

**A Study in the Implementation of a Distributed Soldier
Representation**

**by CPT (P) Kevin Fefferman, Manuel Diego, Chris Gaughan,
Charneta Samms, Howard Borum, Jon Clegg, Joseph S. McDonnell,
and Robert Leach**

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A Study in the Implementation of a Distributed Soldier Representation

Kevin Fefferman, Manuel Diego, Chris Gaughan, and Charneta Samms
Human Research and Engineering Directorate, ARL

Howard Borum
Raytheon-Network Centric Systems

Jon Clegg, Joseph S. McDonnell, and Robert Leach
Dynamic Animated Systems, Inc.

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14. ABSTRACT The representation of human aspects within Soldier-centered modeling and simulation (M&S) environments presents significant challenges in affect model availability, accessibility, and applicability within the condition-specific, parameter-driven Soldier representation and performance trade space. Furthermore, the increasing complexity of affect models poses substantial and often unsupported systems integration effort for timely and efficient use. The Distributed Soldier Representation (DSR) project, led by the U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED) Simulation & Training Technology Center (STTC), aims to develop a service-oriented distributed M&S capability and provide performance factor representation of various degrees of fidelity within entity-level simulation environments in support of Soldier training and mission rehearsal.					
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Executive Summary

Congress and Army senior leadership have recognized modeling and simulation (M&S) as a “National Critical Technology” and as being “absolutely essential” and “indispensable.” M&S is also recognized as a key enabler of activities in support of acquisition, analysis, experimentation, planning, test and evaluation, and training. However, there are gaps in current Army M&S that specifically focuses on the Soldier in the areas of cognition, morale, Soldier resilience, human physiology, human psychology, unit cohesion, stress, unit as a complex adaptive system, leadership, decision science, and the effects of the Soldier as a family member. These are the 11 areas of interest addressed in this report.

The U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED) Simulation & Training Technology Center (STTC) initiated the Distributed Soldier Representation (DSR) research project to investigate those factors that affect Soldier effectiveness, identify where there are gaps in modeling those factors in current Soldier representations, and offer a service-oriented distributed M&S environment able to assist in filling those gaps. The DSR effort aims to provide a capability to represent those human aspects that affect Soldier performance with greater fidelity and an increased realism in the representation of the Soldier within simulations. This report is the product of the DSR research project’s initial effort: conducting a literature search into the human factors that influence Soldier effectiveness and identifying the current supporting M&S options.

The DSR effort envisions that the Soldier to be modeled may be an individual dismounted infantryman, a vehicle crewman, a member of a weapons system crew, or a Soldier manning a position in a command post. The concept of the DSR capability is that it will enhance an entity-level simulation with specific performance factors, e.g., decreasing performance due to stress or fatigue, which could be instantiated for interaction within the simulation. The ultimate goal is a simulation service that can be leveraged by a wide variety of M&S users for numerous purposes while providing a bin for new Soldier models and data to be collected toward that goal.

The DSR Research Project was initiated in 2012 by organizing a team of M&S subject matter experts (SMEs) whose initial effort was to conduct a literature search to document current capabilities, identify gaps, and then decide upon an approach of how to create/obtain those needed M&S capabilities that would address the gaps in current Soldier representations. After reviewing the results of the completed literature search, the team assessed the current status of the available “body of knowledge” in each of the 11 DSR areas of interest (cognition, morale, Soldier resilience, human physiology, human psychology, unit cohesion, stress, unit as a complex adaptive system, leadership, decision science, and the effects of the Soldier as a family member) to determine which could support the initial development of a DSR prototype. It was felt that due to their complexity some areas would require extensive time and resources to

develop/acquire the expertise to support an internal goal of presenting a DSR demonstration at the Inter-service/Industry Training Simulation and Education Conference (I/ITSEC) in December 2013. Some areas do not currently contain sufficient accessible data and data resources to support this quick turnaround effort while others simply need more in depth research by the team. It was determined that of the 11 areas of interest two, specifically human physiology and stress, seem mature and accessible enough to support the initial prototyping and demonstration effort.

Based on the aforementioned conclusions, the team decided to focus its initial proof-of-principle effort in the area of physiology by integrating the ARL Soldier Load Augmented Training Environment (SLATE) application with a DSR server. SLATE is a training application developed by ARL HRED STTC in collaboration with the University of Central Florida's Institute for Simulation and Training. The application was built in support of the U.S. Army Natick Soldier Research Development and Engineering Center (NSRDEC) to teach Soldiers key elements of managing Soldier loads. It is part of the Dismounted Soldier Centric Load and Route Planning Mobile Training effort discussed briefly in section 4.4 of this report (and appendix C). SLATE was selected to support the initial DSR effort due to its developmental maturity level, its access to the Army Institute of Environmental Medicine (ARIEM) database, the co-location of its development team at STTC, and its ability to meet the time constraints established for prototyping and demonstrating a DSR capability at I/ITSEC in December 2013.

To address the area of stress in the proof-of-principle effort, the team decided to develop an application to simulate the cumulative effects of stress on the marksmanship of the individual Soldier. The Effects of Stress (EoS) application generates/maintains a dynamic, overall level of stress for each individual Soldier (individual combatant) within a simulation. Each Soldier's stress level is based upon battlefield conditions, such as being under fire, becoming a casualty, or observing friendly casualties. A Soldier not experiencing battlefield stress factors for a period of time experiences a gradual reduction of overall stress level. Further, a Soldier's stress level is temporarily increased during periods of engaging human targets. Each Soldier's unique, dynamic overall stress level can be used by a simulation to degrade the respective Soldier's performance such as in small-arms fire accuracy.

A detailed discussion of the integration of SLATE and EoS into a DSR Server will be published separately at a later date.

1. Introduction

As we reflect on the role of the individual Soldier during the last decade and we attempt to identify the nature of future conflict, we recognize that the Soldier as an individual, and as part of a small team or squad, has been and will always be the crucial element that ensures success on the battlefield. Recognizing this, the Army continues to focus specific efforts and resources to better prepare, train, and equip Soldiers to meet any challenges they may encounter on that future battlefield. Further, Congress and Army Senior Leadership have recognized modeling and simulation (M&S) as a “National Critical Technology” (U.S. House of Representatives, 2007) and as being “absolutely essential” and “indispensable” to the Army’s preparation for the future. M&S is a key enabler of activities in support of the Soldier in the areas of acquisition, analysis, experimentation, planning, test and evaluation, and training.

The U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED) Simulation and Training Technology Center’s (STTC) total focus on supporting the Soldier has resulted in addressing the Soldier M&S representation need by pursuing a Distributed Soldier Representation (DSR) effort designed to ensure that M&S practitioners and analysts have the most appropriate M&S applications possible to support their efforts in developing the best technology, equipment, and training capabilities for our Soldiers.

ARL HRED STTC formed a DSR team composed of military personnel, Government civilians, and contractors in March 2012. CPT(P) Kevin Fefferman and Mr. Manuel Diego were designated the ARL HRED STTC Government leads with Mr. Robert Leach as their contractor (Dynamic Animation Systems, Inc. [DAS]) counterpart. Ms. Charneta Samms (ARL HRED Manprint, Methods, and Analysis Branch), Mr. Christopher Gaughan (ARL HRED Chief Engineer, Advanced Simulation Branch), Dr. Joseph McDonnell (DAS), Mr. Howard Borum (Raytheon-Network Centric Systems), and Mr. Jon Clegg (DAS) completed the team. Mr. Christopher Metevier, Chief, Advanced Simulation Branch at STTC oversaw the entire project. CPT(P) Fefferman, as well as Mr. Borum and Mr. Leach, who are retired Army officers, were able to bring their military experience and perspective to add additional creditability to the project.

The DSR concept aims to identify those factors that affect Soldier effectiveness, identify gaps in modeling those factors in current Soldier representations, and offer a service-oriented, distributed M&S environment able to fill those gaps. It will provide the capability to represent human aspects that affect Soldier performance for greater fidelity and an increased realism in the representation of the Soldier within simulations. The Soldier to be modeled may be an individual dismounted infantryman, a vehicle crewman, a member of a weapons system crew, or a Soldier manning a position in a command post. The DSR capability will supply the subscribing simulation with specific performance factors, e.g., decreasing performance due to stress or

fatigue, which could be instantiated for interaction within the simulation. DSR functionality may provide for either the representation of a specific characteristic of a Soldier entity within the simulation or the actual representation of the entire entity (a surrogate Soldier) external to the simulation, which would then interact with other entities within the simulation. The ultimate goal is a simulation service that can be leveraged by a wide variety of M&S users for numerous purposes while providing a bin for new Soldier models and data to be collected toward that goal.

This report is the first deliverable of the DSR effort. It provides the results of an extensive literature search conducted by the ARL HRED STTC DSR team to identify those factors that affect Soldier effectiveness and where there are gaps in modeling those factors. The data gathering methodology involved Internet searches on unclassified networks and selective visits to organizations and M&S laboratories that are engaged in modeling of the Soldier. We recognize that this report of our literature search will be a living document evolving over time as new information is found and new SMEs are interviewed. The objectives of this initial effort were fourfold: (1) to familiarize the entire team on current efforts to model those factors that affect Soldier effectiveness; (2) to identify gaps in the associated M&S technology available to the U.S. Army; (3) to develop a technical concept and timeline for actually prototyping a service oriented, distributed M&S environment that includes DSR technology and demonstrating a DSR capability at the Inter-service/Industry Training Simulation and Education Conference (I/ITSEC) in December 2013; and (4) to document the effort in a technical report.

2. Soldier Scope and Methodology

As stated above, the initial effort of the DSR team was to conduct an unclassified Internet literature search to identify those human (non-hardware, non-doctrine) factors that affect Soldier effectiveness and where there are gaps in U.S. Army modeling of those factors. The document search process consisted of Internet search queries of subject titles relating to the physical, psychological, or emotional aspects of Soldier's duty performance, or professional and personal lives that could affect Soldier operational/combat performance. It included Web access to relevant books, peer-reviewed journal articles, and published research papers. When an Internet source was discovered with data that might be of value to the DSR effort, that source was researched in greater detail. If the data were found to be of possible value to the DSR effort, documentation that could apply to application design or development was extracted and placed within the DSR database. The literature search and data accrual process resulted in the DSR database being organized into the following 11 specific DSR areas of interest: cognitive engineering, decision science, human physiology, human psychology, leadership, morale, Soldier as a family member, Soldier resilience, stress, unit as a complex adaptive system, and unit cohesion.

During the literature search, there were also concurrent discussions (and visits) by the Government team members to organizations and M&S laboratories that were doing research and development in some of the identified areas of interest. These included the University of Iowa, United States Military Academy, United States Air Force Academy, the Natick Soldier Research Development and Engineering Center (NSRDEC), ARL HRED, and others.

The results of the literature search for each of the areas of interest are summarized and presented as specific appendices to this report. Each appendix follows a prescribed format, which ensures that all required information categories to support the goals of the project are addressed. Each appendix consists of: an introduction that defines and provides an overview of the subject and its relevance to DSR; findings that identify the data and models/simulations found as well as respective gaps; and conclusions as they relate to the establishment of an initial DSR effort. All appendices conclude with a list of references that were identified during the literature search.

3. Initial Activity

The primary objectives of the DSR research project during FY 12 were to (1) conduct a literature search, (2) develop a DSR path forward, and (3) begin the development of a technical report, which would be completed in FY13. During FY13 the team also began development of a DSR prototype for concept demonstration purposes.

4. Synopsis of Results

The following section provides a synopsis of the results of the literature search in each DSR area of interest. The results are described in greater detail for each of the 11 DSR areas of interest in the appendices. The following section attempts to encapsulate the significant ideas discussed in these appendices and presents the DSR team's conclusions and recommendation for an initial prototype.

4.1 Cognitive Engineering

Cognitive engineering is a multidisciplinary field that specifically focuses on understanding the cognitive demands imposed by workplace environments to analyze, design, and evaluate the complexity of humans and systems interacting. It emerged in the early 1980s and has many military related applications, including Soldier-equipment/system interfacing, intelligence analysis, and command and control systems and processes (Gersh et al., 2005). Cognitive engineering places particular emphasis on the analysis of cognitive processes, e.g., diagnosis, decision making, and planning. It aims to enhance performance of cognitive tasks by means of several interventions, including (1) user-centered design of human-machine interaction and

human-computer interaction (HCI); (2) design of information technology systems that support cognitive tasks, e.g., cognitive artifacts; (3) development of training programs; and (4) work redesign to manage cognitive workload and increase human reliability (Aubin, 2006).

Cognition, the thought process design within cognitive engineering, is comprised of two forms of judgment. The first, rational analysis, is the superior form of judgment provided sufficient time for such analysis is available. The second, intuitive judgment, which is fast and generally easier from which to draw conclusions, is best used in time-constrained environments such as during combat operations (Cognitive Assessment of Military Approaches to Understanding, 24 July 2008). A cognitive assessment is used to determine which military thought process approach best leverages the two natural cognitive processes, rational or intuitive. This cognitive assessment seeks to identify the approach that cues rational analysis the most and intuitive judgment the least (Hibner, 2008).

The U.S. Army relies on tactical-level leaders, not for their physical warfighting skills, but for their ability to employ cognitive thought during stressful situations. The physiological response to combat can degrade that cognitive capability, preventing leaders from performing tasks critical to unit success (Whitaker et al., 1996).

The DSR research team has identified several models that may be useful in developing DSR capabilities. Some are the following:

- The Cognitively-Engineered Multisensory Data Fusion Model examines how humans interpret multisensory data to understand how a data fusion system can be an effective, time-saving means of presenting information in high-stress situations (Muller, 2006).
- A Process Model of Situated Cognition in Military Command and Control presents a general model that combines the technological aspects of a system with the perceptual and cognitive processes of the humans embedded within the system. The model emphasizes that such systems are both process oriented and dynamic (Miller et al., 2004).
- The Vehicle Level Human Performance Model developed by the U.S. Army Tank and Automotive Research, Development and Engineering Center (TARDEC) is an advance design tool that can operate alone or in coordination with human research participants. This model has been used to reduce the number of participants necessary for testing vehicle capabilities, effective survivability measures, and Joint/combined operations. The model's operator-vehicle interface simulation provides for efficient cognitive engineering assessments (Miller et al., 2006).

Further discussion of “cognitive engineering” can be found in appendix A.

4.2 Decision Science

Decision science is the understanding of “human decision making” and the methods and tools to assist in gaining that understanding. The first concern of decision science is the elucidation of the distinction between descriptive and prescriptive: how humans actually decide versus how they should decide (Davis et al., 2005). Military decision making is knowing if to decide, then when and what to decide. It also includes understanding the consequence of decisions. Those decisions are the means by which commanders translates their vision of the end state into action (Field Manual 101-5, 1997).

As with cognition, all decision making involves two forms of judgment: rational analysis and intuitive judgment (Hibner, 2008). Rational analysis is best when a decision is not time constrained. Intuition is something that is known, perceived, understood, or believed by instinct, without actual evidence rather than by use of conscious thought, reason, or rational processes. This does not imply that intuitive decision making is irrational. Instead, the explanation for a choice is not directly available through conscious or logical thought (Decision-Making-Solutions.com, 2012).

The DSR research team has identified several models that may be useful in developing DSR capabilities. There are numerous decision-making models: rational models, intuitive models, and rational-iterative models as well as five-, six-, seven-, and even nine-step decision models. However, most decision-making models use the same basic decision-making stages (McDermott, 2012). Possibly the best general example of a decision-making model is the Seven-Step Model: (1) identify the decision to be made, (2) know yourself, (3) identify options, (4) gather information and data about each alternative, (5) evaluate options, (6) select the best option, and (7) develop and implement a plan of action (McDermott, 2012).

The U.S. Army’s doctrinal problem-solving method is the Military Decision Making Process (MDMP) (FM 101-5, 1997). This formal process is tailorable in application and serves as a standard guide for developing solutions to operational and tactical problems by Army organizations. Information management and decision making are both time critical within MDMP. Alternate U.S. Army decision-making models include recognition primed decision making; observe, orient, decide, and act (OODA); and other emerging processes that are also tailorable to the short reaction times required by combat operations. Additionally, all U.S. Army combat unit decision-making processes employ the Army Battle Command System (ABCS), a suite of networked digital components designed to give commanders and staffs an accurate perspective of their operating environment (Frambes, 2005).

Some of the other decision science specific models identified include the Army’s Combined Arms Support Command “Outside the Wire” gaming program, which allows Forward Support Commanders to practice real-life high risk wartime decision making in the safety of cyberspace (WILL Interactive, 2007) and “A Process Model of Situated Cognition in Military Command and Control” that provides a general model that combines the technological aspects of a system with

the perceptual and cognitive processes of the humans embedded in the system (Miller et al., 2004). ARL's research program "Relevant Information for Social Cultural Depiction (RISC-D)" is working to develop models of how a Soldier's own cultural background influences decision making within a combat environment that includes other cultural groups (Samms et al., 2012).

These models and further discussion of "decision science" can be found in appendix B.

4.3 Human Physiology

Human physiology is the branch of biology that deals with the mechanical, physical, bioelectrical, and biochemical functions of humans in good health, their organs, and the cells of which they are composed. Physiology focuses principally at the level of organs and systems. Most aspects of human physiology are homologous to corresponding aspects of animal physiology, and animal experimentation has provided much of the foundation of physiological knowledge. Anatomy, the study of form, and physiology, the study of function, are intrinsically related and are studied in tandem as part of a medical curriculum (Merriam-Webster Dictionary, 2012).

Factors that affect individual physical and mental effectiveness in combat include battle intensity and type; morale; leadership; horizontal and vertical cohesion; training and fitness; and combat experience. Equally important to unit factors are the individual Soldier physiological factors of load, hydration, sleep, nutrition, personal, family factors, and unit ethical climate (Belenky, 2004).

Human physiology plays a major role in explaining the effects of stress. Stress is characterized by the activation of the sympathetic nervous system (SNS). The SNS is activated when the brain perceives a threat to survival, resulting in an immediate discharge of stress hormones. This "mass discharge" is designed to prepare the body for fight-or-flight. The fight-or-flight response is characterized by increasing arterial pressure and blood flow to large muscle mass resulting in increased strength capabilities and enhanced gross motor skills, such as running from or charging into an opponent; vasoconstriction of minor blood vessels at the end of appendages, which serves to reduce bleeding from wounds; pupil dilation; cessation of digestive processes; and muscle tremors (Grossman, 1999).

During combat, where the threat of physical harm exists or is happening, accelerated brain processes produce perception distortions. The most common perception distortions occurring, by percentage of subjects reporting (e.g., 85% of all subjects reported perception distortions which were described as "diminished sound"), during lethal force encounters are (1) diminished sound, 85%; (2) tunnel vision, 80%; (3) heightened visual clarity, 72%; (4) intensified sounds, 16%; (5) fast motion time (hyper-fast movements), 16%; (6) temporary paralysis, 7%; and (7) automatic pilot ("scared speechless"), 4% (Grossman et al., 2004).

The DSR research team has identified several models that may be useful in developing DSR capabilities. Some are the following:

- Over the last two decades, a database has been established for developing a series of predictive equations for deep body temperature, heart rate, and sweat loss responses of clothed Soldiers performing physical work at various environmental extremes. Based upon that data, the comprehensive model “Modeling of Ambient Temperature Driven Physiological Responses and Human Performance” was developed using the primary physiological inputs of deep body (rectal) temperature and sweat loss while the predicted outputs are the expected physical work-rest cycle, the maximum single physical work time if appropriate, and the associated water requirements (Pandolf et al., 2004).
- The “Prediction Modeling of Physiological Responses and Human Performance in the Heat” model provided the mathematical basis employed in the development of various individual heat stress predictive model equations. The application was programmed on the HP 41 CV, a programmable, expandable, continuous memory handheld calculator manufactured by Hewlett-Packard, and was described as meeting U.S. Army simulation needs (Pandolf et al., 2004). These models have been carried forward into modern computational platforms.
- Virtual Soldier Research (VSR) is a research organization based at the University of Iowa, comprising a multidisciplinary team of faculty, professional staff, and students that has produced a number of models such as the SANTOS virtual human model. Its expertise spans a variety of fields, including computer science, computer graphics, physiology, engineering, biomechanics, robotics, and optimization. VSR balances cutting-edge research with customer-driven product development in the field of digital human modeling (DHM). The inclusion of real-world constraints such as gravity, muscle fatigue, muscle strength, clothing restrictions, material properties, and physical restrictions in all VSR models provides for the creation of exceptionally realistic pre-production simulation test environments. The success of this research led to the spin-off of a private company, Santos Human, Inc., specifically focused on product development (University of Iowa, 2012).
- Dismounted Soldier Centric Load and Route Planning Mobile Training Apps is a project to develop a suite of dismounted Soldier load related tools targeting modern smart mobile devices. The project leverages approved Energy Expenditure Models from the Army Research Institute of Environmental Medicine (ARIEM) heat strain calculations, personnel status, and logistics status to enable dismounted Soldiers to visualize key “load” components, which can be managed and/or reduced to enable Soldiers to minimize their overall metabolic burden and arrive “Fresh to the Fight.” A full range of mobile applications (apps) are being created that range from training to operational. This program is a joint ARL HRED STTC effort with NSRDEC identifying and developing apps targeting their “Nett-Warrior on Android” program (ARL HRED STTC et al., 2012).

