Multi-Aspect Socioeconomic Agent-Based Dynamic Scenario Engine
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SECTION I: General Information

Sandia National Laboratories, a Federally Funded Research and Development Center, will participate in the proposed project. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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SECTION II: Project Funding Information

Estimated cost in FY'09: 1.5M.

SECTION III: M&S Deficiencies and Project Objectives

Effective training for military commanders must match the type of decisions and actions necessary in the field. We believe such decisions are what Gary Klein terms "naturalistic"[1] in that they are missing information, made under severe time pressure, have vague goals and must be enacted in changing conditions. Karl Weick's conceptualization of sensemaking as organizing a streaming flux of experience by mental-model guided "noticing and bracketing" is particularly germane. Both Klein and Weick stress the importance of orienting the decision maker to on-going directed action. Weick states "Furthermore, managers with limited attention face many such issues at the same time, often evaluating several situations, interpretations, choices, and actions simultaneously. Thus, inaccurate perceptions are not necessarily a bad thing … People do not need to perceive the current situation or problems accurately to solve them; they can act effectively simply by making sense of circumstances in ways that appear to move toward general long-term goals."[2] Klein similarly advocates training via the rapid presentation of numerous scenarios intentionally drawn from typical and atypical cases rather than deliberate and drawn out rational analysis.

We believe simulation-based training offers the ability to rapidly and meaningfully interact with the curriculum, providing the rapid feedback critical to

[1] Klein, G. (1998) *Sources of Power: How People Make Decisions*. MIT Press, Cambridge, MA.
[2] Weick, K.E., Sutcliffe, K.M., and Obstfeld, D. (2005) "Organizing and the Process of Sensemaking," *Organization Science*, Vol. 16, No. 4, July–August 2005, pp. 409–421.

developing appropriate action-oriented expertise.[3] Due to the long time constants involved in political organization, economic development, and social structural change, simulation is necessary if students are to actively experiment with and thereby learn the various strategies needed in the modern multifaceted role of the U.S. Military abroad. It is critical, however, that the simulation technology be dynamic enough to provide learning experiences across the multitude of interactions students will have with it throughout the full length of a course. Scripted behaviors betray a scenario-to-scenario regularity that astute students will perceive, study, and ultimately exploit, unintentionally teaching a strategy of exactly the wrong behavior – "paralysis by analysis".

We propose to improve training tools by researching ways to construct rich, dynamically articulated scenarios that evolve over time, even in the absence of any action by the student, driven by plausible data-driven motive forces in political, economic, and information realms. Our goal is not to be predictive but rather to be able to generate training experiences that lead to: 1) improved awareness of likely outcomes; 2) reasonable approaches for assessing the situation 'as-is'; and 3) actionable knowledge of how to affect that situation favorably for the warfighter.

SECTION IV: Milestones and Deliverables

Milestones are planned throughout the proposed project. The initial phase of the project is focused on immersion in the subject matter material, including attending 'as-is' courses and reviewing existing course materials. This immersion will drive the initial information gathering phase, leveraging automated document identification mechanism to expand the pool of both primary source and reference material. We will begin

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[3] Bower, B. (2004) "Reworking Intuition," *Science News*, Vol. 166, No. 17

development of the cognitive representations and hierarchically overlapping networks to drive assimilation of the material. Midway through the project, we will verify that our planned programmatic objectives are on track to deliver a system of value by meeting with TRADOC and walking through the proposed 'to be' course, using low fidelity stand ins for the simulations. Revisions and adjustments will be completed by the 8-month milestone, marked by the delivery of the documentation of the cognitive models. Computational experiments using these models will be ready for demonstration at 9 months, and ready for in-classroom use and comparison to source materials at 11 months. The project will be concluded with a final report to accompany the prototype software. Figure 1 illustrates these events on a project timeline assuming a project start date of November 1, 2008. Table 1 lists the proposed deliverables.

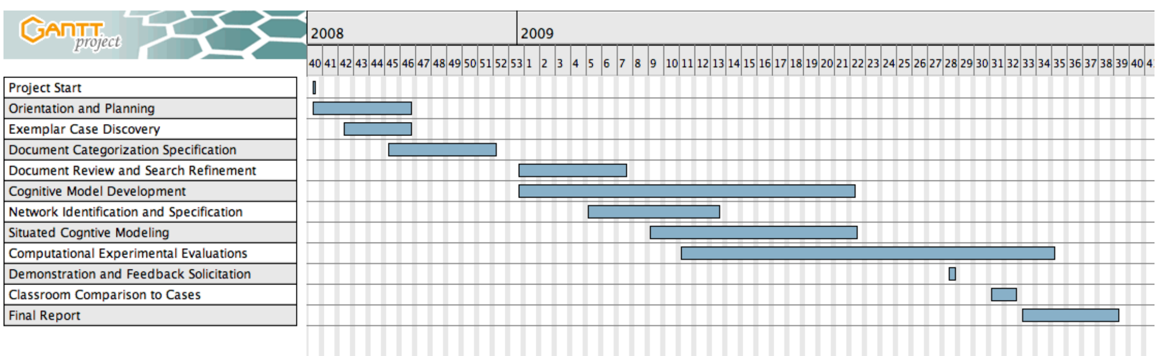

Figure 1: Estimated Project Timeline

Product	**Delivery Date**
Candidate Course Material Search System	6 months after project launch
Agent-Based Scenario Engine	12 months after project launch
Documentation	12 months after project launch

