bed
• Noldus Observer XT
• Behavioral Coding Example:
Federate IWARS with other simulation software programs that are specifically configured for human behaviors, such as Brahms, PMF, Imprint, ACT-R, SOAR, etc (Cassenti, 2010; Schamburg, 2005; Laird, 2012)
Conclusions

- There exist methods of inserting data into IWARS simulation in order to conduct systems engineering analyses of solutions for enhancing squad performance.
- Inserting data that has been specifically collected for insertion into IWARS is the most valid approach for seeding simulations (versus use of data collected for other uses).
• Based on this review of the literature, these recommendations can be made:

  – Design of data collection should be performed by behavioral scientists using human experimentation methods in collaboration with computational engineers familiar with IWARS or the simulation program to be used for analysis.

  – Standardized methods and paradigms for laboratory testing of effects of materiel and personnel solutions for squad performance and insertion into modeling and simulation should be developed.
Questions?

US Army - Target Behavioral Response Lab

Elizabeth Mezzacappa, PhD
Picatinny Arsenal, NJ
elizabeth.s.mezzacappa.civ@mail.mil
• Virtual Employment Test Bed: Operational Research and Systems Analysis to Test Armaments Designs Early in the Life Cycle
• Method and Process for the Creation of modeling and Simulation Tools for Human Crowd Behavior
• Squad Modeling and Simulation for Analysis of Materiel and Personnel Solutions
• The Squad Performance Test Bed
• Crowd Characteristics and Management with Non-Lethal Weapons: A Soldier Survey
• Effectiveness Testing and Evaluation of Non-lethal Weapons for Crowd Management
• Effects of Control Force Number, Threat, And Weapon Type on Crowd Behavior