Further discussion of “human physiology” can be found in appendix C.

4.4 Human Psychology

Psychology is an academic and applied discipline that involves the scientific study of mental functions and behaviors. Psychology has the immediate goal of understanding individuals and groups by both establishing general principles and researching specific cases (Hockenbury et al., 2010). Military psychology is the research, design, and application of psychological theories and experimentation data toward understanding, predicting, and countering behaviors either in friendly or enemy forces or civilian populations that may be undesirable, threatening, or potentially dangerous to the conduct of military operations. It is also applied in the counseling and treatment of stress and fatigue of military personnel or military families as well as in the treatment of psychological trauma suffered as a result of military operations (Military Psychology, 01 May 2012).

The major Soldier psychological effects resulting from combat operations are (1) psychiatric casualties suffered during combat; (2) arousal and fear; (3) the effects of close combat; (4) the effects of killing; and, (5) post-traumatic stress disorder (PTSD) (Grossman et al., 2000).

Physiology effects of combat are at times difficult to separate from psychological effects of combat. As discussed in the section above, the key characteristic that distinguishes combat stress is the activation of the sympathetic nervous system, that immediate “mass discharge” of stress hormones that prepares the body for fight-or-flight. This in-rush of stress hormones can cause psychological effects. A secondary characteristic of combat stress is the resistance to killing one’s own species. Combat is like a roller coaster with highs being an adrenaline rush and lows coming after the rush. This “roller coaster” affects a human body dramatically and can be severely draining physically and psychologically (Frisbee, 2012). These physiological changes are among the primary causes of the immediate and delayed psychological changes addressed in this DSR area of interest.

A Soldier’s psychological state can also affect their decision making. When immersed in the emotional crises and “fog of war” of combat, the potential exists for degraded Soldier decision making. Decisions made in combat can produce exceptionally effective or disastrous outcomes. The difference between the logical brain, operating within a non-combat environment and the wild brain operating in a combat environment is the measure of decision quality. Combat environments can cause Soldier “wild brain” perceptual distortions such as auditory exclusion, tunnel vision, heightened visual clarity, slow motion time, memory loss for parts of an event, memory loss of personal actions, detachment, intrusive distracting thoughts, memory distortions, intensified sounds, fast motion time, as well as seemingly physiological effects such as temporary paralysis and automatic pilot (“scared speechless”). These effects can dramatically affect decision processes (Grossman et al., 2004).

Current virtual reality military training approaches are noteworthy in their emphasis on creating high fidelity graphic and audio realism with the aim to better facilitate procedural and problem solving training. However, less emphasis is placed on inducing emotional stress in a manner similar to what is typically experienced under real-world training conditions (Rizzo et al., 2005).

The DSR research team has identified several models that may be useful in developing DSR capabilities. Some are the following:

- Some of the psychological modeling investigated included emotion modeling, which is the modeling of human behavior simulation in stressful situations. “Fuzzy Emotion Modeling for Human Behavior Simulation in Stressful Situation” provides an emotion model that simulates mineworker’s emotional behavioral response to underground hazardous events. Using fuzzy inference processes, the mineworker’s emotion model evaluates perceived event’s impact on goal attainment and goal importance to generate emotion states for virtual miners. It helps train miner’s decision-making ability when faced with occasional or emergency situations in underground coalmines (Linqin et al., 2012).
- Fear is another aspect of psychology that affects combat effectiveness. The psychological effects of anti-personnel landmines (APLs) are not incorporated into current mine warfare simulations. However, three basic approaches for incorporating fear into mine warfare models have been developed. The APL warfare simulation described in “Modeling the Psychological Effects of Anti-Personnel Landmines” may be relevant to developers of other types of simulations incorporating human representation (Morgan, 2001).

Further discussion of “human psychology” can be found in appendix D.

4.5 Leadership

Field Manual (FM) 6-22 is the Army’s keystone FM on leadership. It establishes leadership doctrine and fundamental principles for all officers, noncommissioned officers, and Army civilians across all components. It uses the BE-KNOW-DO concept to express what is required of Army leaders. The manual states that Army leaders must be agile, “multi-skilled pentathletes” who have strong moral character, broad knowledge, and keen intellects. They must display these attributes and leader competencies bound within the concept of the Warrior Ethos (Field Manual 6-22, 2006). Serving in a U.S. Army leadership position means (1) having a vision about what can be accomplished, (2) making a commitment to the mission and the people you lead, (3) taking responsibility for the accomplishment of the mission and the welfare of those you lead, (4) assuming risk of loss and failure, and (5) accepting recognition for success (Mills, 2005).

Trust is the key to the exercise of leadership in any type of organization. Based upon Soldier surveys, the attributes of a leader who can be trusted in combat are (1) competent, (2) loyal, (3) honest/good integrity, (4) leads by example, (5) self-control (stress management), (6) confident, (7) courageous (physical and moral), (8) shares information, (9) personal connection with subordinates, and (10) strong sense of duty (Crandall, 2012).

The DSR team identified three models that might prove beneficial for further consideration /development:

- Fiedler’s Least Preferred Coworker (LPC) Score Contingency Model is a contingency theory that proposes that selecting the right kind of leader for an appropriate situation or changing the situation in order to adapt it to the particular leader’s style will determine leader effectiveness. The LPC score defines with whom the leader has the greatest difficulty working (Fiedler, 1967).
- U.S. Army analysts have developed competencies, components, and sample actions that were used by SMEs to produce a “core leadership competency framework” that includes eight competencies and 55 components. The core leadership competency framework serves to provide an analytically based description of leader requirements for the future. The eight competencies are (1) leading others to success, (2) exemplifying sound values and behaviors, (3) generating a positive climate, (4) ensuring a shared understanding, (5) reinforcing growth in others, (6) arming one’s self to lead, (7) guiding successful outcomes, and (8) extending influence (Horey et al., 2004). This leadership competency/components framework could provide an initial area to further investigate when attempting to develop an all-encompassing leadership model.
- The U.S. Army Master of Military Art and Science thesis “Increasing Effectiveness in a Dynamic Environment by Implementing a Leadership Mathematical Model” provides a mathematical concept developed to model unit effectiveness within a dynamic/combat environment. The originality of this concept is its use of mathematical formulas to explain key leadership methods/ideas (Naplyokov, 2011).

Further discussion of “leadership” can be found in appendix E.

4.6 Morale

Morale, also known as esprit de corps when discussing the morale of a group, is an intangible quality used to describe the capacity of people to maintain belief in an institution or a goal, or even in oneself and others. Esprit de corps applies particularly to military personnel and members of sports teams, but is also applicable in business and any other organizational context, particularly in times of stress or controversy (Mulrine, 2011).

During deployments, the principle of an operation’s “maintenance of unit morale” is seen as essential for effective military performance and the sustainability of combat readiness (van Boxmeer et al., 2011). Unit morale is comprised of six components: (1) the warrior spirit; (2) unit loyalty and pride; (3) a common shared purpose and goal; (4) trust among Soldiers of all ranks; (5) self-less service; and (6) self-sacrifice (Cox, 1995).

In high risk work environments, such as the military, trust in leadership is essential to the maintenance of unit morale. In general, the relationship between Soldiers’ morale and trust in

leadership is qualified by hierarchical distance. Leaders who stand more closely to their followers have more impact on followers' job-related well-being as compared to higher hierarchical leaders (Boermans et al., 2012).

The DSR research team has identified several models that may be useful in developing DSR capabilities. Some are the following:

- The “Ground Warfare and Troop Morale” model describes how system dynamics can be used for both quantitative and qualitative analysis to understand the interaction of ground warfare effectiveness and troop morale. This model provides the analyst a tool with which to drive and organize discussions with experts as well as produce numerical analytical results. The model's graphical representation is especially valuable for analysts when they are briefing their analysis results to customers who may be unfamiliar with the model (Bletscher, 2008).
- “An Initial Conceptual Model for Morale Factors” provides a model designed to replicate the concept of morale. The model employs a novel method of using military judgment to estimate morale levels over the course of events in a realistic operational scenario. Its designed purpose is to stimulate further morale modeling research (Spear et al., 2009).
- “Modeling and Analysis of Resolve and Morale” provides an analytic framework, based on the principles of fourth generation operations, capturing the effects of will and resolve of both combatants and non-combatant populations. It also provides a strategic-level model that investigates the long-term impacts of asymmetric conflict on public resolve and Soldier morale. The model's results are primarily measures of the socio-political arena rather than the military battlefield. However, the model remains primarily one of conflict and combat, albeit on the macro level. The major potential value of the framework, as pertaining to a DSR Morale capability, is as a theoretical modeling framework that dynamically portrays Soldier morale (Artelli, 2007).

Further discussion of “morale” can be found in appendix F.

4.7 Soldier as a Family Member

The topic of the “Soldier as a family member” examines military family issues associated with combat readiness. The relationship between the military and its families is not static but is ever-evolving. An understanding of past and current military beliefs, customs, and actions that affect this relationship is essential. Both military history and military culture have shaped and determined how the military and its families interact and affect one another. Understanding military history is necessary to understand the military-family interface in the modern armed forces. It is within this comprehensive perspective that families can affect military readiness.

Military readiness may be defined as a combination of a Soldier's willingness and ability to do the job during both peacetime and in combat, and the Army's ability to retain that Soldier

beyond one enlistment. Obviously, this definition involves much more than a simple manpower count. Family life affects a Soldier's military performance during both peacetime and periods of hostilities. Further, families play a major role in the Army's retention of personnel and also affect the Soldier's morale and well-being. While there are only a limited number of empirical studies linking readiness and family issues, there are considerable data from which one can infer a family impact on readiness. For example, domestic problems in the home are believed to translate into decreased combat effectiveness and increased risk for death on the battlefield (Schneider et al., 1994).

Before the creation of the all-volunteer U.S. Army in 1973, less than one-fourth of junior enlisted Soldiers were married, although the majority (80%) of older officers and noncommissioned officers (NCOs) were. The post-1973 Army has seen the percentage of its junior enlisted force that is married approach senior NCO married force levels. The effectiveness of the Army's family support programs, good or bad, has had a corresponding effect upon the junior Soldiers' opinion of military service and correspondingly their retention (Military Family Clearinghouse, 1992).

The marital and parenting issues associated with family responsibilities may distract or physically impede the Soldier from participating in unit training activities, and when severe, these family life difficulties, e.g., a spouse's severe illness or injury, may make the Soldier non-deployable for either training or combat. In this sense, family problems present serious readiness challenges for small unit commanders and military service care providers, such as social workers, family counselors, drug and alcohol counselors, and other specialists (Schneider et al., 1994).

Deployed Soldiers may be engaged in combat within days or even hours of arrival into a theater of operations. They may have little if any time to shift their mental focus from the family environment to the deployed/operational events at hand. This delay in Soldiers obtaining "operational focus" will always adversely affect Soldier initial deployed effectiveness (Schneider et al., 1994).

Even in remote parts of the world, current technology allows Soldiers instantaneous telephone or e-mail communication with their families. While this contact can be comforting to Soldiers and their families, it also means that there is no buffer (of time and psychological distance) between Soldiers and their families. Loneliness and immediate concerns about family well-being are brought into the present, yet both Soldier and family are relatively helpless to effect any change or provide real comfort (Schneider et al., 1994).

Data from the Israeli Defense Force (IDF) show that 30% of their casualties in the Lebanon War were due to combat stress reaction (CSR), a temporary mental and physical breakdown due to accumulated stress. CSR renders the Soldier dysfunctional and unable to effectively perform

duties. The IDF found that Soldiers who had experienced certain marital discord or stress in personal relationships (parents, spouses, or girl/boyfriends) were at especially high risk to suffer CSR (Noy, 1978).

U.S. Army medical personnel have frequently reported that both military sick call and family member outpatient visits increase just before a deployment, probably due in part to an increase in family stress. It has also been demonstrated that negative changes in the general well-being of wives were associated with their Soldier husbands' performance during deployments (Knudsen et al., 1982).

U.S. Air Force investigators have reported that individual performance and combat efficiency are in part directly affected by marital and family issues. One U.S. Air Force Europe study showed that a set of broadly defined personal and family stress factors contributed to 7 of the command's 10 aircraft crashes during the study period. Although these results were based on expert opinion rather than on quantitative data, they point out a dramatic and important relation between family issues and military performance (Dooms, 1983).

The DSR team was not able to identify any models or simulations that they believed could support an initial DSR capability.

Further discussion of "Soldier as a family member" can be found in appendix G.

4.8 Soldier Resilience

Resilience is the ability to adaptively respond to challenges and adverse events. There are many types of resilience, such as emotional resilience, which are important for managing stress. There are also many measures of resilience used by researchers to understand how individuals can actively respond to adversity. Resilience is critical to a Soldier's overall strength. It can be characterized as both physical and psychological strength. Every Soldier needs to be trained in how to develop both physical and psychological resilience, which produces the ability to maintain mission readiness before, during, and after stressful situations in combat. Thus, Soldier resilience is: (1) an essential part of successful transitions in the deployment cycle; (2) critical to facilitating recovery from symptoms of combat stress; and (3) an important way to enhance the effectiveness and decrease the adverse effects of stress in all aspects of military service. More than just stress resistance, resilience is a proactive and adaptive process that emphasizes turning challenges into opportunities (www.realwarriors.net, 2011).

Three major influences have been identified as determining Soldier resilience:

1. *Individual and Unit Effectiveness*: Factors that affect individual and unit effectiveness in combat and other operational settings include: (1) battle intensity and type; (2) morale, Leadership, and horizontal and vertical cohesion; (3) training and physical fitness; (4) combat experience; and (5) physiological factors (Belenky, 2004).

2. *Stress*: Everyone has a breaking point, and for everyone, that breaking point changes over time due to many internal and external factors. Many of these factors can be modified, reduced, or eliminated. The most common, and potentially most serious, stress risk factors contributing to a Soldier approaching the breaking point include: (1) witnessing death, especially of other Soldiers or civilian non-combatants; (2) being responsible for the death or serious injury of a non-combatant or allied combatant; (3) witnessing or participating in violations of the Law of War or Code of Conduct; (4) sleep deprivation; and (5) being young and inexperienced (Grossman et al., 2000).
3. *Mental Health*: Currently, 20% to 25% of deployed service members will experience mental health disorders or diseases, sometimes resulting in suicide. Being married is associated with greater resilience against suicide during deployment. The rate of suicide is highest among those currently deployed. It also appears to be linked to the time between enlistment and deployment. For those at the beginning of their careers, the longer the period between enlistment and first deployment the less mental health risk (Michigan State University, 2012).

The DSR research did not identify any current models of resilience.

Further discussion of “Soldier resilience” can be found in appendix H.

4.9 Stress

Combat stress is the complex and constantly changing result of all the stressors and stress processes inside a Soldier while performing a combat-related mission; it is the result of the complex interaction of many mental and physical stressors (Field Manual 22-51, 1994). Combat stress results in short-term behaviors that decrease a Soldier’s fighting efficiency. The most common symptoms are fatigue, slower reaction times, indecision, disconnection from one’s surroundings, and the inability to prioritize (Dept. of the Army, 2012).

Combat operational stress reactions (COSRs) are normal reactions to abnormally stressful events, such as combat operations. COSRs are the body’s way of protesting or slowing a Soldier down when the Soldier has to push past the regular limits of endurance. COSRs are generated by seven risk factors: (1) duration of current deployment greater than six months; (2) sleeping less than 6–8 h per day on average; (3) witnessing death close up, especially of other Soldiers or civilian non-combatants; (4) being responsible for the death or serious injury of a non-combatant or allied combatant; (5) losing a close friend or valued leader in combat or other operations; (6) close brushes with death, especially if the individual believed they were going to die; and (7) being young and inexperienced (junior in rank) (U.S. Marine Corps, 2012).

Combat like military missions/exercises can also impose COSRs through combinations of: (1) heavy physical work; (2) sleep loss; (3) dehydration; (4) poor nutrition; (5) severe noise, vibration or blast; (6) exposure to heat, cold, or wetness; (7) poor hygiene; and (8) exposure to infectious diseases, toxic fumes, or substances. These, in combination with concerns such as problems back home, can replicate combat-induced COSRs (U.S.MC Field Manual 90-44, 2000).

PTSD is the most severe form of deployment-related stress problem; the closely related acute stress disorder (ASD) is the second. Both involve exposure to a significant traumatic event and a response of intense emotions (Dept. of the Army, 2012).

The DSR research team has identified several models that may be useful in developing DSR capabilities. Some are the following:

- The Department of Defense's (DoD) Defense Modeling and Simulation Office's (DMSO) Master Plan has enumerated a number of human performance models (HPMs). The Air Force Research Laboratory has integrated HPMs with constructive models of systems, e.g., cockpit simulations. The U.S. Navy's Human Performance Center (HPC) has also produced human-system HPMs. Of the three (DMSO, AFRL, HPC), DMSO's "Human Performance Modeling Soldier Fatigue" addresses Soldier fatigue and the potential impacts of Soldier fatigue upon system of systems (SoS) performance (Lawton et al., 2005). Since fatigue is the one of the primary symptoms of stress (fatigue, slower reaction times, indecision, disconnection from surroundings, and inability to prioritize), an application capable of estimating fatigue based upon operational environment and activity could be the basis for a stress application/simulation.
- "A Framework for the Representation of Cohesion in Small Combat Units" provides a model that represents a classical Greek phalanx. The phalanx model has proven to accurately generate a reasonable simulation of infantry combat to include the effect of stress and cohesion. The phalanx model could generate DSR Soldier combat stress data, but only on an "aggregate unit" basis (Lawton et al., 2005).
- Considerable combat stress data are available within the public domain, which could be employed in drafting a "basic" DSR combat stress model that would add a profound degree of realism to any simulation.

Further discussion of "stress" can be found in appendix I.

4.10 Unit as a Complex Adaptive System

The complex adaptive systems theory maintains that the universe is full of systems, such as weather systems, immune systems, and social systems, and that these systems are complex and constantly adapting within their respective environments. The agents within a complex adaptive system are the components of that system; the air and water molecules in a weather system or the

flora and fauna in an ecosystem are all agents within larger systems. Agents interact and connect with each other in unpredictable and unplanned ways. But from this mass of interactions regularities emerge and start to form patterns, which feedback upon the system and alter the interactions of the agents (Fryer, 2012). Military conflicts possess all of the attributes of complex adaptive systems. Combat forces are composed of many nonlinearly interacting parts while being organized in a dynamic command and control hierarchy. Local action, which often appears disordered, self-organizes into long-range order. Military forces adapt to a changing combat environment. Despite the existence of a command and control hierarchy, there is no “master voice” that dictates the actions of every Soldier, instead Soldiers act as independent agents within that hierarchy to define the behavior of the larger system (Ilachinski, 2004).

One concept of military complex adaptive systems describes combat as more like an interpenetration of two living, coevolving fluids rather than an elastic collision between two hard billiard balls. Artificial-life techniques, specifically, multi-agent based models coupled with evolutionary learning algorithms, provide a powerful new approach to understanding the fundamental processes of war (Ilachinski, 2004).

Another concept of military complex adaptive systems is described as an amalgamation of a large number of simpler entities or military units organized in a specific hierarchy, each with its own understanding of the overall mission, knowledge of operational doctrine, and local perception of the threat environment. Though orders and guidance emanate down through the chain of command, it is the actions at the lower levels, i.e., the individual agents, where the emergence of global behavior is induced (Ho et al., 1999).

An additional area that merits further investigation is in the understanding of a military organization as a living system. A living system’s characteristics of self-preservation and self-organization leads to three conclusions pertaining to a military unit in combat (Abb, 2005):

1. A military system is a living system for it possesses both human systems and battlefield operating systems, both representing self-organizing networks within the larger/parent system. A military system has the natural attribute of being both an organizationally closed and open system. A military system has multi-leveled cognitive decision-making processes.
2. The aforementioned three criteria for a living system make up the components and processes that allow military systems, who are facing overwhelming odds, to spontaneously behave in a way that facilitates what can be viewed as miraculous survival and sustained combat effectiveness.
3. Viewing the enemy as a living military system leads to planning imperatives that result in military operations focused at exploiting and manipulating both friendly and enemy survival abilities and combat effectiveness.

Twelve models and simulations were identified that purport to employ the complex adaptive system theory within the simulation of combat operations. The more promising of those models

for DSR purposes are the Irreducible Semi-Autonomous Adaptive Combat (ISAAC)/Enhanced ISAAC Neural Simulation Toolkit (EINSTEIN), the Marine Corps' Pythagoras model, and the Army's COMBAT XXI. These are largely agent-based models with the advantages (ease of scenario development, flexibility) and disadvantages (difficulty of validation) common to such models.