Table 1: Project Deliverables

SECTION V: Technical Approach and Development Risk

We are proposing a multi-thrust approach, leveraging existing Army data and Sandia expertise and models, to represent target societies in agent-based frameworks operating over networks. The initial phase will be focused on information gathering, and in particular specialized computerized techniques to expand the corpus of material the classes draw on. The second phase will focus on creating targeted learning opportunities by building computational models based on the information deemed relevant in the first phase. Each of these phases is discussed below.

The motivation behind the information retrieval task is to ensure that the data used to guide the design of the system is sufficiently broad and encompassing to capture the essence of the doctrine to be taught without building in particular assumptions. Malcolm Gladwell's book *Blink* describes the outcome of the Joint Forces Command (JFCOM) Millennium Challenge '02. The Blue Team used Operational Net Assessment tools to plan an Effects-Based Operation designed to debilitate the Red Team's war-making capability. Although the operation correctly identified the critical needs of the adversary correctly – for example, communication – it assumed a dependency on infrastructure for fulfillment of those needs based on Western industrialized experience. The Blue Team knocked out microwave towers and fiber optic lines, and set up monitoring for satellite and cell phone links. Paul Van Riper, the Red Team leader, responded with a network of couriers and mosques for internal communications, and lighting systems for military communications. As a result, he was able to sink sixteen ships – approximately half – of Blue's aircraft carrier battle group.

We propose to use a Sandia technology called STANLEY (Sandia Text ANalysis Extensible libraryY) to broaden the document pool to be used for building, evaluating, and teaching with the proposed Agent-Based Dynamic Scenario Engine. STANLEY's technical basis can be roughly described as a cognitively enhanced latent semantic analysis (LSA) approach. LSA mathematically detects how patterns of words co-vary across large samples of text. Classically, it has been used to compare documents in a conceptual space, find similar documents, find relationships between terms, and provide a concept-based document query system. STANLEY adds the ability to extract a generic cognitive model as well as synthetic individual instantiations of the generic model. These enhancements, along with additional cognitively motivated optimizations, improve the performance of STANLEY by more than 2.5 times on filtering tasks,[4] and better than 8 out of 10 published algorithms on information retrieval document categorization tasks.[5] STANLEY has been successfully used in 17 different applications developed for 6 different institutions. In this proposed use, STANLEY will both find candidate materials related to core doctrinal concepts (for example, by searching the web to find new materials such as studies of infrastructure adoption in Amish communities, or gang formation in cities) and prime research for the second phase by preparing candidate cognitive models. A software instantiation of STANLEY will be provided as a deliverable ('Candidate Course Material Search System' in Table 1), so that instructors can easily find new materials to keep their classes up to date and relevant to the missions the Army faces on an on-going basis.

The second major initiative in the project uses the knowledge obtained in the information-gathering phase to implement an agent-based model representing the political, economic, and information effects on collectives of individuals. Agent-Based Models (ABMs) are computational models of systems in which the fundamental unit of

[4] Filtering task based on the Reuters-21578 data set, where articles must be filtered if they belong to the topics "cocoa," "coffee," "gold," "lumber," "platinum," "rice," or "yen" from those articles that do not contain any topics.
[5] Document categorization task based on TREC 7 with 50 categories.

analysis is the interaction between the constituent components of a system (agents). Agents are autonomous entities capable of perceiving their environment, making decisions, and effecting some action within the system. Agents frequently have non-trivial limitations (such as access to local and not global information, or severely constrained decision-making capability), but coordination, cooperation, and competition between agents can lead to surprising global consequences emerging for the system. An agent-based modeling approach allows us to represent problems where an individual's choices (to assist coalition or enemy forces, to participate in illegal or legal markets, whether to accept a bribe), taken collectively, are central to the outcome of the global system (security, economic viability, degree of corruption). An ABM approach also provides a convenient way to partition the larger problem down to a more tractable problem of representing how individuals would respond to political, economic, and information stimuli.

