U.S. Army TRADOC Analysis Center
Naval Postgraduate School
Monterey, CA 93943

TRAC-MONTEREY

RESEARCH PLAN

for the

U.S. ARMY TRADOC ANALYSIS CENTER MONTEREY

For

FISCAL YEAR 2003

Lieutenant Colonel Thomas M. Cioppa, Ph.D.
Director, TRAC-Monterey
Monterey, California

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TRAC-Monterey Mission
TRAC-Monterey serves as the principal research activity for the U.S. Army Training and Doctrine Command Analysis Center (TRAC). Research topics are broad in nature. Appropriate research topics meet the TRAC director's criteria of being a high return on investment, a benefit to the soldier, and presentable at analytic conferences and in applicable journals.

TRAC-Monterey is located at the Naval Postgraduate School and allies itself with several of the departments, including Operations Research, Mathematics, and Computer Science, as well as the MOVES Institute. TRAC-Monterey's research program offers NPS faculty and students a broad range of opportunities for studying challenging, applied problems that support NPS curricula and enhance professional development. The research program supports students from all branches of military service with opportunities to investigate a wide range of interdisciplinary issues, and it is particularly well suited to military officers who wish to apply concepts studied in the classroom to real-world military problems.

Organization and Facilities
TRAC Headquarters is located at Fort Leavenworth, Kansas. TRAC-Monterey is one of four analysis centers organized under TRAC Headquarters. The other centers shown in Figure 1 are: TRAC-Fort Leavenworth, Kansas (TRAC-FLVN); TRAC-White Sands Missile Range, New Mexico (TRAC-WSMR); and TRAC-Fort Lee, Virginia (TRAC-LEE).

TRAC-Monterey is located in building 203 of the Naval Postgraduate School in Monterey, California. Facilities include a combat simulation laboratory, contractor and student work areas, and a modern network of computers and peripherals.

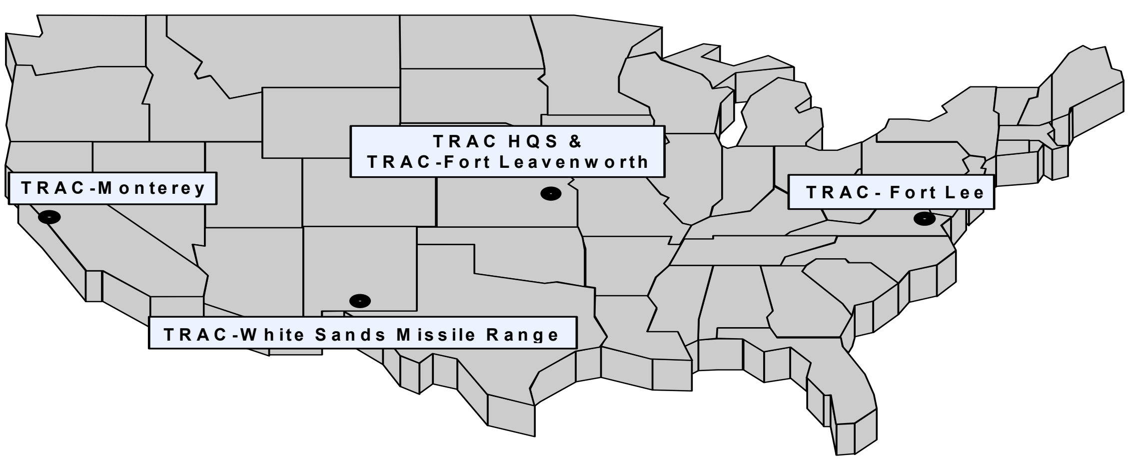

Figure 1: U.S. Army TRADOC Analysis Center (TRAC) Sites

TRAC-Monterey analysts identify research opportunities, write research proposals, solicit funding and support, write statements of work for contractor and professor support, collaborate with professors, students and contractors, and lead small research teams.

TRAC-Monterey augments its organic research capability in various ways. A major source of support comes from NPS faculty members who conduct TRAC-sponsored research. A second source is NPS Masters students who work on TRAC-sponsored projects and who are advised by NPS faculty and TRAC-Monterey analysts. TRAC-Monterey also partners with other TRAC centers and other government organizations. Finally, private contractors provide software development support and assistance with proof-of-principle demonstrations.