Further discussion of “the unit as a complex adaptive system” can be found in appendix J.

4.11 Unit Cohesion

Historically, units that have done well in combat have been “cohesive units.” Cohesive units have certain common traits: esprit de corps (unit morale), the warrior spirit, a common shared purpose and goal, trust among Soldiers of all ranks, and unit members possessing the shared values of selfless service and self-sacrifice. Behavioral scientists designate unit cohesion into one of two categories: social cohesion (interpersonal bonds among unit members) or task cohesion (a shared commitment to the unit's mission) (Evans et al., 1996).

A U.S. Army War College study of unit cohesion in the Iraq War describes how successful unit performance is determined by social cohesion (the strength of interpersonal bonds among members) rather than task cohesion (a sense of shared commitment to the unit's mission) (Mac Coun et al., 2005).

In the study “Relationships between Vertical Cohesion and Performance in Light Infantry squads, platoons, and companies at the Joint Readiness Training Center (JRTC),” scales were developed to determine weaknesses in vertical unit cohesion (cohesion between leaders and subordinates) from squad members through company commanders. These weaknesses are termed “breaks.” After a pattern of breaks was determined, the pattern was related to simulated combat performance at a U.S. Army Combat Training Center (CTC). No or few breaks in the platoon vertical-cohesion chain from squad member to company commander were associated with better platoon performance. Breaks in vertical cohesion with the top platoon leadership (platoon sergeant and/or platoon leader) were associated with below-average platoon performance. A break at the squad leader level affected how the Soldiers rated their proficiency prior to a rotation at the CTC, but did not have significant bearing on platoon performance (Alderks, 1992).

Only one model has been identified that might prove of value in developing a unit cohesion application. “A Framework for the Representation of Cohesion in Small Combat Units” provides a model that represents a classical Greek phalanx unit. The phalanx model has proven to accurately generate a reasonable facsimile of infantry combat to include the effect of cohesion and stress. The phalanx model can generate Soldier combat cohesion/stress data, but only on an aggregate unit basis (Warner, 2006).

Further discussion of “unit cohesion” can be found in appendix K.

5. Conclusions and Recommendations

After reviewing the results of the completed literature search, the DSR research team assessed the current status of the available “body of knowledge” in each of the 11 DSR areas of interest (cognition, morale, Soldier resilience, human physiology, human psychology, unit cohesion, stress, unit as a complex adaptive system, leadership, decision science, and the effects of the Soldier as a family member) to determine which could support the initial development of a DSR prototype. It can be quickly ascertained from the above discussion that most of the 11 areas of interest overlap each other with no precise demarcation. The DSR team estimated that, due to their complexity, some areas would require extensive expenditures of time and resources to develop/acquire the expertise to support a demonstration by December 2013. Some of the areas of interest currently do not contain sufficient accessible data and data resources to support this desired quick-turnaround effort while others just need more in-depth research by the DSR team. It was determined that of the eleven areas of interest two seemed mature and accessible enough to support the initial prototyping and demonstration effort, specifically human physiology and stress.

Based on the aforementioned conclusions, the team decided to focus its initial proof-of-principle effort in the area of physiology by integrating the SLATE application with a DSR server. The SLATE is a training application developed by ARL HRED STTC in collaboration with the University of Central Florida’s Institute for Simulation and Training. The application was built in support of the U.S. Army NSRDEC to teach Soldiers key elements of managing Soldier loads. It is part of the Dismounted Soldier Centric Load and Route Planning Mobile Training effort discussed briefly in section 4.4 of this report (and appendix C). SLATE was selected to support the initial DSR effort due to its developmental maturity level, its access to the ARIEM database, the co-location of its development team at STTC and the time constraints established for prototyping and demonstrating a DSR capability at I/ITSEC in December 2013.

To address the area of stress in the proof-of-principle effort, the team decided to develop an application to simulate the cumulative effects of stress on the marksmanship of the individual Soldier. The application generates/maintains a dynamic, overall level of stress for each individual Soldier within a simulation. Each Soldier’s stress level is based upon battlefield conditions such as being under fire, becoming a casualty, or observing friendly casualties. A Soldier not experiencing battlefield stress factors for a period of time, experiences a gradual reduction of overall stress level. Further, a Soldier’s stress level is temporarily increased during periods when engaging human targets. Each Soldier’s unique, dynamic overall stress level can be used by a simulation to degrade the respective Soldier’s performance such as in small-arms fire accuracy.

A detailed discussion of the integration of SLATE and EoS into a DSR server will be published separately at a later date.

6. Future Work/Vision

As the DSR research project continues, the team will provide recommendations for areas of further research to the research community working in the 11 areas identified within this report based on gaps identified. The hope of DSR is to be able to provide a collection point for the types of models, empirical data, etc., that could be used by the simulation community. This will additionally drive the methodologies used to collect data during studies. Conversely, the DSR team is building a service-oriented architecture to provide the Soldier representation to a disparate set of simulations. While initial implementations of simulations consuming DSR data may be simulation-specific, the long-term goal is to standardize an interface that any simulation can conform to in order to take advantage of DSR. The initial integration efforts in progress at the time of this writing will hopefully provide the launching point toward this end.

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Appendix A. Cognitive Engineering

1. Introduction:

- a. **Overview:** Cognitive Engineering is a multidisciplinary field that specifically focuses on understanding the cognitive demands imposed by workplace environments to analyze, design, and evaluate the complexity of humans and systems interacting. It emerged in the early 1980s and has many military related applications, including Soldier-equipment/system interfacing, intelligence analysis, and command and control systems and processes (Gersh et al., 2005).

It is often the case that human factors practitioners focus their attention on the humans while equipment designers focus on the technological aspects of the system. The point of intersection between humans and technology has become a boundary with respect to system effectiveness evaluation; that intersection comprises Cognitive Engineering. Additionally, human factors practitioners also study the result of cognitive activity (e.g., a decision) rather than the processes that lead to the outcome (Miller et al., 2004).

b. Topic Definition:

- 1) Cognitive Engineering, also called Cognitive Ergonomics, comes from Industrial Engineering. It is an integration of Engineering and Cognitive Ergonomics (Aubin, 2006).
- 2) Cognitive Engineering places particular emphasis on the analysis of cognitive processes, e.g., diagnosis, decision making, and planning. It aims to enhance performance of cognitive tasks by means of several interventions, including: (1) user-centered design of human-machine interaction and human-computer interaction (HCI); (2) design of information technology systems that support cognitive tasks, e.g., cognitive artifacts; (3) development of training programs; and, (4) work redesign to manage cognitive workload and increase human reliability (Aubin, 2006).
- 3) Cognition, the thought process design within cognitive engineering, is comprised of two forms of judgment. The first, rational analysis, is the superior form of judgment provided sufficient time for such analysis is available. The second, intuitive judgment, which is fast and generally easier from which to draw conclusions, is best used in time-constrained environments such as during combat operations (Cognitive Assessment of Military Approaches to Understanding, 24 July 2008). A cognitive assessment is used to determine which military thought process approach best leverages the two natural cognitive processes, rational or intuitive. This cognitive assessment seeks to identify the approach that cues rational analysis the most and intuitive judgment the least (Hibner, 2008).

c. Significance/Relevance:

- 1) The complex and dynamic nature of the contemporary operating environment faced by the U.S. Army makes it clear that mission performance depends on systems that are engineered to ensure that the complex systems of people and technology (i.e., sociotechnical systems) can sustain the high levels of cognitive performance needed for success (McDowell et al., 2009).
- 2) Decision makers often interact with equipment and personnel in stressful, dynamic, and uncertain environments. The complicated nature of military operations can have dramatic and unexpected consequences, as is seen in the analysis of military and industrial disasters such as the shooting down of Iran Air flight 655 (McDowell et al., 2009).

2. Findings:

a. Key Data:

- 1) The technical aspects of combining multisensory information continue to be studied at a steadily increasing rate within the military and the industrial base. Prior research in the field of Cognitive Engineering has shown that the cognitive aspects of any human-machine system, such as a sensor-analysis or sensor-shooter linking systems, should be taken into consideration in order to achieve systems that are both safe and useful, and with optimized effectiveness (Muller, 2006).
- 2) Cognitive Engineering places particular emphasis on the analysis of cognitive processes, e.g., diagnosis, decision making, and planning. It aims to enhance performance of cognitive tasks by means of several interventions, including the following:
 - a) User-centered design of human-machine interaction, and HCI.
 - b) Design of information technology systems that support cognitive tasks (cognitive artifacts).
 - c) Development of training programs.
 - d) Work redesign to manage cognitive workload and increase human reliability (Aubin, 2006).
- 3) In cognition, the thought process design within cognitive engineering, there are two forms of judgment:
 - a) Rational analysis is the superior form of judgment provided sufficient time for such analysis is available.

- b) Intuitive judgment, which is fast and generally easier with which to draw conclusions, is best used in time constrained environments such as during execution of missions or during crisis action planning (Hibner, 2006).
- 4) A cognitive assessment is used to determine which military thought process approach best leverages the two natural cognitive processes, analysis or intuitive. This cognitive assessment seeks to identify the approach that cues rational analysis the most and intuitive judgment the least (Hibner, 2006).
- 5) The U.S. Army relies on tactical-level leaders, not for their physical warfighting skills, but for their ability to employ cognitive thought during stressful situations. The physiological response to combat can degrade that cognitive capability, preventing leaders from performing tasks critical to unit success (Whitaker et al., 1996).
- 6) Relevant to tactical-level combat leadership are the following principles:
 - a) The brain sacrifices cognitive resources to respond emotionally.
 - b) Stress degrades the form of conscious attention known as “working memory.”
 - c) Certain brain areas can be deliberately activated to exert control over emotions (Whitaker et al., 1996).
- 7) The Distributed Soldier Representation (DSR) research team has identified several models that may be useful in developing DSR capabilities.
 - a) Specific Target Capability (also known as the Common Battle Space Picture): Information Warfare (IW) is emerging as the most critical aspect of military operations. Specific Target Capability provides a framework for research addressing the IW processes that employs the “observe, orient, decide, act” (OODA) model (figure A-1) (Whitaker et al., 1996).

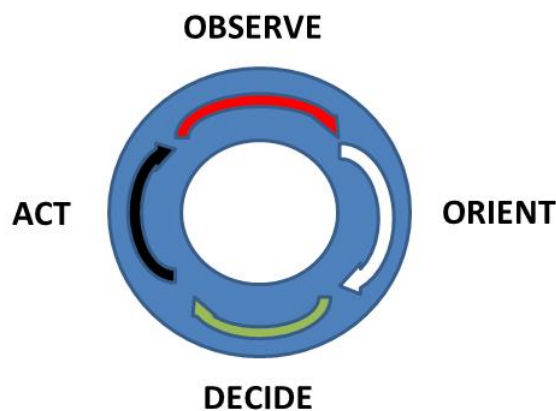


Figure A-1. OODA model.

- (1) Observe: the transformation of phenomena into a data set. The observe phase concludes at the point that observed data have been entered into the systems' knowledge base.
 - (2) Orient: distilling information (observed data) from the data stream (systems' knowledge base) and integrating that information along with prior facts and understandings into a coherent state of situational knowledge.
 - (3) Decide: evaluating the situational knowledge, projecting its ramifications for the ongoing tactical operation, focusing on a set of chosen ramifications, and developing/selecting the most appropriate tactical plan.
 - (4) Act: transforming the tactical plan into a tactical operation (Whitaker et al., 1996).
- b) The Cognitively Engineered Multisensory Data Fusion Model examines how a human interprets multisensory information from multiple data sources. It has been implemented with the development of algorithms for fusing imagery from several disparate sensors (visible and infrared). Results show that the model is an accurate depiction of how humans interpret information from multiple disparate sensors, and that the algorithms show promise for assisting fighter pilots in quicker and more accurate target identification. (Muller, 2006)
- c) Researchers working to simulate the psychological effects of anti-personnel landmines (APLs) suggest the need to consider fear, stress, and operational consequences into mine warfare models:
- (1) An Institute for Defense Analysis (IDA) simulation model centered upon the Janus simulation environment has been used to conduct a series of simulated battles involving APLs, anti-tank (AT) mines, various possible mine substitutes, and the subsequent effects observed. This series of the simulations resulted in three principal summary observations:
 - (a) At least in high intensity mechanized land warfare, landmines provide economy of force, canalize attacks, increase an attacker's losses, and reduce a defender's losses.
 - (b) The magnitude and, possibly, the direction of the effect of landmines in terms of those four capabilities are strongly related to both the nature of the fighting (defense vs. offense) and the type of landmines considered (anti-personnel vs. anti-tank).
 - (c) Increased artillery fire or non-explosive obstacles may not be the most efficient substitutes for landmines. (Kolasinski Morgan, 2001)

- (2) A series of standard combat simulations employing Janus, CASTFOREM and the Joint Conflict Model were conducted in a two-phase study to establish the battlefield contribution of APLs (Phase I) and assess the ability of APL alternatives as replacements (Phase II). Like the IDA studies, these studies compared the results of a battle with APLs to the results of the same battle without, as well as to the same battle with each proposed APL alternative. The summarized results of the standard simulation events were as follows:
- (a) The chosen methods of modeling casualties, and delay and change in movement rates provided a conservative equivalency.
 - (b) Phase I results suggested that the most important battlefield contribution of APLs was to reduce friendly force casualties and the second most important contribution was to increase the effectiveness of other weapons (i.e., AT minefields, artillery, and direct fire). Other contributions were to increase enemy force casualties, reduce battle tempo, and allow the friendly force to win.
 - (c) Phase II examined conceptual alternative APL concepts. Post-event analysis of Phase II results suggested that the simulation environments failed to adequately model fear and psychological factors thus causing APL alternatives to appear overly effective in comparison to actual APLs. (Kolasinski Morgan, 2001)
- d) Cognitive Models for Computer Generated Forces and Human Tutoring: The computer generated forces community and the online training community do not share much overlap. The small overlap that currently exists is that training groups need to use computer generated forces, but these two tasks are implemented separately and in different ways. The subject document presents a method for unifying these two seemingly disparate areas, by using a single cognitive model to provide both tutoring and a computer generated forces capability. It describes a prototype system that uses the technique to deliver both computer-generated forces and tutoring to multiple human players in a three-dimensional (3D) first-person simulation. (Livak et al., 2012)
- e) A Process Model of Situated Cognition in Military Command and Control: A general model that combines the technological aspects of a system with the perceptual and cognitive processes of the humans embedded in the system. The model emphasizes that such systems are both process oriented and dynamic. It describes a process tracing methodology that can be used to investigate the flow of data and information through both the technological and human components of the system. The results of the process tracing analysis have implications for the

design of complex systems and the training received by those who operate such systems. (Miller et al., 2004)

- f) The Vehicle Level Human Performance Model (VLHPM) developed by the U.S. Army Research, Development and Engineering Command, Tank Automotive Research, Development and Engineering Center (TARDEC) is an advance design tool that can operate alone or in coordination with human research participants. This model has been used to reduce the number of participants necessary for testing vehicle capabilities, effective survivability measures, and joint operability in the TARDEC-Naval Air Command (NAVAIR) Joint Survivability Experiment and its functionality was expanded for use in the Modeling Architecture for Technology, Research, and EXperimentation (MATREX) program and a joint experiment with the Canadian Army. The VLHPM has benefited the Research and Development Command (RDECOM) by providing a portable alternative to human participant use, reducing development of prototypes, manpower costs, and the need for training. (Miller et al., 2006)
 - g) Human-Centric, Network-Enabled Battle Command (HC-NEBC) Model: A simulation environment developed by the MATREX program which provides constructive simulation of individual warfighters based on human performance constraints to facilitate analysis of human performance and optimization of organizational designs. The HC-NEBC architecture uses three key federates of the Advance Simulation Branch of ARL HRED STTC: the Battle Command Management Services (BCMS), which model network-centric communications; the C3 Human Performance Model (C3HPM), which models individual Warfighter behavior; and the One Semi-Automated Forces (OneSAF), which model friendly and enemy platforms and unit behaviors. (Fogus et al., 2006)
- b. Consensus of Data: Military systems and processes designed to comply within Cognitive Engineering parameters will lessen the possibilities of those systems/processes failing during the stress of operations/combat.
 - c. Gaps in Research or Models: While significant research and modeling of how humans process sensory data has been conducted, it is not clear that the effects of emotional responses on cognitive processes have been modeled sufficiently.
3. Conclusion: Paragraph 2.a.7) above lists seven cognitive engineering models that might provide the basic concept or design aspect for a DSR Cognitive Engineering federate, providing that the selected model would generate the required federate/simulation data.

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Appendix B. Decision Science

1. Introduction:

a. Overview:

- 1) The U.S. Army's doctrinal decision-making/problem-solving method is the Military Decision Making Process (MDMP). This formal process is "tailorable" in application and serves as a standard guide for developing solutions to operational and tactical problems by Army organizations (Frambes, 2005). The MDMP process has proven to be genuinely appropriate for organizational/unit decision making but far less so for individual Soldier decision making.
- 2) "As the missions of U.S. Soldiers expand and the variety of cultural environments in which they operate increase, Soldiers are required to make more complex decisions when dealing in environments where non-combatants reside and combatants hide. Unfortunately, the research conducted to understand decision making has not focused on the inclusion of culture and more specifically on decision making in a military environment including the effects of culture. Even less of this research is focused on the Soldier's own socio-cultural attributes and how they affect his or her decision making" (Samms et al., 2012).

b. Topic Definition: Decision science concerns understanding human decision making and the development and use of methods and tools to assist in accruing that understanding. The first concern includes the distinction between descriptive and prescriptive decision making, how humans actually decide versus how they should decide (Davis et al., 2005).

c. Significance/Relevance: The U.S. military is certain to remain captivated by high technology systems. Computerized, digitized, networked, and even robotic or biochemical performance enhancement tools can be force multipliers of great value, but they are only as useful as the human designers who engineer those systems, and more importantly, are only as productive and effective as the human operators who employ those systems. Thus, human/individual Soldier decision making remains the primary component of successful military operations. Therefore, individual combat entities, and equipment/vehicle/aircraft entities which in reality are operated by individual Soldiers, should attempt to replicate the decisions expected from Soldiers/combatants and/or neutrals/non-combatant (Schoemaker, 2007).

2. Findings:

a. Key Data:

- 1) Much of the early decision science literature prescribed rational-analytic methods, such as embodied in systems analysis and policy analysis. The descriptive literature, however, has long noted that humans use heuristics (cognitive shortcuts), which are usually quite valuable but which sometimes introduce unintended biases. Efforts have

been made to improve decision support by “de-biasing” the presentation of information. However, newer literature on “naturalistic” decision making emphasizes the strengths of intuitive decision making based on heuristics and questions the desirability of de-biasing (Davis et al., 2005).

- 2) Ultimately, decision science should include both the rational-analytic and the intuitive capabilities of the decision maker, with a balance of “cold” and story-based presentation of analysis and recommendations (Davis et al., 2005).
- 3) The most common decision analysis techniques can be detailed in one diagram (figure B-1), which provides a comprehensive view of the current scope of decision analysis/making, the key concepts and the most common techniques used by practicing decision analysts (Parnell, 2009).

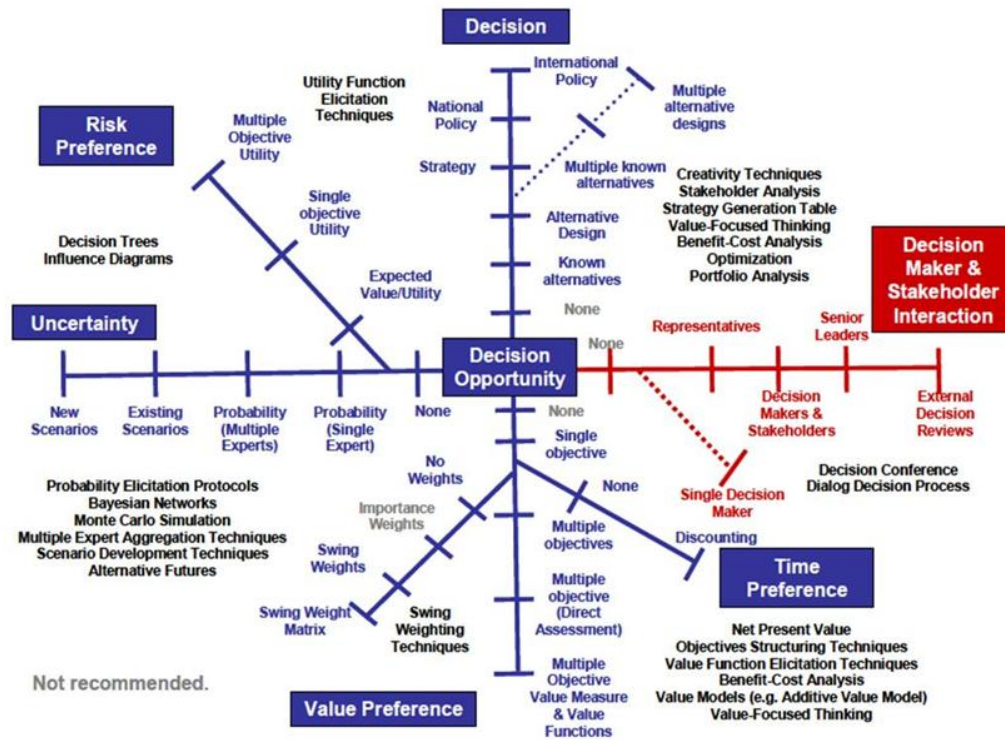


Figure B-1. Decision analysis in one chart (Parnell, 2009).