Our proposal calls for the creation of cognitively sophisticated agents, leveraging Abraham Maslow's hierarchy of biological, psychological, and social needs of human beings. Multiple networks (interconnections of agents) exist in our simulation, and these networks provide resources (such as money, power, prestige, acceptance) that meet these needs. Networks may be based on geography, activity (such as interactions around a economic transaction), personal attributes (such as ethnicity or tribal affiliation), or other conceptions of self (professional occupation, national identity, political beliefs). Networks may also have attributes in and of themselves, such as degree of legality (open, gray, and black markets), power ("strong" vs. "weak" tribes[6]) or anthropomorphic qualities ("hard-headed, stubborn, conciliatory, brave, trustworthy, and loyal, etc."[7]). Agents will have psychologically plausible mechanisms that try to minimize cognitive dissonance across the various networks to which they belong. For example, agents engaged in growing poppies for the illicit drug trade (a "dark" network) would be less likely to be supportive of initiatives of local government. (William Colby articulated a similar theory, that economic development would counter the appeal of terrorists, in his Civil Operations and Revolutionary Development Support (CORDS) program.[8]) Agents' behavior will be influenced by cultural-specific data, such as those collected by Professor Geert Hofstede on the distribution of roles between the genders, tolerance for uncertainty and ambiguity, individual-group integration, respect for tradition, fulfilling social obligations, and protecting one's 'face', and the extent to which power is expected to be distributed unequally.

We propose a recurrent game model for situating the cognitively sophisticated agents in religious, political, and social structures based on a model proposed by Glass and Ehlen.[9] Agents are able to generate some portion of 'energy' (which dependent on the network may be economic returns, social acceptance, power, etc.) on their own in a quantity represented as e_n. A cluster C of cooperating agents, however, can

[6] Eisenstadt, M. (2007) "Tribal Engagement Lessons Learned," *Military Review*, September-October 2007, pp. 16 – 31.
[7] McCallister, W.S. (2007) *Coin and Irregular Warfare in a Tribal Society*, Pamphlet, Applied Knowledge International, LLC.
[8] Kipp, J., Grau, L., Prinslow, K., Smith, D. (2006) "The Human Terrain System: A CORDS for the 21st Century," *Military Review*, September-October 2006, pp. 8-15.
[9] Glass, R. and Ehlen, M. (2003) " Growth and Defection in Hierarchical, Synergistic Networks," Unpublished manuscript, Sante Fe Institute Summer Research Program.

synergistically generate a total energy of $\left(\sum_{n \in C} e_n\right)^{\rho}$. The synergy S of the cluster is defined as the difference between the total energy of the cluster and the sum of the agents' individual energies. If $\rho > 1$, the cluster synergy is positive; the energy created is greater than the sum of individual energies. This synergistic surplus is then distributed back to the members of the cluster, with each member receiving some fraction, π_i, of the total synergy. The fraction of payback is determined by the ratio of energy directly below a given agent *j* raised to the power γ ($\left(\sum_{n \in C_j} e_n\right)^{\gamma}$) to the sum across the entire cluster. When γ=0, each member gets an equal share of the cluster's synergy. As γ increases above 0, higher positions in the hierarchy receive an increasing proportion of the synergy. Clusters evolve over time as each agent considers defecting, either to form a new independent cluster or to join another cluster, and attempts recruitment of others to positions reporting to him or her.

This model of dynamic and temporal hierarchical networks, which experience pressures to organize to achieve objectives and then distribute the rewards throughout their organization, will be applied to represent many of the overlapping and competing social and political structures in the simulated system. Attention will be focused on the emotional and cognitive impacts on individuals of interactions across different levels of these hierarchical structures. Information flow occurs over abstract social (small world) and economic (scale free) networks as well, and the cognitive modeling of each socially and politically situated individual will capture heterogeneous responses to the same information and the local development of sense-making world reference frames. The focus will be on a small-scale system (on the order of tens of thousands of agents) to fully investigate the interdependencies and interrelationships, but with an emphasis on grounding system behavior on actual cases documented in reports accepted by TRADOC personnel as worthy of instruction. The interplay of geographically referenced events, internal competition between various networks experiencing various levels of economic and political success, and the cognitively informed responses to events and information will provide a unique and dynamic environment in which to explore issues of military decision-making with respect to economic, political, and information domains.

Technical risk in the proposed approach is manageable, and chiefly related to the diversity in the suite of desired outcomes that are be represented by the model (e.g. directly proportional to scope). Schedule and cost risks are both low.

The proposed work will draw upon infrastructure modeling and economic consequence modeling expertise developed in service to the Department of Homeland Security's National Infrastructure Simulation and Analysis Center (NISAC). It will also draw upon Sandia's internal research and development strategic focus on Cognitive Systems and the external funding this program has attracted.

SECTION VI: Exit Criteria

Evaluation must keep in mind the ultimate goal, improving the performance of the warfighter. We therefore propose to use in-classroom learning assessments of prototype materials near the 6-month milestone to verify utility to the Army. Once case studies are known to be valuable, a statistical verification of model output correlation to cases will be performed. Project deliverables listed in Table 1 will be provided directly to the TRADOC personnel conducting the courses.