- 4) A summation of the most common decision-making models is as follows:
 - a) Rational decision-making models: decision matrix analysis, Pugh matrix, strengths, weaknesses/limitations, opportunities, and threats (SWOT) analysis, Pareto analysis, and decision trees. These models are based around a cognitive judgment of the pros and cons of various options. They are organized around selecting the most logical and sensible alternative that will have the desired effect.

Rational decision models can be quite time consuming and often require a lot of preparation in terms of information gathering (McDermott, 2012).

b) Seven-step decision-making model: The seven-step model was designed for choosing careers and may be classed as a rational decision-making model. The seven steps are designed to firstly identify the frame of the decision. Based on the information available, alternatives are generated. Further information is then gathered about these alternatives in order to choose the best one. The process terminates with implementation of a plan of action:

- (1) Identify the decision to be made – exactly what are you trying to decide?
- (2) Know yourself – what are your strengths, weaknesses, skills, values, and interests.
- (3) Identify options – list the various choices so far.
- (4) Gather information and data about each alternative.
- (5) Evaluate options that will solve the problem – pros, cons, and risks of each alternative.
- (6) Select the best option – may be necessary to loop back and gather more info.
- (7) Develop a plan of action – and implement it (McDermott, 2012).

c) Intuitive decision making models:

- (1) Sometimes considered to be unlikely coincidences or lucky guesses. In military schools the rational, analytical models have historically been used. However, it has been long recognized that once the enemy is engaged, the analytical model may do more harm than good. History is full of examples where battles have more often been lost by a leader's failure to make a decision than by making a poor one (McDermott, 2012).
- (2) The U.S. military are educating their personnel of every rank in how to make intuitive decisions. Information overload, lack of time, and chaotic conditions are poor conditions for rational models. Thus, instead of attempting to improve their rational decision making, the U.S. military has turned to intuitive decision models. Moreover, within the deployed military the intuitive approach is actually employed upwards of 90% of the time. (McDermott, 2012).
- (3) When talking about intuition we are describing something that is known, perceived, understood or believed by instinct, feelings or nature without actual evidence, rather than by use of conscious thought, reason, or rational

processes. This does not imply that intuitive decision making is irrational. Instead, we mean that the explanation for a choice is not directly available through conscious or logical thought (Decision-Making-Solutions.com, 2012).

- 5) Military decision making is knowing if to decide, and then when and what to decide. It includes understanding the consequence of decisions. Decisions are the means by which a commander translates the vision of the end state into action. Decision making is both science and art (Field Manual 101-5, 1997).
- 6) Many aspects of military operations such as movement rates, fuel consumption, and weapons effects are quantifiable, and therefore, part of the science of war. Other aspects such as the impact of leadership, the complexity of operations, and the uncertainty regarding enemy intentions belong to the art of war. (Field Manual 101-5, 1997) As mentioned above, military decisions must include both science and art.
- 7) The MDMP is a single, established, and proven analytical process. It is an adaptation of the Army's analytical approach to problem solving. The MDMP is a tool that assists the commander and staff in developing estimates and a plan. The basic steps in the MDMP process are the following:
 - a) Receipt of mission
 - b) Mission analysis
 - c) Course of action (COA) development
 - d) COA analysis (war gaming)
 - e) COA comparison
 - f) COA approval
 - g) Orders production (Field Manual 101-5, 1997)
- 8) While the formal MDMP process may start with the receipt of a mission and has as its goal the production of an order, the analytical aspects of the MDMP continue at all levels during operations (Field Manual 101-5, 1997).
- 9) Application of the MDMP process requires specific information to make decisions, develop courses of action, and issue orders. Because the MDMP relies on information, both information management and decision making are critical relative to time. (Frambes, 2005) The MDMP's time requirement factor is the primary reason experienced Soldiers consider the MDMP process to be problematic at best and totally unrealistic at worst for employment by individual Soldiers or small units (platoon echelon and below).

- 10) Of late, numerous military professionals and decision-making theorists hold that an analytical process such as the MDMP is inappropriate for tactical operations. Officers supporting this line of reasoning suggest that the tempo and uncertainty of the brigade/battalion fight calls for an intuitive decision-making process. However, this supposition has been proven incorrect by efforts that first established the validity of using an analytical model in the tactical environment, and then demonstrating that the MDMP is the right analytical model. The MDMP's effectiveness is supported by two sets of criteria. The first set includes planning imperatives suggested by historical doctrine. The second set represents the psychological processes that human decision makers need to overcome the combined friction of the tactical environment. Together, these two sets of criteria explain how the MDMP is an appropriate analytical model, which answers the second question. Therefore, as an analytical planning tool, the current MDMP is appropriate for tactical operations (Marr, 2005).
- 11) The ABCS is a suite of networked digital communications components designed to give commanders a better perspective of their operating environment thus facilitating their making better informed decisions. It includes a mix of fixed, semi-fixed, and mobile networks. It is also designed for interoperability with U.S. and Coalition C4I systems. ABCS Version 6.4 is an integrated suite that allows units/Soldiers to obtain an automated view of friendly activities, supply status, movements, fires planning, situation and intelligence reports, airspace monitoring and automatic weather reports, and information/data dissemination (Frambes, 2005).
- 12) ABCS components support deliberate MDMP planning, but may also require newly defined decision making processes to guide how information exploitation can be leveraged over networked battle command systems. Alternate decision-making models may include recognition-primed decision making, OODA as defined by Colonel John R. Boyd, or other emerging processes tailorable to the short reaction time required during combat operations in the contemporary operating environment (Frambes, 2005).
- 13) ARL's research program "Relevant Information for Social Cultural Depiction" (RISC-D) is working to develop models of how a Soldier's own cultural background influences decision making within a combat environment that includes other cultural groups (Samms et al., 2012).
- 14) RISC-D research was initiated with a synthetic analysis of the current literature to develop a taxonomy (a classification of key characteristics that focus on the general principles that describe a particular phenomenon) of socio-cultural factors believed to influence how people make decisions. The RISC-D taxonomy (figure B-2) will serve as the base of ARL research supporting the development of a framework to develop a socio-culturally influenced model of decision making (Samms et al., 2012).

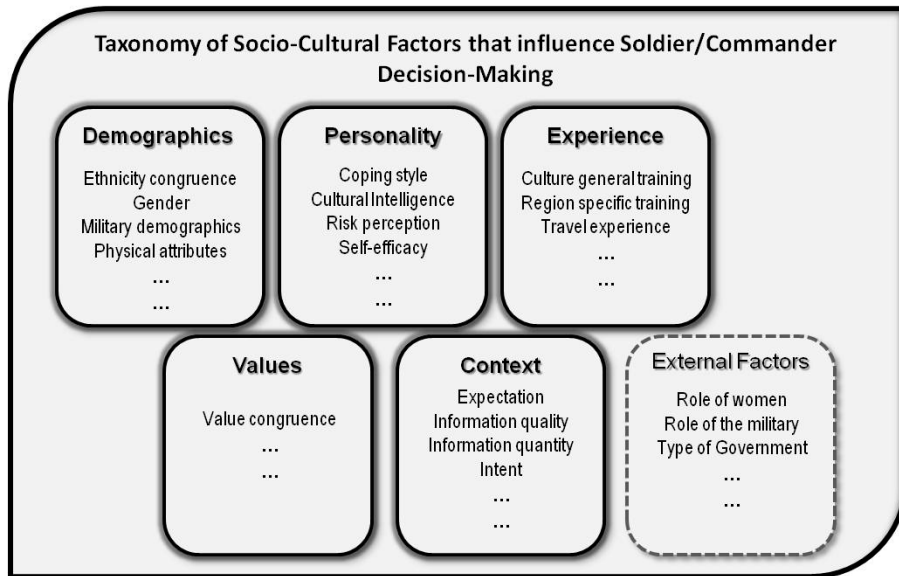


Figure B-2. Taxonomy of social-cultural factors that influence Soldier/commander decision making.

- 3) The most common decision analysis techniques can be detailed in one diagram, which provides a comprehensive view of the current scope of decision analysis/making, the key concepts and the most common techniques used by practicing decision analysts (Parnell, 2009).
 - b. Soldier decision making is dramatically affected by a broad range of stimuli such as individual family values, customs, background, upbringing, geographic/ethnic area of operations, group/unit values/experiences, and operational mission. Within any specific operational/combat scenario, Soldiers react dramatically differently depending upon the collective influences of the aforementioned stimuli and perhaps countless other similar type personality and motivating stimuli.
 - c. Databases have not yet been identified that contain both descriptive (demonstrated, intuitive reaction) and prescriptive (trained, doctrinal reaction) driven responses to specific combat environment events by U.S. and non-U.S. combatants and non-U.S. non-combatants.
3. Decision science is a complex and theoretical discipline that would require extensive expenditures of time and resources prior to offering any contribution to the currently projected Distributed Soldier Representation (DSR) objective. Decision science as pertaining to any DSR federate would require providing the following attributes to individual combatant entities and/or the equipment entities operated by Soldiers (humans):

- a. Some form of descriptive decision making process; most probable some type of tree/rule based decision selection process based upon approved/current U.S. Military tactics, techniques, and procedures (TTPs).
- b. The employed descriptive process should include socio-cultural attributes.

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Appendix C. Human Physiology

1. Introduction:

- a. Overview: The military has identified Human Performance Modeling (HPM) as a significant requirement and challenge of future systems modeling and analysis initiatives as can be seen in the Department of Defense's (DoD) Defense Modeling and Simulation Office's (DMSO) Master Plan (DoD 5000.59-P 1995). To this goal, the military is currently spending millions of dollars on programs devoted to HPM in various military contexts. Examples include the Human Performance Modeling Integration (HPMI) program within the Air Force Research Laboratory (AFRL), which focuses on integrating HPMS with constructive models of systems (e.g., cockpit simulations) and the Navy's Human Performance Center (HPC) established in September 2003. Nearly all of these initiatives focus on the interface between humans and a single system. Little work has been expended upon developing HPM, especially human physiology, simulation for a broad spectrum of simulation entity types common within a deployed, combined arms, ground combat unit (Lawton et al., 2005).
- b. Human physiology is the science of the mechanical, physical, bioelectrical, and biochemical functions of humans in good health, their organs and the cells of which they are composed. Physiology focuses principally at the level of organs and systems. Most aspects of human physiology are closely homologous to corresponding aspects of animal physiology, and animal experimentation has provided much of the foundation of physiological knowledge. Anatomy and physiology are closely related fields of study, are intrinsically related, and are studied in tandem as part of a medical curriculum. Anatomy is the study of form and physiology is the study of function (Merriam-Webster, 2012). The Human Physiology DSR category entails the addition of physiological effects upon all simulated entities representing humans or equipment entity types that are operated by humans such as individual, dismounted infantrymen/non-combatants or ground or aerial vehicles operated/driven/flown by humans.
- c. Significance/Relevance: The U.S. Army relies on tactical-level leaders, not for their physical warfighting skills, but for their ability to employ cognitive thought during stressful situations. The physiological response to combat can degrade that cognitive capability, preventing leaders from performing tasks critical to unit success (Steadman, 2012). Simulation of Soldiers, whether dismounted or mounted in ground or aerial vehicles, should include physiological factors.

2. Findings:

a. Key Data:

- 1) The combat/operational environment is demanding both physically and mentally. Soldiers, to be effective, must grasp complex, rapidly evolving, and often ambiguous situations. Individual failure translates into unit failure, wounded and dead, and for

the survivors the possibility of long-term physical and mental disability (Belenky, 2004). The physical demands of combat operations impose extraordinary stresses upon Soldier physiology, especially strength and endurance. The greater the combat induced physiological demands, the greater the affects upon Soldier effectiveness.

- 2) Human physiology plays a major role in explaining the effects of stress. Stress is characterized by the activation of the sympathetic nervous system (SNS). The SNS is activated when the brain perceives a threat to survival, resulting in an immediate discharge of stress hormones. This “mass discharge” is designed to prepare the body for fight-or-flight. The response is characterized by increasing arterial pressure and blood flow to large muscle mass (resulting in increased strength capabilities and enhanced gross motor skills, such as running from or charging into an opponent), vasoconstriction of minor blood vessels at the end of appendages (which serves to reduce bleeding from wounds), pupil dilation, cessation of digestive processes, and muscle tremors (Grossman, 1999).
- 3) Factors that affect individual and unit effectiveness in combat and other operational settings include the following:
 - a) Battle intensity and type.
 - b) Morale, leadership, and horizontal and vertical cohesion
 - c) Training and fitness
 - d) Combat experience
 - e) Physiological factors:
 - (1) Load
 - (2) Hydration
 - (3) Sleep
 - (4) Nutrition
 - (5) Personal and family factors
 - (6) Unit ethical climate (Belenky, 2004)
- 4) Military operational medicine (MOM) researches stressors and hazards encountered by Soldiers in operational and training environments to provide timely and realistic biomedical solutions that protect and enhance Soldier performance and health. Research goals include the following:
 - a) Maximized capabilities to exploit extreme environments

- b) Equipment optimized to Soldier physiology
 - c) Enhanced endurance from strategically timed interventions
 - d) Maintained effectiveness in noise and laser environments
 - e) Rapid training without injury through accelerated tissue repair
 - f) Prognostics and diagnostics from physiological monitoring
 - g) Psychologically hardened for full situational awareness (USAMRMC, 2000)
- 5) The most common perceptual distortions that occur within combat environments, are the following: (Also provided are average percentages of each type perception distortion that can be expected from individual unit combat actions/incidents.)
- a) Diminished sound (auditory exclusion) – 85%
 - b) Tunnel vision – 80%
 - c) Heightened visual clarity – 72%
 - d) Slow motion time – 65%
 - e) Memory loss for parts of the event – 51%
 - f) Memory loss for some of the subject’s actions – 47%
 - g) Dissociation (detachment) – 40%
 - h) Intrusive distracting thoughts – 26%
 - i) Memory distortions – 22%
 - j) Intensified sounds – 16%
 - k) Fast motion time – 16%
 - l) Temporary paralysis – 7%
 - m) Automatic pilot (“scared speechless”) – 4% (Grossman et al., 2004)
- 6) The DSR research team has identified several models that may be useful in developing DSR capabilities:
- a) Over the last two decades the U.S. Army has been establishing databases and developing a series of predictive equations for deep body temperature, heart rate, and sweat loss responses of clothed Soldiers performing physical work at various environmental extremes. Individual predictive equations for rectal temperature, heart rate, and sweat loss as a function of the physical work intensity, environmental conditions, and particular, clothing ensemble have been published

in the open literature. Additionally, important modifying factors such as energy expenditure, state of heat acclimation and solar heat load have been evaluated and appropriate predictive equations developed. The primary physiological inputs are deep body (rectal) temperature and sweat loss while the predicted outputs are the expected physical work-rest cycle, the maximum single physical work time if appropriate, and the associated water requirements (Pandolf, 2004).

- b) The “Prediction Modeling of Physiological Responses and Human Performance in the Heat” model provides the mathematical basis employed in the development of various individual heat stress predictive model equations. The application is programmed on the HP 41 CV, a programmable, expandable, continuous memory handheld calculator manufactured by Hewlett-Packard, and is described as meeting U.S. Army simulation needs. (Pandolf et al., 2004)7) The U.S. Army Research Institute of Environmental Medicine (ARIEM) conducts basic and applied research to determine how exposure to extreme heat, severe cold, high terrestrial altitude, occupational tasks, physical training, deployment operations, and nutritional factors affect the health and performance of military personnel. The mission of ARIEM is to conduct biomedical research to protect the health and performance of Soldiers in training and operational environments. This largely involves “enhancement” of the Soldier capabilities by preventing the degradation of health and performance in the face of external stressors that may include the natural environment or manmade exposures, including our own materiel systems. This article outlines the core competencies and accomplishments of ARIEM and highlights the current and future goals of the research program for the warfighter (Friedl et al., 2010).
- c) Virtual Soldier Research (VSR) is a research organization based at the University of Iowa, comprising a multidisciplinary team of faculty, professional staff, and students. Its expertise spans a variety of fields, including computer science, computer graphics, physiology, engineering, biomechanics, robotics, and optimization. VSR balances cutting-edge research with customer-driven product development in the field of digital human modeling (DHM). The inclusion of real-world constraints such as gravity, muscle fatigue, muscle strength, clothing restrictions, material properties, and physical restrictions in all VSR models provides for the creation of exceptionally realistic pre-production simulation test environments. VSR has successfully secured long-term strategic partnerships with DoD agencies as well as private industries that contribute to its development and deployment of technologies designed to test products and manufacturing processes from a human-centric perspective. Its success has led to the spin-off of an innovative private company, SantosHuman Inc., specifically focused on product development (University of Iowa, 2012).

- d) Dismounted Soldier Centric Load and Route Planning Mobile Training Apps is a project to develop a suite of dismounted Soldier load related tools targeting modern smart mobile devices. The project leverages approved Energy Expenditure Models from ARIEM, heat strain calculations, personnel status, and logistics status to enable dismounted Soldiers to visualize key load components, which can be managed and/or reduced to enable Soldiers to minimize their overall metabolic burden and arrive “Fresh to the Fight.” A full range of mobile apps are being created that range from training to operational. This program is a joint effort with NSRDEC with apps targeting their “Nett-Warrior on Android” program. The Soldier Load and Route Planning Suite includes energy expenditure models, terrain information including soil types, heat strain representation, automatic personnel statistics and logistics management, route analysis, and artificial intelligence (AI) dynamic auto planning, Soldier load equipment distribution, individual Soldier equipment views, and an immersive 3D training app (ARL HRED STTC et al., 2012).
- e) ONR Performance Shaping Functions is a science and technology solutions research effort conducted by ONR that includes adaptive training systems and cognitive tutors, decision-making aids, M&S, and HSI to improve Navy and Marine Corps capabilities in manpower and personnel, training and education, and human systems design. Solutions from diverse areas such as behavioral, biological, physiological, computational, and cognitive sciences; and the engineering and modeling disciplines are encouraged. The objective of the ONR Performance Shaping Functions effort is to mature basic research concepts and develop new technologies, methodologies, processes, systems, and/or devices to improve the human performance of tomorrow’s Navy and Marine Corps Warfighters. This ONR effort could possibly provide a source of software design principles pertaining to Human Physiology type applications (ONR, 2011).
- b. Consensus of Data: Soldier performance is considerably affected by physiological factors; these factors include environmental factors such as heat, humidity and altitude, hydration, nutrition, load, physical conditioning, and stress. Considerable research pertaining to the human physiological effects upon Soldiers in combat continues and considerable data has been accrued. A substantial number of models have been implemented as a result.
- c. Gaps in Research or Models: Models exist which apply specialized aspects of human physiology to combat simulations, especially those involving very small numbers of Soldier entities. However, no model or application has been identified that applies human physiology factors to simulations containing large numbers of dismounted and

mounted entities. The simulated Soldiers in current large-scale simulations never become fatigued, hungry, or thirsty nor are they ever physically affected by the threat of death or injury.

3. Conclusion: During the course of combat operations, “human flesh and blood” Soldiers are subject to fatigue/exhaustion, dehydration, sleep deprivation, fear/nervousness, heat/cold injury, weakness from hunger, and countless other physiological effects/symptoms that either degrade or improve their combat effectiveness. To add realistic Soldier physiological aspects to ground combat, simulations will increase their validity of use for material acquisition or training purposes.

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Appendix D. Human Psychology

1. Introduction:

- a. Overview: Any attempt to create a representation of the Soldier should account for human psychology. Human psychology is ultimately the underpinning for the majority of the topics in the Distributed Soldier Representation (DSR) category list; Cognition, Morale, Soldier Resilience, Unit Cohesion, Stress, Leadership, Decision Science, and Soldier as a Family Member all rely on an understanding of human psychology.
- b. Topic Definition: Human psychology is the study of the mind, occurring partly via the study of behavior. Grounded in scientific methods, psychology has the immediate goal of understanding individuals and groups by both establishing general principles and researching specific cases. Psychologists attempt to understand the role of mental functions in individuals and group social behaviors, while also exploring the physiological and neurobiological processes that underlie certain cognitive functions and behaviors. (Hockenbury et al., 2010) Because the topic of human psychology is so broad and has such overlap with other DSR topics, it will be necessary to focus this discussion to the areas of human psychology not covered by those other topics. Two factors that are touched on by the other DSR topics, but not significantly explored, are the factors of fear and the natural human reluctance to kill another human being.
- c. Significance/Relevance: German Captain Adolph von Schell said of his World War I battlefield experiences, “Soldiers can be brave one day and afraid the next. Soldiers are not machines but human beings who must be led in war. Each one of them reacts differently; therefore each must be handled differently To sense this and arrive at a correct psychological solution is part of the art of leadership” (von Schell, 1933). Significantly, most simulations currently treat the simulated Soldier as a machine; the human factors are ignored that can lead to unrealistic expectations in terms of the Soldiers’ performance under combat conditions.

2. Findings:

a. Key Data:

- 1) A survey of wounded combat veterans in the European Theater during World War II is telling. Of the 277 Soldiers interviewed, “65 percent of the men admitted having had at least one experience in combat in which they were unable to perform adequately because of intense fear” (Stouffer et al., 1949).
- 2) Although it is agreed that APLs are very powerful psychological weapons, their psychological effects are not incorporated into current mine warfare simulations (Kolasinski Morgan, 2001).

- 3) Understanding the psychological advantage that effectively led, well-trained, and cohesive organizations have over an opponent should encourage commanders to train their units to recognize and overcome fear (Daddis, 2004).
- 4) Although fear is ubiquitous on the battlefield, its source is not so readily apparent. Numerous environmental and operational factors conjoin to create physiological and psychological effects on Soldiers that can ultimately lead to combat ineffectiveness (Daddis, 2004).
- 5) Cumulative lack of sleep, combined with other privations such as hunger, affect efficiency on the field of battle and the individual (psychological) and organizational will to resist fear (Daddis, 2004).
- 6) Individual factors can stimulate fear just as easily as the operational environment can. In his memoir, William Manchester recalls his fright while fighting in the Pacific during World War II. He felt paralyzed with fear one night in part because of his active imagination: "A fresh fear was creeping over my mind, quietly, stealthily, imperceptibly. I sat up; my muscles rippling with suppressed panic" (Manchester, 1979). Research has suggested that men with active imaginations are prey to fears (Caputo, 1977).
- 7) Fear can be mitigated through certain factors, but there is no single absolute way to reduce fear. Soldiers need a battery of tools to deal with fear because Soldiers react individually to combat situations (Daddis, 2004).
- 8) If leaders are to understand how fear affects their unit's effectiveness, they cannot lead and fight relying solely on rigid precepts from manuals and procedures. They need to take measures to integrate fear's effects into the unit's preparation for combat (Daddis, 2004).
- 9) Controlling fear is within reach of well-trained units. Realistic, demanding training provides a Soldier advantages in the struggle of natural instincts for self-preservation against real or perceived threats (Daddis, 2004).
- 10) Another factor of Human Psychology is an inherent reluctance to kill another human being. If one studies history and is able to cut through the hype, one will find that a person is often unwilling to kill another person, and the fighter finds it very traumatic when having to do so. On the battlefield, the stress of being killed and injured is not always the main fear (Frisbee, 2012).
- 11) It should be noted that although Soldiers may shoot, they may not try to kill. They may be ordered to fire but it is very hard to determine if they are trying to hit as can be noted by the 52,000 rounds fired for one hit ratio estimated for U.S. forces within Vietnam (Frisbee, 2012).

- 12) The psychology of killing changes over the time that Soldiers are committed to combat. Within the first 10 days, a unit becomes “battle wise,” they become used to the demands of watching from every direction, they learn to deal with the enemy threat, and they become more “undisturbed” by what goes on around them. Between 10 and 30 days, they reach maximum efficiency. They fall into the pattern of combat. After about 30 days, Soldiers in combat may become over confident and believe their efficiency is not decreasing when it is. Their bodies are running out of stored energy and the battlefield environment is beginning to take its toll on more than just their mind. Combat exhaustion begins to set in. Combat exhaustion is the effect of the elements, poor food, and physical exhaustion. It also includes what happens to the body. When a human experiences an adrenaline rush, there is a price to pay afterwards. Combat is like a roller coaster in this way with highs being the adrenaline rush and lows coming after the rush. This “roller coaster” affects a human body dramatically because of the hormonal highs and lows, and can be severely draining physically and emotionally. These physiological factors directly affect a Soldier’s psychological state. After about 45 days within a combat environment, emotional exhaustion may begin to be experienced by combat troops and their unit’s efficiency decreases dramatically. Troops aren’t willing to attack and are even unwilling to dig fighting positions or run patrols. They lack the will they had before (Frisbee, 2012).
- 13) Leaders have a responsibility in training to understand and prepare for the human aspects of war, recognizing their Soldiers’ limits, needs, and motivations while remaining technically proficient. While they must manage their own fear in combat, they must also cope with their subordinate’s fears. Most important is setting a good example—what Napoleon viewed as keeping a cool head—despite good news or bad (Daddis, 2004).
- 14) One other combat leader essential task is providing their Soldiers with as much information as possible, for it reduces uncertainty and anxiety. The “absence of information” is one of the conditions that foster panic within troops. Fears arise from matters they don’t understand (Kindsvatter, 2003).

b. Consensus of Data:

- 1) Human psychology is conspicuously absent as a factor in current combat simulations.
- 2) Human psychology in the form of fear is a significant factor in the effectiveness of a unit in combat.
- 3) Human psychology is interdependent with a number of other factors including time in combat, tactical environment, training, leadership, and unit cohesion.

- c. Gaps in Research or Models: There are no models currently identified that fully represent the human psychological factors within a combat situation. One effort to model human emotions in stressful situations has been identified; however, this model would require extension to be useful in the simulation of human psychology in combat.
3. Conclusions: Human/military psychology is a complex and arguably theoretical discipline. Prior to any currently conceivable DSR objective being benefited by a human/military psychology model, extensive expenditures of time and resources in the research and study of the subject would be required, all of which would need to precede any actual model development.
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Appendix E. Leadership

1. Introduction:

- a. Overview: Although Peter Drucker, “the Father of Modern Management,” died in 2005, his teachings are studied and practiced by forward-thinking managers worldwide. His lessons and wisdom on the topic of leadership—the central element of management—are in constant demand, yet he wrote little under that actual subject heading. Two of his most unexpected teachings concerning leadership are “leadership is a marketing job” and “the best leadership lessons for business or any nonprofit organization comes from the military” (Cohen, 2006). Military leadership is and must be the most effective leadership possible, for a military leader’s first responsibility is to assure the accomplishment his/her unit’s mission (regardless) and secondly to assure the welfare of his/her Soldiers (Field Manual 6-22, 2006).
- b. Topic Definition: FM 6-22 is the U.S. Army’s keystone Field Manual on leadership. It establishes leadership doctrine and fundamental principles for all officers, noncommissioned officers, and Army civilians across all components. It uses the BE-KNOW-DO concept to express what is required of Army leaders. FM 6-22 stresses that Army leaders must be agile, “multi-skilled pentathletes” who have strong moral characters, broad knowledge bases, and keen intellects; and display those attributes and leader competencies bounded within the concept of the Warrior Ethos (Field Manual 6-22, 2006).

1) A leader must BE:

- a) A person of strong and honorable character
- b) Committed to the professional military ethic
- c) An example of individual values
- d) Able to resolve complex ethical dilemmas (Field Manual 6-22, 2006)

2) A leader must KNOW:

- a) The four factors of leadership and how they affect each other
- b) Standards
- c) Him/herself
- d) Human nature
- e) His/hers job
- f) His/hers unit (Field Manual 6-22, 2006)

3) A leader must DO:

- a) Provide direction
- b) Provide purpose
- c) Provide motivation (Field Manual 6-22, 2006)

c. Significance/Relevance:

- 1) Military leaders must make it their business to understand the linkages among victory, fire, combat performance, combat motivation, morale factors, combat environment, and leadership. Collectively, this is a leadership task of the first importance and should take precedence over digitization, force modernization, quarterly training briefings, command inspections, mission-essential task lists, and the other priorities in the seemingly inexhaustible list of things to do and know in today's U.S. Army. The bottom line remains—it is the leader's primary duty to motivate the Soldiers in combat. To do that, the leader must know how to enhance and develop morale factors while using them and other means to mitigate the trauma of combat. There is never enough time to do everything, but the aforementioned primary leadership task cannot be neglected (Spiszer, 2012). Moreover, once a leader earns the trust of the subordinates, they will allow the leader to influence not only their behavior in combat but also their thoughts, attitudes, values, goals and motivation; the leader will be permitted to mold them into dedicated, professionally focused Soldiers (Crandall, 2012).
- 2) To improve leadership effectiveness is one of the ways to increase unit effectiveness without requiring additional economic resources in comparison with other factors that influence unit combat readiness. Thus, to look for an improved method to lead a military unit is a task that could produce measurable increases in unit readiness but at no fiscal expense (Naplyokov, 2011).
- 3) Soldiers who rated their leaders more highly and who reported higher unit cohesion also reported lower scores on both stigma and perceived barriers to requesting and receiving combat stress related psychological care. Thus, positive leadership can reduce instances of PTSD (Wright et al., 2009).
- 4) Current U.S. military unit combat simulations, such as OneSAF, assume that all leadership entities possess the same, fully effective leadership capability. This is decidedly not the case in the real world.

2. Findings:

a. Key Data:

- 1) The four individual values that all Soldiers and especially leaders are expected to possess are the following:
 - a) Courage: overcoming the fears of both bodily harm (physical courage) and other than bodily harm (moral courage) while continuing to accomplish the mission in a professional manner.
 - b) Candor: being frank, open, honest, and sincere with subordinates, peers, and seniors.
 - c) Competence: being proficient in required professional knowledge, judgment, and individual Soldier skills.
 - d) Commitment: being dedicated to assuring responsibility for the accomplishment of all assigned unit missions while maintaining the unit, Army, and national values (Field Manual 6-22, 2006).

- 2) The core leadership competency framework consists of eight competencies and 55 components. The eight competencies are the following:
 - a) Leading others to success
 - b) Exemplifying sound values and behaviors
 - c) Vitalizing a positive climate
 - d) Ensuring a shared understanding
 - e) Reinforcing growth in others
 - f) Arming self to lead
 - g) Guiding successful outcomes
 - h) Extending influence (Horey et al., 2004)

- 3) Attributes of a leader who can be trusted in combat (listed in order from Soldier surveys) are the following:
 - a) Competent
 - b) Loyal
 - c) Honesty/good integrity
 - d) Leads by example
 - e) Self-control (stress management)
 - f) Confident

- g) Courageous (physical and moral)
 - h) Shares information
 - i) Personal connection with subordinates
 - j) Strong sense of duty (Crandall, 2012)
- 4) The U.S. Army relies on tactical-level leaders not for their physical war fighting skills, but for their ability to employ cognitive thought during stressful situations; in other words, to be combat leaders. The physiological response to combat can degrade that cognitive/leadership capability, preventing leaders from performing tasks critical to unit success. Relevant to combat leadership are the following principles:
- a) The brain sacrifices cognitive resources to respond emotionally.
 - b) Stress degrades the form of conscious attention known as “working memory.”
 - c) Certain brain areas can be deliberately activated to exert control over emotions (Steadman, 2012).
- 5) Leadership in literature sources is mostly described with static processes in which all domains remain constant. In a military setting, however, the domains change quickly and commanders/leaders have to frequently and quickly change their leadership tools in order to lead a military unit effectively. Moreover, keeping the previous leadership style regardless of the unit’s current situation can measurably decrease the effectiveness of a military unit or completely destroy it (Naplyokov, 2011). The right behavior in one situation is not necessarily the right behavior in another situation (Huges et al., 2011).
- b. Consensus of Data: In spite of a number of generally accepted descriptions of leadership effectiveness, there is no quantifiable leadership attribute listing that would facilitate the design of a computer simulation model replicating different levels of combat leadership. Rather, existing leadership models are designed to predict and/or explain group/unit responses to various types of leadership styles. However, two models have been identified that might provide a basis for the development of quantifiable leadership algorithms thus providing the basis for the design of a DSR Leadership federate:
- 1) Fiedler’s Least Preferred Coworker (LPC) Score Contingency Model; this contingency theory proposes that selecting the right kind of leader for an appropriate situation or changing the situation in order to adapt it to the particular leader’s style will determine leader effectiveness. The LPC score defines with whom the leader has the greatest difficulty working. Low-LPC leaders are motivated by the task and get satisfaction from task accomplishment. High-LPC leaders are motivated by relationships and are satisfied by establishing close interpersonal relationships.

However, the relationship between a leader's LPC score and effectiveness depends on a complex situational variable called situational favorability, which shows which situation gives a leader control over subordinates (Fiedler, 1967).

- a) The LPC scale asks leaders to think of all the people with whom they have ever worked and then describe the person with whom they have worked least well, using a series of bipolar scales of 1 to 8, such as the following:

Unfriendly	1 2 3 4 5 6 7 8	Friendly
Uncooperative	1 2 3 4 5 6 7 8	Cooperative
Hostile	1 2 3 4 5 6 7 8	Supportive
.....	1 2 3 4 5 6 7 8
Guarded	1 2 3 4 5 6 7 8	Open

- b) The responses to these scales (usually 18–25 in total) are summed and averaged. A high LPC score suggests that the leader has a human relations orientation, while a low LPC score indicates a task orientation. Fiedler assumes that everybody's least preferred coworker in fact is on average about equally unpleasant. But people who are indeed relationship motivated tend to describe their least preferred coworkers in a more positive manner, e.g., more pleasant and more efficient. Therefore, they receive higher LPC scores. This method reveals an individual's emotional reaction to people they cannot work with (Fiedler, 1967).

2) *Increasing Unit Effectiveness in a Dynamic Environment by Implementing a Leadership Mathematical Model* by LTC Yuriy V. Naplyokov, Ukrainian Army, describes/predicts leadership actions within a dynamic or combat environment employing mathematical formulas. LTC Naplyokov employs concepts from both game theory and decision theory, which requires that losses or expected losses associated with a variable that can be controlled be minimized in order to get maximum probable gain. His methods may be applied with any organizational level and in any situation. LTC Naplyokov's method postulates that leadership as a science has a mathematical interpretation (Naplyokov, 2012).

3. Conclusion: Leadership is absolutely essential to a military unit successfully operating within a combat environment. However, combat leadership is exceptionally difficult to quantify in such a manner that would facilitate the design of an "individual Soldier combat leadership model." While the DSR database contains a number of possible document sources that could support the design of a leadership model and subsequent application, the model listed in paragraph 2 above (*Increasing Unit Effectiveness in a Dynamic Environment by Implementing a Leadership Mathematical Mode*) holds the greatest promise as a concept and data source for the design of an individual Soldier leadership

model. This conclusion is taken due to the document offering mathematical formulas, which could be transformed into software algorithms.

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Appendix F. Morale

1. Introduction:

a. Overview: One of the most fundamental factors of any effective fighting force is the morale of the men and women who make up that force. Morale can be a determinant factor in any army's offensive and defensive combat effectiveness (Edmonds, 1948).

b. Topic Definition:

1) Morale, also known as esprit de corps when discussing the morale of a group, is an intangible term used to describe the capacity of people to maintain belief in an institution or a goal, or even in oneself and others. Esprit de corps applies particularly to military personnel and members of sports teams, but is also applicable in business and in any other organizational context, particularly in times of stress or controversy (Merriam-Webster, 2012).

2) Perhaps the most extreme example of the extent to which low morale can render an army ineffective are the mutinies that occurred within the French Army at the end of April 1917. In reaction to the disastrous "Nivelle offensive," drunkenness became rife; there was widespread absenteeism, and a general refusal to obey orders. Whole divisions refused to go into the front-line, particularly to take the offensive, and as a result the French Army had to maintain a defensive posture until 1918 when American forces arrived in sufficient numbers to lend practical help (Edmonds, 1948).

3) Clausewitz stresses the importance of morale for both the Soldier and the commander. He states that the Soldier's first requirement is moral and physical courage, both the acceptance of responsibility and the suppression of fear. Clausewitz considers the commander's responsibilities to include being bold, but: "The higher up the chain of command, the greater the need for boldness to be supported by a reflective mind, so that boldness does not degenerate into purposeless bursts of blind passion" (von Clausewitz, 1831).

4) Within a culturally and racially heterogeneous environment such as the U.S. military, morale and cohesion (cohesion being an integral component of morale) are especially critical to unit effectiveness. The common traits of effective unit and Soldier morale are the following:

a) The warrior spirit and esprit de corps, the latter being the one common unit trait that can transcend the problems of race and prejudice (Cox, 1995).

b) Unit loyalty and pride.

c) A common shared purpose and goal.

d) Trust between unit members (peers) and between subordinates and superiors.

- e) Self-less service and self-sacrifice.
 - f) Collectively, the intangible attribute that bonds Soldiers together and motivates them to push themselves to the last ounce of their strength or ability (Cox, 1995).
- 5) A large body of empirical research on military and nonmilitary groups reflects the fact that social cohesion has no independent impact on unit performance. Rather, task cohesion (a sense of shared commitment to the unit's mission) is the major morale component that determines a unit's operational effectiveness (MaCoun et al., 2005).
- c. Significance/Relevance: For the 21st-century U.S. military to successfully operate in the dispersed and isolated battlefield of the future, its Soldiers must be highly committed and well trained, and led to successfully transition, without pause, across the full spectrum of operations. The fundamental principle that will make this all possible is creating and maintaining a high state of unit morale (Burwell, 2000).

2. Findings:

a. Key Data:

- 1) "An Initial Conceptual Model for Morale Factors" describes an approach for the capturing and understanding of the complex human concept of morale. Generation of the document began with a literature review that identified over 200 factors affecting morale. British Army officers were then interviewed to validate the set of factors within the context of an operational environment. These data offer a solution for a formal computational model to be constructed. The document provides both the research domain with opportunities for further investigation and development, and the initial information required for the development of a unit morale controlling/effecting model. While this data set is most valid for UK Land Forces, its generalizability in a wider domain is obvious (Spear et al., 2009).
- 2) "Modeling and Analysis of Resolve and Morale for the 'Long War'" offers a theoretical framework that dynamically portrays Soldier morale. By using the second order response to an impulse, the morale of a Soldier, or unit, can be estimated in a combat model based on the expected deployment duration and the number of days deployed. This provides a capability to model and evaluate impacts upon Soldier morale from various courses of action or from other external factors (Artelli, 2007).
- 3) "Ground Warfare and Troop Morale: A System Dynamics Approach" provides a system dynamics model of the basic combat component modeling the interplay between force sizes, attrition rates, and reinforcement policies to understand the interaction of ground warfare effectiveness and troop morale. The second major part of the model is the implementation of fatigue effects on combat. Using the document's method of system dynamics to model troop morale effects allows analysts

to easily alter the model and either increase fidelity on factors of interest or conduct sensitivity analyses on the included basic factor representations. By implementing additional feedback loops between contributing factors, an analyst can create an effective model that produces both numerical results and a graphical representation of the relationships between the important factors. The graphical representation is especially valuable for analysts when they are briefing their analysis results to customers who may be unfamiliar with the model. Because the customers are able to look at the model and understand how relationships are being represented, they can easily offer valuable feedback and help the analyst change the model to better reflect reality. Getting this feedback from experts is invaluable for analysts wishing to better understand complex systems (Bletscher, 2008).

b. Consensus of Data:

- 1) Unit and individual Soldier morale is a major component in determining the combat effectiveness of any military organization.
- 2) Any DSR morale model or federate will involve exceptionally complex algorithms.

c. Gaps in Research or Models: Sufficient data and model examples do not exist to produce a DSR morale federate using anything other than the most basic, notional models.

3. Conclusion: Morale is a critical component of unit combat effectiveness. However, except for the most basic, notional models, developing a scientifically defensible morale model or simulation would require extensive specialized data and algorithms, which have not yet been developed.

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Appendix G. Soldier as a Family Member

1. Introduction:

- a. Overview: Military operations today are such that every Active, Guard, or Reserve Soldier can expect to be deployed or re-deployed, if that has not happened already. Whether the mission is combat operations, peace keeping, humanitarian, or disaster relief, back to back deployments or trainings with varied lengths cause Soldiers to spend more time away from their families (Dept of the Army, 2008). Historically, military families were simply not considered a part of military readiness. This is not surprising because until fairly recently (circa 1967), our enlisted military force consisted of mostly single men (61%). Among units that actually face the enemy on the battlefield (combat and combat support units), it was unusual to find married Soldiers in the enlisted ranks (Schneider et al., 1994).
- b. Topic Definition: This topic examines military family issues associated with combat readiness. It includes a description of the history of the still-evolving relation between the military and its families. Discussion of military culture is included to enhance understanding of current military beliefs, customs, and actions. Both military history and military culture have shaped and determined how the military and its families interact and affect one another. Their inclusion is necessary to understand the military-family interface in the modern armed forces. It is within this interface that families can affect military readiness.
- c. Significance/Relevance: Readiness may be defined as a combination of a Soldier's willingness and ability to do the job and cope in peacetime and during combat, and the Army's ability to retain trained service members during peacetime. Obviously this definition involves much more than a simple manpower count.(Schneider et al., 1994) Family life affects a service member's military performance during peacetime and during combat. Families play a major role in the Army's retention of personnel and also affect the service member's well-being.

2. Findings:

- a. Key Data:
 - 1) Before the creation of the all-volunteer U.S. Army in 1973, less than one-fourth of enlisted Soldiers were married, although the majority (80%) of older officers and noncommissioned officers (NCOs) were married (Military Family Clearinghouse, 1992).
 - 2) It is important to remember that the composition of Army families is not static. Every year, large numbers of families leave the military and return to civilian life, while other new families join (or are established in) the Army (Schneider et al., 1994).

- 3) Today, the employed husband-father and his homemaker wife-mother no longer reflect the normative U.S. family. Like society at large, the military services also have a wide variety of family types, including dual-career families, single-parent families, and families where the wife is the military member and the husband is a civilian dependent. Despite this variety, the career component of the military, especially the Army, is still composed almost exclusively of stable, two-parent families (Harris, 1993), and traditional family values remain the institutional norm (Schneider et al., 1994).
- 4) In 1983, the U.S. Army formally embraced the family when the then Army Chief of Staff, General John A. Wickham, Jr., issued a white paper stating that “A partnership exists between the Army and Army families. . . . Towards the goal of building a strong partnership, the Army remains committed to assuring adequate support to families in order to promote wellness; to develop a sense of community; and to strengthen the mutually reinforcing bonds between the Army and its families.” Underlying this partnership was a clear sense of its import to the mission: The Army recruits Soldiers but retains families (Wickham, 1983).
- 5) While there are some demographic differences between services, the major difference in family demographics (and especially family lifestyle) is in the comparison between military and civilian populations. The vast majority of today’s military families are young couples with small children. When compared to their civilian age cohorts, military members marry earlier, bear children at an earlier age, and have somewhat more children than their civilian counterparts. There are also proportionally fewer single parent families in the Army than in the similar-aged civilian population (Zellman, 1987).
- 6) The dramatic increase in the number of young enlisted families led to a corresponding need to expand and enhance a variety of family support services designed to ease some of the stressors associated with military life (Schneider et al., 1994).
- 7) The stressors can be categorized into two major areas: (1) cultural, based on organizational norms developed over the years; and (2) military life, based on unit demands on the service member (Schneider et al., 1994).
- 8) Before the increases in the number of married enlisted Soldiers, military families were predominantly wives of NCOs and officers. There was an expectation that these wives would support their husband’s military careers by performing various service or charitable activities. Senior enlisted and officers’ families were implicitly made part of the military, but they received little formal recognition and no compensation (Schneider et al., 1994).

- 9) Today, military spouses are increasingly likely to be employed outside the home. The spouses of career military members may also be trying to establish their independent careers. In spite of these trends, military spouses often feel that they should not work, and they are sometimes even made to feel that it is their duty to volunteer for post community activities. Not long ago, complaints by a group of U.S. Air Force wives led to a letter by the Secretary of Defense banning such pressure in all services (Army Times, 1987).
- 10) It is easy to see how the stress normally associated with such expectations is exacerbated in a marriage where one partner is often unavailable for “domestic duty” because of the priority attached to military duties and where frequent separations are considered the norm (Schneider et al., 1994).
- 11) While the number of single parents, male spouses of service members, and the number of dual-career couples are relatively small in comparison with the traditional male service member (female family member, military family), the issues of balancing the requirements of military duty and family life are even more complicated and often more stressful for these families (Schneider et al., 1994).
- 12) Regardless of the nature of their extended family relationships, these families often lack the immediate availability of extended family support during some of the most difficult and challenging phases of both marital and military life. The increased stress this places on the Soldier can certainly decrease effectiveness on the job during peacetime training and wartime combat. To the extent that spouses are dissatisfied with family life in the military, they will not support further active duty by the service member (Schneider et al., 1994).
- 13) The marital and parenting issues associated with these family responsibilities may distract or physically impede the Soldier from participating in unit training activities, and when severe, these family life difficulties (e.g., a spouse’s severe illness or injury) may make the Soldier non-deployable for combat. In this sense, family problems present serious readiness challenges for small unit commanders and military service care providers, for example, social workers, family counselors, drug and alcohol counselors, and other specialists (Schneider et al., 1994).
- 14) Unit factors, especially the attitude and behaviors of small unit leaders, have a tremendous effect on Soldier well-being and, in turn, on the well-being of the Soldier’s family. When leadership and morale in the unit suffer, the problem is often transferred to home and family (Schneider et al., 1994).
- 15) Unit leader attitudes and practices often betray a contrary belief that does not include family members as full-fledged partners in the military mission. For example, we have observed rules against wives telephoning the military unit, expectations that

- wives must join affiliated wives' clubs, ignorance of spouses' and children's needs for a reasonably predictable time off-duty, and the need for reasonable duty schedules with sufficient time off to meet family needs. Such practices contribute to negative attitudes toward further military service (Schneider et al., 1994).
- 16) Many of these military life stressors impact on children. Father (and now, mother) absence can have a profound negative impact on children's social and psychological development (Baker et al., 1967; Schneider et al., 1977). Furthermore, family relocations require children to change schools and disrupt their social networks of friends, teachers, and other important sources of developmental support. The developmental problems to which this mobility can contribute were reported by Shaw and Pangman (Pangman, 1975).
 - 17) For most Soldiers, worries about the home front can be a source of severe distress, can jeopardize the individual Soldier's ability to adequately participate in training activities, and most important can interfere with the Soldier's ability to adequately perform a combat role. Worry or preoccupation with home-front issues jeopardizes self and other unit members, risks the success of the mission, and places the Soldier at risk for psychological breakdown (Schneider et al., 1994).
 - 18) Deployed Soldiers may be engaged in combat within hours or days of arrival into the theater of operations. They may have little if any time to shift their mental focus from family environment to the deployed/operational events at hand (Schneider et al., 1994).
 - 19) Even in the remotest parts of the world, current technology allows Soldiers instantaneous telephone communication with their families. While this contact can be comforting to Soldiers and their families, it also means that there is no buffer (of time and psychological distance) between the Soldier and family. Loneliness and immediate concerns about well-being are brought into the present in a situation where the Soldier and family are relatively helpless to effect any change or provide real comfort (Schneider et al., 1994).
 - 20) Across a typical military career, families face a variety of life-cycle issues. These issues include marriage; birth of children; raising and educating children; moving households; career decisions of civilian spouses; and so forth. Various life stages will be stressful for some families and most families will experience some type of family or individual member physical, psychological, or social crisis during one or more of these periods. Such personal or family crises inevitably have at least a temporary impact on the service member's military performance (Schneider et al., 1994).
 - 21) Military readiness includes the retention of trained service members. The link between family issues and retention has been well documented.

- (Moghadam, 1989), in a study across time, found that wives' attitudes toward reenlistment were as important as Soldiers' intent in predicting Soldiers later actual reenlistment behavior. Lewis found that wives' attitudes toward reenlistment in the U.S. Air Force predicted career intent of their Airman husbands (Schneider et al., 1994).
- 22) The implication that the military must attend to family needs to maintain force levels is clear. This issue will become more critical in the future if current demographic trends continue. Thus, the personnel pool of young men and women is predicted to shrink. At the same time, job complexity with its increased training costs and costs to replace skilled workers will continue to rise (Schneider et al., 1994).
 - 23) The link between family issues and military performance is supported primarily by assertion and belief and only somewhat by empirical research. A bibliography of military research prepared by the Military Family Resource Center in 1984 (Military Family Resource Center, 1984) illustrates this point.
 - 24) While there are only a limited number of empirical studies linking readiness and family issues, there are considerable data (Krikland et al., 1989; Rosen, 1990; Sadacca et al., 1993) from which one can infer a family impact on readiness. For example, domestic problems in the home are believed to translate into decreased combat effectiveness and increased risk for death on the battlefield (Schneider et al., 1994).
 - 25) Data from the Israeli Defense Force (IDF) show that 30% of their casualties in the Lebanon War were due to combat stress reaction, a temporary breakdown due to accumulated stress. It renders the Soldier dysfunctional and unable to effectively carry on. The IDF found that Soldiers who had experienced certain marital discord or stress in personal relationships (parents or girl-friend) were at especially high risk to suffer a combat stress reaction. (Noy, 1978; Neumann et al., 1984).
 - 26) U.S. Army medical personnel have frequently reported (Rothberg et al., 1982) that both military sick call and family member outpatient visits increase just before a deployment, probably due in part to an increase in family stress. Knudson and colleagues demonstrated negative changes in the general well-being of wives associated with their husbands' deployment (Knudson et al., 1982). In 1979, a major study of the relation between unit deployment and various associated health problems was begun at the Walter Reed Army Institute of Research. This study was among the first to detail the reciprocal relation between family life stress and Soldier adaptation (Van Vranken, 1984).
 - 27) Other investigators (Schneider et al., 1994; Griffith, 1993) reported that individual performance and combat efficiency are in part dependent on marital and family

issues. For example, U.S. Air Force–Europe study that identified broadly defined personal and family factors related to air crew stress as figuring in 7 of the command’s 10 aircraft crashes during the study period. Although these last results were based on expert opinion (rather than on quantitative data), they point out a dramatic and important relation between family issues and military performance (Dooms, 1983).

b. Consensus of Data:

- 1) The proportion of Soldiers with families has significantly increased in recent years. This increase has in turn required a greater attention by the armed forces to the stresses placed upon families by the requirements of the Soldier’s units, as well as the impacts on military effectiveness due to family issues.
- 2) The proportion of Soldiers with families has a significant impact upon combat readiness; Soldiers’ and spouses’ satisfaction with military family life has been shown to impact Soldier retention rates. Retention rates directly impact military readiness.
- 3) Length and frequency of deployments affects the quality of family life and by extension the retention rate of Soldiers with families.
- 4) Family life stresses have been shown to effect individual performance and combat efficiency.

c. Gaps in Research or Models:

- 1) While studies have implicated family and domestic stresses in a reduction in individual performance and combat efficiency, no empirical data exist to directly tie these issues together; what data that do exist are largely based upon expert opinion.
 - 2) No model currently exists that directly relates family stress to combat efficiency at the individual level.
 - 3) No model currently exists to emulate the impact of family stresses on retention rate and therefore unit combat efficiency.
3. Conclusion: A model to address the topic of the “Soldier as a Family Member” would need to incorporate models at the unit level, which affect unit readiness and combat efficiency due to effects on retention rate, as well as models at the individual level, which reflect family stress induced effects on emotional states and levels of attentiveness/distraction during military operations.

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Appendix H. Soldier Resilience

1. Introduction:

- a. Overview: U.S. Army officials are trying to increase the resilience of Soldiers and family members by increasing their physical, emotional, social, spiritual, and family strengths. The resilience program is modeled after the Army's physical fitness program, where standards and assessment/reassessment of standards achievement are conducted that measures psychological fitness (McCluney, 2010). The Army's goal of increasing Soldier resilience is due to the historical fact that armies that do not field resilient Soldiers lose wars.
- b. Topic Definition: Combat places extraordinary demands on every individual, particularly the junior leader. The cumulative demands of combat may degrade Soldiers' resilience thus affecting their ability to lead or follow within their unit. As Soldier resilience degrades, Soldiers of any rank may be tempted to quit. However, there are actions that leaders can take to build resiliency within their Soldiers, enabling them to maintain operational effectiveness through the stressors of combat. (Adler, 2006) The Army is programmatically addressing the building of unit and individual Soldier resilience through its Comprehensive Soldier Fitness (CSF) Program:
 - 1) The CSF Program defines resilience as the ability to do the following:
 - a) Grow and thrive in the face of challenges and bounce back from adversity.
 - b) Function well under stress; sustain mental fitness during challenging situations.
 - c) Take care of self, peers, friends, and subordinates (TRADOC, 2012).
 - d) Trust between unit members (peers) and between subordinates and superiors.
 - 2) The CSF Program is designed to increase the resilience of Soldiers and families by developing five dimensions of strength:
 - a) Physical
 - b) Emotional
 - c) Social
 - d) Spiritual
 - e) Family (Army War College, 2010)
- c. Significance/Relevance: Ground combat tactical simulation environments that do not include the effects of combat upon Soldier resilience equate to the simulation of robots, no human (Soldier) front line involvement.

2. Findings:

a. Key Data:

- 1) A Soldier had to be resilient in order to “endure” the Great War (World War I). If he did not possess those innate qualities, then he would quickly become a casualty or he would be rendered combat-ineffective. Resilience was a common attribute shared by many Soldiers of all sides and was intimately connected to morale and endurance (5). As has been the case with all major wars, World War I was a test of nation state, army, small unit, and individual Soldier “resilience.”
- 2) WWI Soldiers were more resilient than has been previously suggested because they fought for their homelands, their loved ones, and their future; and were confident that they would achieve victory. It was the notion of uncontrollability, rather than discomfort or the objective danger of the trenches, that was the primary cause of resilience degrading stress. Belief in a future of one’s own choosing was a powerful incentive to carry on until the Soldier’s respective nation/army/unit had achieved its objective (Watson, 2008).
- 3) Approximately 30% of Vietnam veterans experienced PTSD, an exceptional accurate indicator that their deployed service resilience had been measurably degraded. Since the Vietnam conflict, 20% to 25% of deployed service members have experienced mental health disorders or diseases (Michigan State University, 2012). It can therefore be inferred that upwards of 30% of any U.S. force deployed to a combat environment are experiencing resilience degrading stress.
- 4) The most significant risk factors for PTSD inducing stress are genetic predisposition, a family history of psychiatric problems, exposure to a traumatic event during childhood or adolescence, and poor social support before, during, or after a traumatic experience. Research has further shown that PTSD risk increases when a Soldier is wounded or is deployed multiple times (Michigan State University, 2012).
- 5) Preliminary findings from the “Army Study to Assess Risk and Resilience in Service members” (Army STARRS) show that being married is associated with greater resilience against suicide during deployment. The rate of suicide is highest among those currently deployed. It also appears to be linked to the time between enlistment and active duty for those at the beginning of their careers—the longer the period, the less risk (Michigan State University, 2012). Of course, a propensity toward suicide is a strong indication of faltering resilience.
- 6) Any highly stressful event, such as ground combat, will have life-changing effects, especially early on; these effects will be disruptive to functioning.

- a) People who are affected may not need external help, other than friends and family.
 - b) Integration of personal stress effects with positive concepts or focus will shape more positive personal outcomes.
 - c) Most people will become stronger as a result of these experiences (Greene, 2012).
- b. Consensus of Data: Stress injuries are the major factor contributing to Soldier resilience degradation. All Soldiers are at risk for stress injuries, no matter how strong, seasoned, or experienced. Certain risk factors increase the probability that stress reactions or injuries will occur. The presence of risk factors does not automatically mean someone will be injured by excessive stress, but it raises that risk. Many of these risk factors can be modified, reduced, or eliminated. Stress injury risk factors include the following:
- 1) Duration of current deployment
 - 2) Repeated deployments
 - 3) Sleep deprivation
 - 4) Witnessing death, especially of other Soldiers or civilian non-combatants
 - 5) Being responsible for the death or serious injury of a non-combatant or allied combatant
 - 6) Losing a close friend or valued leader in combat or other operations
 - 7) Witnessing or participating in violations of the Law of War or Code of Conduct
 - 8) Being physically injured
 - 9) Sustaining a traumatic brain injury
 - 10) Close brushes with death
 - 11) Handling remains
 - 12) History of previous stress injuries
 - 13) Previous mental health problems
 - 14) Being new to the unit or lacking mutual trust with other unit members
 - 15) Being impacted by family, relationship, or other home-front stressors
 - 16) Being young and inexperienced (Grossman et al., 2000)
- c. Gaps in Research or Models: Few DSR categories possess less identified research data than Soldier Resilience.

3. Conclusion: Considerable additional source data research needs to be conducted in order to determine the potential of Soldier Resilience as a source of DSR modeling data.

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Appendix I. Stress

1. Introduction:

- a. Overview: The U.S. Military has identified Human Performance Modeling (HPM) as a significant requirement and challenge of future systems modeling and analysis initiatives. To this goal, the military is currently spending millions of dollars on programs devoted to HPM in various military contexts. (Lawton et al., 2005) It is self-evident that any combat HPM should include the effects of combat stress reaction (CSR) upon the simulated individual combatants (ICs) whether those ICs are mounted in /operating in equipment/vehicles or dismounted/on foot.
- b. Topic Definition: CSRs are expected and predictable emotional, intellectual, physical and behavioral reactions from exposure to stressful events. Such reactions may occur as the result of combat-like conditions that are present throughout the entire spectrum of military operations to include training, all phases of the deployment cycle, peacekeeping missions, humanitarian missions, stability and reconstruction, and Government support missions (U.S. Army Medical Department, 2012).
- c. Significance/Relevance: The ratio of CSR-induced stress casualties to battle casualties varies with the intensity of the fighting. Within very low-level, police action type conflicts CSR casualties can be less than 10% of all casualties. As the intensity of the operational/combat environment increases, the CSR casualty rate can approach a one to one ratio with physical casualties. However, regardless of the intensity of the operational/combat environment, to some extent, CSR always degrades IC operational effectiveness.

2. Findings:

a. Key Data:

- 1) The ground combat/operational environment is demanding both physically and mentally. To remain effective, Soldiers must grasp complex, rapidly evolving, and often ambiguous situations. Individual failure translates into unit failure, wounded, and dead, and for the survivors the possibility of long-term physical and mental disability. Factors that affect individual and unit effectiveness in combat and other operational settings include the following:
 - a) Battle intensity and type
 - b) Morale, leadership, and horizontal and vertical cohesion
 - c) Training and fitness
 - d) Combat experience
 - e) Physiological factors:

- (1) Load
 - (2) Hydration
 - (3) Sleep
 - (4) Nutrition
- f) Personal and family factors
- g) Unit ethical climate (Belenky, 2004)
- 2) The key characteristic that distinguishes combat stress is the activation of the sympathetic nervous system (SNS). The SNS is activated when the brain perceives a threat to survival, resulting in an immediate discharge of stress hormones. This hormone “mass discharge” is designed to prepare the body for fight-or-flight. The response is characterized by increasing arterial pressure and blood flow to large muscle masses (resulting in increased strength capabilities and enhanced gross motor skills—such as running from or charging into an opponent), vasoconstriction of minor blood vessels at the end of appendages (which serves to reduce bleeding from wounds), pupil dilation, cessation of digestive processes, and muscle tremors (Grossman, 1999).
- 3) Combat stress is induced by two categories of risk factors:
- a) CSR Factors:
- (1) Duration of current deployment greater than six months.
 - (2) Sleeping on average less than 8 h per day.
 - (3) Witnessing death close up, especially of other U.S. military personnel or civilian non-combatants.
 - (4) Actually causing or feeling responsible for, the death or serious injury of a non-combatant or allied combatant.
 - (5) Losing a close friend or valued leader in combat or other operations.
 - (6) Close brushes with death, especially if the individual believed he/she was going to die.
 - (7) Being young and inexperienced (junior in rank). Soldiers who possess at least a med-career level of military training and experience, thus who also possess greater life experience than a newly joined Soldier, better resist CSR (Department of the Navy, 2012).

- b) **Combat Resiliency Factors:** Military personnel also possess traits and abilities that make them resilient to the potentially damaging effects of combat and operational stress. Some of these resiliency factors are inborn, while others are acquired through training and experience or interactions with others. Compared to CSR factors, including resiliency factors within a simulation environment, would be exceptionally challenging. The major resiliency factors are the following:
- (1) Tough and realistic training
 - (2) Knowing what to expect at every turn
 - (3) Being more mature
 - (4) Having served in a previous operational deployment without physical or stress injury
 - (5) Having faith in God, the Army/Navy/Marine Corps, leaders, and peers
 - (6) Being physically fit
 - (7) Having a stable and supportive home and family life
 - (8) Being good at pushing self-defeating thoughts or perceptions out of conscious awareness
 - (9) Tending to cope with problems by taking action
 - (10) Having an optimistic attitude (Department of the Navy, 2012)
- 4) CSR involves a range of behaviors resulting from the stress of battle, which decrease the combatant's fighting efficiency. The most common symptoms are fatigue, slower reaction times, indecision, disconnection from one's surroundings, and inability to prioritize.
- 5) CSR is generally short term and should not be confused with ASD, PTSD, or other long-term disorders attributable to combat stress, although any of these may commence as a combat stress reaction.
- 6) Mild CSRs are indicated by physical, emotional, and behavioral changes. Often these changes are noticed, but not recognized as CSRs by leaders or Soldiers.
- 7) Severe CSRs prevent individuals from performing their duties and create safety concerns. These duty performance changes are easily recognized as CSR by observant leaders and other Soldiers (U.S. Army Medical Department).

- 8) The ratio of stress casualties (the Soldier is ineffective due to psychological injuries and usually requires evacuation) to battle casualties (physical injuries requiring medical treatment) varies with the intensity of the fighting. With intense fighting it can be as high as 1:1. In low-level conflicts, it can drop to 1:10 (or less) (Wikipedia, 2012) (Miller, 2012).
- 9) Combat and combat-related military missions can impose combinations of heavy physical work, sleep loss, dehydration, poor nutrition, severe noise, prolonged vibration, blast pressure exposure, heat, cold, wetness, poor hygiene, infectious diseases, toxic fumes, or substances. These, in combination with other influences, such as concerns about problems back home, can affect a Soldier's ability to cope with the perception of danger and diminish the skills needed to accomplish the mission.
- 10) Possible simulation environment mild CSR symptoms:
 - a) Trembling
 - b) Jumpiness
 - c) Easily startled by noise, movement, and light
 - d) Dizziness
 - e) Fatigue/exhaustion
 - f) Difficulty thinking, speaking, and communicating
- 11) Mild CSR symptoms could be simulated by decreasing the ballistic accuracy of affected simulated Soldiers (trembling), implementing random reactions to weapon fires and munition detonations (jumpiness), and impairing the Soldier's ability to communicate (difficulty speaking and communicating).
- 12) Possible simulation environment severe CSR symptoms:
 - a) Constant movement
 - b) Flinches/ducks at sudden sound or movement
 - c) Shakes, trembles
 - d) Loss of use of part of body (hand, arm, leg, etc.)
 - e) Inability to see or hear
 - f) Inability to speak
 - g) Physical exhaustion

- h) Freezes under fire
 - i) Sees or hears things that do not exist
 - j) Panics, runs when under fire (Department of the Navy, 2012)
- 13) Severe CSR symptoms could be simulated by further decreasing the ballistic accuracy of affected simulated Soldiers (shakes/trembles); implementing constant, random movement; implementing random reactions to weapon fires and munition detonations (jumpiness); and impairing the Soldier's ability to move, shoot, or communicate.
- 14) Junior-level leadership continues to be identified as a key factor contributing to Soldier well-being and resilience. During combat operations, the loss of a platoon leader or company commander will measurably increase stress levels throughout subordinate unit(s) (U.S. Army Medical Department, 2009).
- 15) The U.S. Army relies on tactical-level leaders not for their physical warfighting skills, but for their ability to employ cognitive thought during stressful situations. The physiological response to combat can degrade that cognitive capability, preventing leaders from performing tasks critical to unit success.
- 16) Especially relevant to combat leadership are the following principles:
- a) The brain sacrifices cognitive resources to respond emotionally.
 - b) Stress degrades the form of conscious attention known as "working memory."
 - c) Certain brain areas can be deliberately activated to exert control over emotions (Steadman, 2012).
- 17) One major modern revelation in the field of military psychology is the observation that resistance to killing one's own species is also a key factor in human combat. Brigadier General S. L. A. Marshall first observed this during his work as the official U.S. historian of the European Theater of Operations in World War II. Based on his post combat interviews, Marshall concluded in his landmark book, "Men Against Fire," that only 15% to 20% of the individual riflemen in World War II fired their weapons at an exposed enemy Soldier. Specialized weapons, such as a flame-thrower, usually were fired. Crew-served weapons, such as a machine gun, almost always were fired. And firing would increase greatly if a nearby leader demanded that the Soldier fire. But when left to their own devices, the great majority of individual combatants throughout history appear to have been unable or unwilling to kill (Grossman, 1999).
- 18) The following models/simulations are currently available that could either benefit from a stress federate or could provide a component of such a federate:

- a) Virtual Soldier Research (VSR) is a research organization based at the University of Iowa, comprising a multidisciplinary team of faculty, professional staff, and students. Its expertise spans a variety of fields, including computer science, computer graphics, physiology, engineering, biomechanics, robotics, and optimization. VSR balances cutting-edge research with customer-driven product development in the field of DHM. The inclusion of real-world constraints such as gravity, muscle fatigue, muscle strength, clothing restrictions, material properties, and physical restrictions in all VSR models provides for the creation of exceptionally realistic pre-production simulation test environments. VSR has successfully secured long-term strategic partnerships with DoD agencies as well as private industries that contribute to its development and deployment of technologies designed to test products and manufacturing processes from a human-centric perspective. Its success has led to the spin-off of an innovative private company, SantosHuman, Inc., specifically focused on product development (University of Iowa, 2012).
- b) Virtual Army Experience (VAE), Program Executive Office for Simulation, Training & Instrumentation (PEO STRI) and Product Manager for Special Operations Forces Training Systems (PM STS): VAE is a mobile U.S. Army simulator created by the Army development team with the digital development handled by Zombie Studios. The interactive exhibit brings the Army's computer game, "America's Army; Special Forces (Overmatch)," to a life-size, networked environment to provide visitors with a limited test drive of Soldiering. VAE uses a complex setup of computers, local area network (LAN) based scenarios, motion simulators, and videos. The VAE is managed by the Army's Office of Economic and Manpower Analysis (OEMA) at the United States Military Academy, West Point, NY.
- c) Virtual Battlespace 2 (VBS2) Army, PEO STRI, Project Manager Combined Arms Tactical Trainers: VBS2 Army provides an Army-wide, game-based training system that provides Soldiers with a platform to train in small unit TTPs for full spectrum operations. VBS2 Army is a 3-D, first-person, games-for-training platform that provides realistic semi-immersive environments, dynamic terrain areas, hundreds of simulated military and civilian entities, and a range of geo-typical (generic) as well as actual geo-specific terrains. U.S. Army, U.S. Marine Corps and multinational equipment is modeled. Over 100 users can join the same exercise on a network. A 3-D scenario editor is included as well as a robust after action review (AAR) capability. VBS2 is compatible with Distributed Interactive Simulation (DIS) and the High-Level Architecture (HLA) in order to provide integration with live, virtual, and constructive architectures.

- d) Infantry Warrior Simulation (IWARS), Natick Soldier Center, the Army Materiel Systems Analysis Activity (AMSAA), HRED, ARL: IWARS provides a capability to assess the combat worth of network-centric warfare technologies of warrior systems concepts for individuals and small units. IWARS provides a small unit force-on-force model with battle command capabilities and algorithms and methodologies to assess the impact of information on small unit operations.
- e) Synthetic Environment Core (SE Core), U.S. Army PEO STRI: SE Core enhances the training and mission rehearsal capabilities of U.S. Army Warfighters to ensure that the Army's virtual simulation systems are fully integrated, interoperable, and compatible with live and constructive training systems so that Warfighters can truly "train as they fight." The two primary initiatives under the SE Core program are the Architecture and Integration (A&I) and the Database Virtual Environment Development (DVED). A&I is integrating the U.S. Army's One Semi-Automated Forces (OneSAF) program into both the Close Combat Tactical Trainer (CCTT) and the Aviation Combined Arms Tactical Trainer (AVCATT) systems. DVED's primary mission is to rapidly generate correlated simulation system runtime databases for supported simulation systems.
- f) OneSAF: The design goal of OneSAF is to provide a semi-automated forces (SAF) architecture that incorporates and expands existing SAFs (Henderson & Rodriguez, 2002). OneSAF is a system that allows modeling and simulation of a full range of military operations, systems, and control processes. In addition, OneSAF will support models of various fidelity and resolution levels, suitable for different uses, including both training and analytical objectives and at the same time exchange information with other simulations. The key for building OneSAF is the component based approach, providing separate services for presentation, composition, and execution. Special attention is focused on behavior models. Entities in OneSAF are classified as physical agents, behavior agents, and units, where each can have a set of primitive and composite behaviors. OneSAF provides timelines, rule sets, and behavior metadata, which allow the agents in OneSAF to exhibit qualities such as autonomy, collaboration, adaptability, and mobility (Stoykov, 2008).

b. Consensus of Data:

Causes of CRS:

- 1) Combat Experiences: battle intensity and type, witnessing death close up (especially of other unit personnel/close friends or civilian non-combatants), being responsible for the death or serious injury of a non-combatant or allied combatant, close brushes with death.

- 2) Preparations for Combat: training and physical fitness, prior combat experience, being young and inexperienced (junior in rank), personal and family issues.
- 3) Unit Environment: morale, leadership, horizontal and vertical cohesion, unit ethical climate.
- 4) Sleep: sleeping fewer than 8 hours per day on average.
- 5) Physical: hydration, nutrition, equipment load.

Symptoms of CRS:

- 1) Memory: memory loss, memory distortions for parts of an event.
- 2) Dissociation: feeling detached/unaware of surroundings, intrusive distracting thoughts, inattention, indecisiveness, difficulty thinking/speaking/ communicating, carelessness, “outside body experiences.”
- 3) Physical Effects: physical exhaustion/fatigue, hyper-alertness, constant movement, jumpiness, shaking and tremors, flinches/ducks at sudden sound or movement, loss of use of part of body (hand, arm, leg), inability to see or hear, cannot speak, freezes under fire.

c. Gaps in Research or Models: Published research pertaining to the effects of stress during combat operations is exceptionally prolific. However, no model/simulation can be located that provide for CSR symptoms being instantiated within individual entities.

3. Conclusion: HPM Soldier fatigue provides the only model with the potential of providing the basis for a DSR Soldier combat stress model/application that could generate combat stress induced reactions within ground vehicle and/or aircraft crew personnel. Dismounted combatants appear not to be addressed by this model. However, more than sufficient research data are readily available to develop a narrowly focused, proof-of-concept Soldier combat stress model/application pertaining to both vehicle/aircraft crews and dismounted infantry/combatants. Such a model would alter the combat effectiveness of individual Soldiers, both dismounted and mounted, based upon situation induced fear, accrued fatigue, or similar individual physical or psychological factors. The model could provide for some or all of the following CSR symptoms to individual entities based upon intensity and duration of combat operations:

- a. Physical exhaustion; slowing of both IC movements across terrain and responses to hostile IC/vehicle discovery.
- b. Constant movement by small increments when in assigned position.
- c. Shaking and tremors; hand-operated equipment/weapon degradation.

- d. Slowing of reporting and/or reaction times.
- e. Inability to perceive (cannot see/hear)
- f. Inability to report (cannot speak)
- g. Freeze or panics and runs away while under fire
- h. Decreasing small arms accuracy proportional to increases in combat induced stress. This stress reaction model/simulation would capture the collective effects upon Soldier combat effectiveness of several of the above more narrowly focused CSR symptoms.

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Appendix J. Unit as a Complex Adaptive System

1. Introduction:

a. Overview: In recent years the focus of M&S at the tactical level has evolved from modeling Soldiers as weapon platforms to modeling the Soldier as an individual interacting within a unit. The military analysis community approach has been to adapt for individual Soldiers the methodologies originally developed for large weapons platforms. While a tank-like view of the human has some validity for modeling the physics-based aspects of movement, target detection, employment of ballistic projectiles, message transmission, and the like, it falls significantly short of describing the complexity of human behavioral response to the dynamics of the battlefield and as such it is not sufficient to explore the complexities of human behavior essential to adequately represent the individual Soldier within a combat environment. Tanks and airplanes don't become fatigued, hungry, frightened, or vengeful. They don't make decisions influenced by their psycho-physiological status, and they are not generally subject to wide variations in performance as functions of morale, training, unit cohesion, national characteristics, and a host of other "soft factors" that have long been recognized as key contributors to battlefield outcomes. Representation of these factors requires moving beyond the physics of the battlefield to an understanding of human physiology and psychology (Middleton, 2010). Thus, "realistic" modeling of the individual Soldier must take into account the concept of humans as processors of information. This process is exceptionally complex consisting of a very large number of constantly changing and adapting internal and external factors—it is a complex adaptive system.

b. Topic Definition:

1) Description. For many years scientists saw the universe as a linear place, one where simple rules of cause and effect apply. They viewed the universe as a big machine and thought that if they took the machine apart and understood the parts, then they would understand the whole. They also thought that the universe's components could be viewed as machines, believing that if we worked on the parts of these machines, and made each part work better, then the whole would work better. But, however hard they tried to find the missing components to complete the picture they failed. Despite using the most powerful computers in the world, the weather remained unpredictable. Despite intensive study and analysis, ecosystems and immune systems did not behave as expected. It was in the world of quantum physics that the strangest discoveries were being made and it was apparent that the very smallest sub-nuclear particles were behaving according to a very different set of rules. Gradually as scientists of all disciplines explored these phenomena a new theory emerged—complexity theory, a theory based on relationships, emergence, patterns, and iterations. A theory that maintains that the universe is full of systems, weather systems, immune systems, social systems, etc., and that these systems are complex and constantly adapting to

their environment, hence “complex adaptive systems.” Complex adaptive systems can be illustrated with the following diagram (figure J-1) (Fryer, 2012).

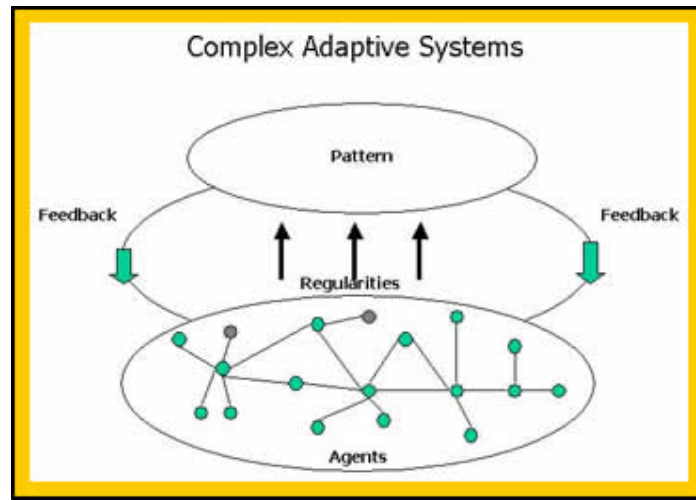


Figure J-1. Complex adaptive systems (Fryer, 2012).

2) Agents. The agents within a complex adaptive system are the components of that system. For example, the air and water molecules in a weather system and flora and fauna in an ecosystem are the components of larger systems. These agents interact and connect with each other in unpredictable and unplanned ways. But from this mass of interactions, regularities emerge and start to form patterns, which feed back upon the respective systems and inform/alter/modify the interactions of the agents. For example, in an ecosystem, the depletion of one species by a virus results in a greater or lesser food supply for others in the system, which, in turn, affects their behavior and their numbers. A period of flux then occurs in all the populations within the system until a new balance is established (Fryer, 2012).

3) Properties (most important):

- a) Emergence: Rather than being planned or controlled, the agents in a system interact in apparently random ways. From all these interactions, patterns emerge that inform the behavior of the agents within the system and the behavior of the system itself.
- b) Co-evolution: All systems exist within their own environment and they are also part of that environment. Therefore, as their environment changes, they need to change to ensure their best fit within the system. But because they are part of their environment, when they change, they change their environment, and as it has changed they need to change again, and so it goes on as a constant process.

(NOTE: A distinction can be drawn between complex adaptive systems and complex evolving systems. The former continuously adapt to the changes around

them but do not learn from the process. The latter learn and evolve from each change enabling them to influence their environment, thus better predict likely changes in the future and prepare for them accordingly.)

- c) Sub-optimal: A complex adaptive systems does not have to be perfect in order for it to thrive within its environment. It only has to be slightly better than its competitors and any energy used on being better than that is wasted energy. A complex adaptive systems once it has reached the state of being good enough will trade off increased efficiency every time in favor of greater effectiveness.
- d) Requisite Variety: The greater the variety within the system, the stronger it is. In fact, ambiguity and paradox abound in complex adaptive systems, which use contradictions to create new possibilities to co-evolve with their environment.
- e) Connectivity: The ways in which the agents in a system connect and relate to one another is critical to the survival of the system, because it is from these connections that the patterns are formed and the feedback disseminated. The relationships between the agents are generally more important than the agents themselves.
- f) Simple Rules: Complex adaptive systems are not complicated. The emerging patterns may have a rich variety, but like a kaleidoscope, the rules governing the function of the system are quite simple.
- g) Iteration: Small changes in the initial conditions of the system can have significant effects after they have passed through the emergence-feedback loop a few times (often referred to as the butterfly effect). A rolling snowball, for example, gains on each roll much more snow than it did on the previous roll and very soon a fist sized snowball becomes a giant one.
- h) Self Organizing: There is no hierarchy of command and control in a complex adaptive system. There is no planning or managing, but there is a constant re-organizing to find the best fit with the environment.
- i) Edge of Chaos: Complexity theory is not the same as chaos theory, which is derived from mathematics. But chaos does have a place in complexity theory in that systems exist on a spectrum ranging from equilibrium to chaos. A system in equilibrium does not have the internal dynamics to enable it to respond to its environment and will slowly or quickly die. A system in chaos ceases to function as a system. The most productive state to be in is at the edge of chaos where there is maximum variety and creativity, which lead to new possibilities.
- j) Nested Systems: Most systems are nested within other systems and many systems are systems of smaller systems (Fryer, 2012).

- 4) Military Complex Adaptive Systems: Military conflicts, particularly land combat, possess all of the key attributes of complex adaptive systems:
 - a) Combat forces are composed of many nonlinearly interacting parts and are organized in a dynamic command-and-control hierarchy.
 - b) Local action, which often appears disordered, self-organizes into long-range order.
 - c) Military conflicts, by their nature, proceed far from equilibrium.
 - d) Military forces adapt to a changing combat environment.
 - e) There is no master “voice” that dictates the actions of every Soldier (i.e., battlefield action is decentralized).
- c. Significance/Relevance: The explanation of the phenomenon of how a military unit, which seemingly is on the verge of annihilation, can manage to survive and fight effectively lies in the understanding that a military organization is a living system—a “complex adaptive system.”

2. Findings:

a. Key Data:

- 1) One concept of military complex adaptive systems describes combat as more like an interpenetration of two living, coevolving fluids rather than an elastic collision between two hard billiard balls. Artificial-life techniques—specifically, multi-agent based models coupled with evolutionary learning algorithms—provide a powerful new approach to understanding the fundamental processes of war (Ilachinski, 2004).
- 2) Another concept of military complex adaptive systems is described as an amalgamation of a large number of simpler entities or military units organized in a specific hierarchy, each with its own understanding of the overall mission, knowledge of operational doctrine, and local perception of the threat environment. Though orders and guidance emanate down through the chain of command, it is the actions at the lower levels (i.e., the individual agents) where we see the combat occurring. It is through the chaotic and adaptive behavior of the individual agents or players that the emergence of global behavior is induced (Ho et al., 2010).
- 3) Networks and information systems that are being constructed today are complicated. Integrating these networks together into a global Internet yields an extremely complicated environment. These intranet and internet cyber environments are beginning to exhibit the traits of complex adaptive systems. Moreover, it can be argued that the cyber domain can be thought of as the ultimate complex adaptive

system (e.g., the global Internet or a large military organization's intranet) (Phister, 2010). This ultimate complex adaptive system possesses the following key attributes:

- a) New information technology now permits a vastly increased degree of connectivity in military communication networks. This more connected architecture will result in faster response times and greater efficiencies in military operations—tactical data generation and exchange rates are accelerating (Miller, 2001).
- b) Highly connected network architectures are more prone to chaotic behaviors. These behaviors are nonlinear, frequently counter intuitive, usually manifested only under severe stress, and difficult to discern under the “artificial” conditions of training exercises (Miller, 2001).
- c) The required model/simulation approach is to consider military information networks to be complex adaptive systems made up of autonomous decision nodes (of variable capacity and responsiveness) coupled by information flows (of variable urgencies and multiplicities) (Miller, 2001).

b. Consensus of Data:

- 1) Recognizing the parallels between a living/complex adaptive system and a military system's need to survive and prosper within an environment full of positive and inimical forces results in four conclusions:
 - a) A military system is a living/complex adaptive system, for it possesses human systems and battlefield operating systems (BOSs), both representing self-organizing networks within the system; has the natural attribute of being both an organizationally closed and open system; and has a multi-leveled cognitive decision-making process.
 - b) The above three criteria for living/complex adaptive systems make up the components and processes that allow military systems, which in the face of overwhelming odds, to spontaneously behave in a way that facilitates, what can be viewed as miraculous survival and sustained combat effectiveness.
 - c) Viewing friendly forces as living/complex adaptive systems produces planning decisions that are focus upon maximizing and exploiting friendly unit combat effectiveness.
 - d) Viewing enemy forces as living/complex adaptive systems produces planning decisions that increase the probability of successful combat operations (Abb, 2005).

2) Models or Simulations: Emphasis on emergent simulation behavior over predetermined behavior enables the simulation to focus on what is possible to occur rather than what is probable. The potential to explore a multitude of possible outcomes from similar initial conditions makes a complex adaptive systems approach to simulation well suited for effects-based operations evaluation and course of action assessment (Ho et al., 1999). Some of the most promising models/simulations that do, or possibly could, employ the complex adaptive systems paradigm are the following:

- a) The Complex Adaptive Systems-based Toolkit (CAST) for Dynamic Plan Assessment. This model will support Air Force air campaign operations through the integration of combat agent behavior models, effects-based operations environment models, and a complex adaptive systems simulation engine. Specific challenges include modeling interactions between agents and environment; formulating an agent model with the potential for emergent group dynamics; and applying the models and simulation to a realistic urban operations scenario (Ho et al., 1999).
- b) Simulating Small Unit Military Operations with Agent Based-Models (ABM) of Complex Adaptive Systems. This is a concept for modeling small unit combat as complex adaptive systems. It begins with “a human-centric” view of the individual combatant and small unit operations, which incorporates the concept of the individual as an integrated weapon system, the Warrior System. It addresses representation of situation awareness/situation understanding (SA/SU), and morale, leadership, training, and nationality/ethnicity through ABM. Using ABM further supports the view of small unit operations as complex adaptive systems—dynamically interacting open systems, characterized by “emergence” of nonlinear and chaotic behaviors (Eidelson, 1997).
- c) Human Behavior Representation of Military Teamwork (HBRMT):
 - a) This model replicates the behaviors of artificial intelligence agents, with emphasis on creating teamwork through individual behaviors. The conceptual objective is to set up a framework that enables teams of simulation agents to behave more realistically. Better teamwork can lead to a higher fidelity of human behavior representation in a simulation, as well as provide opportunities to experiment with the factors that create teamwork. The framework divides agent behaviors into three categories:
 - 1) Leadership behaviors consist of planning, decision making, and delegating.
 - 2) Individual behaviors consist of moving, shooting, environment monitoring, and self-monitoring.

- 3) Team-enabling behaviors consist of communicating, synchronizing actions, and team member monitoring (Nitzschke, 1997).
- b) HBRMT's team-enabling behaviors augment the leadership and individual behaviors at all phases of an agent's thought process, and create aggregate team behavior bridges the gap between emergent and hierarchical teamwork. The individual behaviors synergistically combine to create teamwork, allowing a group of agents to act in such a manner that their overall effectiveness is greater than the sum of their individual contributions (Nitzschke, 1997).
- d) Irreducible Semi-Autonomous Adaptive Combat (ISAAC) / Enhanced ISAAC Neural Simulation Toolkit (EINSTEIN):
- a) The ISAAC/EINSTEIN model uses a bottom-up, synthesis approach to the modeling of combat where the individual combatants are modeled, and their interactions within a battlefield produce desired data for combat analysis. It provides a "conceptual playground" to explore high-level emergent behaviors arising from various low-level interaction rules. In this virtual combat environment, each agent has its own set of characteristics and rules of behavior, which can evolve over time. Examples of these characteristics are state (alive, injured, or killed), mission awareness, and ability to adapt. Another important element in ISAAC is the notion of the agent's personality. By incorporating agent personalities, a driving force for each agent is created. This is the mechanism defining the agent's decision to fight, retreat, or help a team member. The model is patterned after mobile cellular automata rules. Example:
- (1) $\omega = (1/20, 5/20, 0, 9/20, 0, 5/20)$ five times more interested in moving toward alive enemies than alive friendlies, even more interested in moving toward injured enemies
- (2) $\omega = (-1/6, -1/6, -1/6, -1/6, -1/6, -1/6)$ wants to move away from, rather than toward, every other agent and both flags, i.e., it wants to avoid action of any kind (Ilachinski, 1998).
- b) EINSTEIN builds upon and extends ISAAC into a bona-fide research tool for exploring self-organized emergent combat behavior. Some of the features of EINSTEIN include the following:
- (1) A fully integrated Windows graphical user interface (GUI) front-end.
- (2) Object-oriented C++ code base (compared to ISAAC's plain vanilla ANSI-C source code).

- (3) Context-dependent and user defined agent behaviors (i.e., personality scripts).
 - (4) On-line genetic algorithm, neural-net, reinforcement-learning, and pattern recognition toolkits.
 - (5) Online data collection and multidimensional visualization tools.
 - (6) Online chaos-data/time-series analysis tools.
 - (7) An online mission-fitness co-evolutionary landscape profiler (Ilachinski, 1998).
- c) Map-Aware Non-uniform Automata (MANA): The MANA software was developed by New Zealand Defense Technology (DTA), a business unit of the New Zealand Defense Force (NZDF). MANA is considered to be a continuation of the work on Ilachinski's ISAAC/EINSTEIN model. In MANA, Ilachinski's ideas are used, but some improvements have been made. For example, the entities communicate not only with their neighbors, but also on the unit or formation level. MANA has an extensive set of prebuilt entities, which allows rich combat scenarios to be created. The set includes entities such as individual Soldiers, vehicles, or fixed wing aircraft. Additionally, each entity has a broad list of properties which make it adjustable for different requirements. Example: Entity movements are done with the help of objective waypoints. The terrain is presented as a bitmap where a different coloring is used to represent the features on the map, such as roads, obstacles, or areas that cannot be passed (Stoykov, 2008)
- d) Pythagoras. Pythagoras is an agent-based simulation originally developed by Northrop Grumman to support a U.S. Marine Corps sponsored international initiative focusing on human factors in military combat and noncombat situations. Pythagoras is platform independent and is written in Java. It can be run as a batch job on a cluster of computers, enabling thousands of replications to be executed in a short time. Pythagoras is unique in the sense that it introduces fuzzy-logic and soft decision rules in agent decision making. This is an attempt to turn commander's orders, in a written format, into a numeric format. Some of the advantages of Pythagoras are simple scenario development and the flexibility to incorporate abstract ideas. At the same time, it is difficult to validate the models made in Pythagoras, which is a common problem found in all agent-based simulations (Stoykov, 2008).
- e) OneSAF: The design goal of OneSAF is to provide a SAF architecture that incorporates and expands existing SAFs (Henderson & Rodriguez, 2002). OneSAF is a system that allows M&S of a full range of military operations,

systems, and control processes. In addition, OneSAF supports models of various fidelity and resolution levels, suitable for different uses, including both training and analytical objectives and at the same time exchange information with other simulations. The key for building OneSAF is the component based approach, providing separate services for presentation, composition, and execution. Special attention is focused on behavior models. Entities in OneSAF are classified as physical agents, behavior agents, and units, where each can have a set of primitive and composite behaviors. OneSAF provides timelines, rule sets, and behavior metadata, which allow the agents in OneSAF to exhibit qualities such as autonomy, collaboration, adaptability, and mobility (Stoykov, 2008).

- f) Real-Time Strategy (RTS): RTS games support the notion of real-time. Usually, this means the players in RTS games do not have to wait for an opponent's move. This creates situations close to real warfare where the commanders must assess and respond to changes on the battlefield as quickly as possible. Real battles prove that, in many cases, a decision in the right time is more important than the best decision at the wrong time. This real-time feature of RTS games is a serious challenge for AI designs. An RTS simulation can be treated as an abstraction of a conflict between two or more sides, each of which is trying to achieve total dominance through numerous battles of virtual forces (Stoykov, 2008).
- g) Open Real-time Strategy (ORTS): ORTS was developed by the University of Alberta, Canada (Buro, 2002; Buro & Furtak, 2003; Buro & Furtak, 2004). The ORTS game engine has a client-server architecture. The server is responsible for managing the state of the "world" of the game, and the clients are responsible for analyzing the current situation in the game and responding by sending commands back to the server. To enforce fairness in the game, the ORTS server executes received commands in random order. Some of the reasons for choosing ORTS as a research platform are: RTS was built mainly as a research project for studying real-time AI problems such as path finding, scheduling, planning, and dealing in situations with imperfect information. ORT is also free software written in C++ and distributed under General Public License (GPL) (Stoykov, 2008).
- h) Combat XXI: COMBAT XXI is a joint Army-Marine Corps effort to replace the Combined Arms and Support Evaluation Model (CASTFOREM) (Posadas, 2001), a legacy combat simulation. It is a closed form, high-resolution, event driven stochastic, multi-sided, agent-based analytical combat simulation focused on the tactical level (Brigade and below). Scenario sizes range ~50 –10,000+ entities with typical size being between

the low 100s to 1500.(MOVES IBA) Combat XXI is being developed by the U.S. Army TRADOC Analysis Center – White Sands Missile Range (TRAC-WSMR) and the Marine Corps Combat Development Command (MCCDC). COMBAT XXI is written in Java and uses SimKit (a Naval Post Graduate School software package for creating Discrete Event Simulation [DES] models written in Java) as a simulation engine. Each of the simulated entities consists of a decision component and a functional component. The decision component is a set of decision interaction modules, which define the response capabilities of each entity to each simulation event. The functional component creates an interface to physical algorithms. The set of functional modules defines how a simulated entity will perceive and interact with the outside world. In addition, COMBAT XXI provides a global mediator mechanism, which creates the next level of abstraction in interaction mechanism between entities. Examples of these mediators are the observe mediator and the damage mediator. Additional important concepts in COMBAT XXI are pyramidal structure behavior models (primitive, procedural, tactical and cognitive), the introduction of stochastic elements in the OODA decision cycle and the presence of a scripting capability for extending behaviors (Stoykov, 2008).

- i) Infantry Warrior Simulation (IWARS): The IWARS is an analysis driven, multi-sided simulation focused on individual and small-unit dismounted combatants, their equipment, and the resulting capabilities. It is a user-friendly simulation tool to assess the impact of technologies on Soldiers and small units. IWARS was designed to use and implement Soldier related algorithms, data sets, and behaviors to help answer “so what” questions and has been used to assess operational effectiveness across a spectrum of missions, environments, and threats. It has been verified and validated for various capabilities such as limited SA/battle command analysis, Soldier sensor performance, and Soldier survivability analysis. Future development will look to improve human representations (physiological and suppressive responses) (NSRDEC, 2011).
- j) Conceptual Research Oriented Combat Agent Distillation Implemented in the Littoral Environment (CROCADILE): CROCADILE is an open, extensible, agent-based distillation engine developed at the Australian Defense Force Academy (ADFA). It was developed to study combat as a complex adaptive system at the conceptual level using an agent-based paradigm and also to address limitations in current distillations. CROCADILE has been developed in Java, is thus able to be run in any platform with a Java Virtual Machine implementation, and has also been designed with a strong emphasis on the

object oriented programming paradigm. One of the important features of CROCADILE, from the point of view of studying various types of emergent behaviors, is the separation of the simulation engine from the agents operating in the CROCADILE environment. Each agent in CROCADILE is represented by two facets corresponding to the physical and behavioral components. The physical component is manipulated and affected by events during the simulation, and the behavioral component determines how the agent interacts with other agents and the environment. CROCADILE allows users to create their own agents by constructing objects, which represent the behavioral facet of an agent, to control an associated physical agent supplied by the simulation. CROCADILE has a supporting Website (<http://www.cs.adfa.edu.au/research/vesl/Croc/>) from which the system and supporting documentation can be downloaded (Lowis et al.).

- c. Gaps in Research or Models: Research in the area of complex adaptive systems are varied in nature/objective and spread over the globe. Two areas of concern are the verification and validation (V&V) of complex adaptive system models and simulations, and obtaining M&S community/analyst acceptance of the data they provide.
3. Conclusion: Military conflicts, particularly land combat, possess all of the characteristics of complex adaptive systems:
- a. Combat forces are composed of a large number of nonlinearly interacting parts and are organized in a command and control hierarchy.
 - b. Local action, which often appears disordered, induces long-range order (i.e., combat is self-organizing).
 - c. Military conflicts, by their nature, proceed far from equilibrium.
 - d. In order to survive, military forces must continually adapt to a constantly changing combat environment, a live complex adaptive system.
 - e. There is never a “master voice” that dictates the actions of each and every individual combatant; a unit in combat operates under decentralized control (Ilachinski, 1998).

The study of complex adaptive systems, in concert with the development of agent-based M&S, would assist in the overall investigation of military units within combat environments consisting of made up of the interactions of individual Soldiers, all of whom are employing varying levels/types of system of systems technology. Such models and simulations could generate very “realistic” virtual environments.

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Appendix K. Unit Cohesion

1. Introduction:

- a. Overview: Current combat simulations deal well with large unit formations, weapon systems, and numerical effects such as attrition. Human factors such as morale, stress, and cohesion are modeled much less adequately. Of the human factors affecting the psychology of a combat unit, military psychologists have identified cohesion as one of the most important (Warner, 2006).
- b. Topic Definition: The concept of cohesion, referring to both the interpersonal relationships between Soldiers in a military unit and the morale solidarity of a military force, has been central to military analysis for many years. A model framework has been developed that can operationalize the concept of cohesion by measuring the relationship between members of a small combat unit to the individual Soldier's reaction to battlefield stress. This framework is such that it will be able to be implemented in any modeled environment that has a need to represent cohesion within the context of a training event or analysis experiment (Warner, 2006).
- c. Significance/Relevance: Historically, armies that have done well in combat have been cohesive units (Alexander, 1995).

2. Findings:

a. Key Data:

- 1) Unit cohesion is an important consideration in the best of times. In the worst of times—for a unit encircled, low on supplies, out of communication, beset by foul weather, and facing overwhelming odds—cohesion may be the one thing that enables it to hang on and survive until it can breakout or be relieved. The “guarantees” offered by persistent intelligence, surveillance, and reconnaissance (ISR), modern communications, and other technologies make it tempting to dismiss as impossible the eventuality of American units being cut off and isolated from all forms of support. But the U.S. Military ignore this threat, however unlikely, at its own peril, particularly in light of the grave strategic consequences that would accompany such a disaster (Van Epps, 2008).
- 2) Scientific research has made it clear that cohesion is not a unitary construct. Many dimensions of cohesion have been discussed in research literature. Perhaps the most common distinction made by behavioral scientists is between social cohesion and task cohesion (Evans et al., 1996). However, a large body of empirical research on military and nonmilitary groups proves that social cohesion has no independent impact on combat unit performance (MacCoun et al., 2005).
- 3) The explanation to the phenomenon of how a military unit, which seemingly on the verge of annihilation, still manages to survive and fight effectively, lies in the

- understanding that a military organization is a living (cohesive) system. Subscribing to the theory that a tactical unit (living cohesive system) strives for self-preservation and self-organization produces three conclusions:
- a) A military system is a living system for it possesses human systems (Soldiers) and battlefield operating systems (BOS), both representing self-organizing networks within the overall system. A military system has the natural attribute of being a system that is organizationally closed but also open thus exposed to external influences. Such a system has multi-leveled cognitive decision-making processes.
 - b) The above listed aspects of a living system make up the components and processes that allow military systems, which are facing challenges ranging from low intensity combat through defense against overwhelming odds, to spontaneously behave in ways that facilitates what can be viewed as miraculous survival and sustained combat effectiveness.
 - c) By viewing the enemy as a living military system, it leads to the discovery of planning imperatives that are applicable to designing military operations focused at exploiting and manipulating the enemy's survival ability and combat effectiveness (Abb, 2005).
- 4) Breaks in vertical cohesion between platoon leader, platoon sergeant, and squad leaders proved associated with below-average platoon performance. However, breaks between squad leaders and their subordinates proved to have no significant bearing on platoon performance (Alderks, 1992).
- 5) Cohesion and morale are characterized by six common contributing traits:
- a) The warrior spirit
 - b) Unit loyalty and pride (esprit de corps)
 - c) A common shared purpose and goal
 - d) Trust between peers and between subordinates and leaders
 - e) Self-less service and self-sacrifice
 - f) The intangible trait that bonds men together and motivates them to push themselves to the last ounce of their strength or ability (inter-personal loyalty) (Cox, 1995)
- 6) Old Dominion University has created a very detailed modeling framework design entitled the "Unit Model" that represents a classical Greek phalanx unit. Three historically based scenarios were run to validate the model. The results show that a model with the properties defined in the "Unit Model" can represent a reasonable

facsimile of infantry combat showing the effect of stress, cohesion, and combat effectiveness (Warner, 2006). This modeling framework could be applied to any type modern infantry small unit simulation.

- b. Consensus of Data: In the future, the U.S. Army will continue to conduct a broad spectrum of both short-term and protracted tactical operations. The success of these operations will depend on the Army's ability to field cohesive tactical units.
 - c. Gaps in Research or Models: Research summarized in this report discovered two unit cohesion models that might prove useful in the development of a unit cohesion simulation: the "Unit Model" (Warner, 2006) and the "Mental Model" (Van Epps, 2008).
3. Conclusion: Unit cohesion is an integral component of any combat unit's fighting power. The greater the unit cohesion, the greater the capability of the respective unit to attack, defend, or merely survive within a losing tactical situation. However, the component factors of unit cohesion are complex and would be difficult to quantify on an individual Soldier basis. The complexity of unit cohesion is reflected by the paucity of models that could be used to replicate it within a simulation environment. Developing a unit cohesion model or simulation would be almost a "start from scratch" proposition.

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List of Symbols, Abbreviations and Acronyms

A&I	architecture and integration
ABCS	Brmy Battle Command Systems
ABM	agent based models
ADFA	Australian Defense Force Academy
APL	anti-personnel landmines
ARIEM	Amy Research Institute of Environmental Medicine
ARL	U.S. Army Research Laboratory
ASD	acute stress disorder
AT	anti-tank
AVCATT	Aviation Combined Arms Tactical Trainer
BCMS	Battle Command Management Services
BOS	Battlefield Operating Systems
C3HPM	Command, Control and Communications (C3) Human Performance Model
CAS	complex adaptive system
CAST	complex adaptive systems-based toolkit
CASTFOREM	Combined Arms and Support Evaluation Model
CCTT	Close Combat Tactical Trainer
COA	course of action
COSR	combat operational stress reaction
CSF	comprehensive Soldier fitness
CROCADILE	Conceptual Research Oriented Combat Agent Distillation Implemented in the Littoral Environment
CSR	combat stress reaction
CTC	combat training center
DAS	Dynamic Animations Systems, Inc.

DHM	digital human modeling
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DSR	distributed Soldier representation
DVED	Database Virtual Environment Development
FM	field manual
FY	fiscal year
GUI	graphical user interface
HBRMT	human behavior representation of military teamwork
HC-NEBC	human-centric, network-enabled battle command
HIC	human-computer iteration center
HPC	Human Performance Center (U.S. Navy)
HPM	human performance model
HPMI	human performance modeling integration
HRED	Human Research and Engineering Directorate
IDA	Institute for Defense Analysis
IDF	Israeli Defense Force
IC	individual combatants
ISAAC	Irreducible Semi-Autonomous Adaptive Combat/Enhanced ISAAC Neural Simulation Toolkit (EINSTEIN)
ISR	intelligence, surveillance and reconnaissance
IW	information warfare
IWARS	Infantry Warrior Simulation
JRTC	Joint Readiness Training Center
LAN	local area network
LPC	least preferred coworker
M&S	Modeling and Simulation

MANA	map-aware non-uniform automata
MATREX	Modeling Architecture for Technology, Research and EXperimentation
MCCDC	Marine Corps Combat Development Command
MDMP	Military Decision Making Process
MOM	military operational medicine
NAVAIR	Naval Air Command
NCO	Non-Commissioned Officers
NSRDEC	Natick Soldier Research, Development, and Engineering Center
NZDF	New Zealand Defense Force
OEMA	Office of Economic and Manpower Analysis (Army -USMA)
OneSAF	One Semi-Automated Forces (SAF)
OODA	observe, orient, decide, act model
ORTS	open real-time strategy
PEO-STRI	Program Executive Office for Simulation, Training, and Instrumentation
PM STS	Product Manager for Special Operations Forces (SOF) Training Systems
PTSD	post-traumatic stress Disorder
RDECOM	Research, Development, and Engineering Command
RISC-D	relevant information for social cultural depiction
RTS	real-time strategy
SA/SU	situation awareness/situation understanding
SAAFMM	Soldier as a family member
SE Core	Synthetic Environment Core
SNS	sympathetic nervous system
SoS	system of systems
STARRS	study to assess risk and resilience in service members (Army)
STTC	Simulation and Training Technology Center
SWOT	strengths, weaknesses/limitations, opportunities, and threats

TARDEC	Tank-Automotive Research, Development, and Engineering Center
TRAC-WSMR	TRADOC Analysis Center – White Sands Missile Range
TTPS	Tactics, Techniques, and Procedures
USARIEM	U.S. Army Research Institute of Environmental Medicine
VAE	Virtual Army Experience
VBS2	Virtual Battlespace 2
VLHPM	Vehicle-Level Human Performance Nodel
VSR	Virtual Soldier Research

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