The Research Council plans and directs TRAC-Monterey's research. The council consists of the director of TRAC, the director of TRAC-Monterey, TRAC-Monterey analysts and liaisons, and selected members of the NPS faculty and student body.

The TRAC-Monterey Research Council reviews all proposed projects and approves only those projects regarded as viable and applicable research endeavors.

Research Focus

TRAC-Monterey conducts research into three broad areas, identified as research pillars by the Director, TRAC-Monterey: Military Operations in Urban Terrain (MOUT) Modeling and Simulation (M&S); Elements of Combat Power; and Advancements in Simulations.

The Director of TRAC-Monterey serves as the Army-wide coordinator of the MOUT Focus Area Collaborative Team (MOUT FACT). His responsibilities include publishing a coordinated research plan, evaluating proposed research for MOUT M&S, and providing a coordinated recommendation to Army decision makers for MOUT research funding. These responsibilities necessitate an in-house workforce knowledgeable about MOUT related issues. TRAC-Monterey analysts and liaisons represent TRAC, TRADOC, and other Army interests in conferences and symposia related to MOUT M&S issues.

The Elements of Combat Power Pillar has as its origins the five elements of combat power from FM 3.0: Maneuver, Firepower, Protection, Leadership, and Information. These elements form the basis for a wide range of military operations research and are key to Army transformation principles. TRAC-Monterey research under this pillar supports on-going or future Objective Force and Future Combat System analyses, some of which are in partnership with TRAC's other elements.

The Advancements in Simulations Pillar focuses on transforming existing, new, and developmental simulations with technologies or techniques that will potentially revolutionize Army modeling capabilities. Under this pillar, operations research analysts perform multifaceted functions such as systems design, systems integration, and technology research that cross many functional areas. TRAC-Monterey maintains close ties with organizations that have ongoing simulation development efforts, specifically the combat developers and material developers of OneSAF and Combat^{XXI}.

Purpose of the Research Plan
The Research Plan formalizes TRAC-Monterey's research and problem-solving activities for the upcoming fiscal year. The plan provides a concise summary of each applied research project undertaken by TRAC-Monterey. The summaries include the title, sponsoring agencies, problem statement, technical approach, requirements and milestones, products and deliverables, success criteria, and points of contact. The plan also serves as a means of announcing TRAC-Monterey's planned research activities to other TRAC elements, NPS faculty and students, and various agencies throughout DoD.

Purpose of the Annual Report
The *Annual Report* describes the manner in which the *Annual Research Plan* was executed. The report provides a project status at the end of the fiscal and a list of presentations and publications associated with the project. The *Annual Report* serves as a means of announcing TRAC-Monterey's research accomplishments to other TRAC centers, NPS faculty and students, and various agencies throughout the Department of Defense.

MOUT Modeling and Simulation

Military Operations in Urban Terrain Focus Area Collaborative Team (MOUT FACT)

Sponsoring Agency:
Army Modeling and Simulation Office (AMSO), Attn: Mr. Dell Lunceford, 1111 Jefferson Davis Hwy Crystal Gateway North, Suite 503E Arlington, VA 22202, (703) 601-0005 wendell.lunceford@hqda.army.mil

Problem Statement:
Though modeling and simulation (M&S) has played a large role in the development and refinement of Army tactics, techniques and procedures, current model research for military operations in urban terrain (MOUT) is fragmented and inadequately resourced. Core physical models of military operations are judged to be insufficient as a foundation for simulation of urban operations. Pursuit of enhanced MOUT simulation capabilities without credible knowledge, models, and data is both inefficient and misleading to decision makers.

To combat deficiencies in the representation of the urban environment, the US Army Modeling and Simulation Office (AMSO) formed a MOUT Focus Area Collaborative Team (FACT). The mission of the MOUT FACT is to facilitate MOUT modeling and simulation (M&S) by developing, publishing and distributing a plan of research that highlights Army M&S priorities as they pertain to urban operations. Coordinated, coherent Army research for urban M&S will reside in three main areas: Physical models, Terrain/Synthetic Natural Environments (SNE) and Behaviors. The overall purpose of the FACT is to ensure a coherent plan of research for urban M&S is formulated, documented and published, and to monitor the progress of existing projects that fall under the auspices of the MOUT FACT.

Technical Approach:
There are four major stages the MOUT FACT is using to achieve its goals. The first stage identifies the areas requiring improvement. These areas include indirect and direct fires, search and target acquisition, tactical communications, acoustics, signal intelligence, radar, mobility, opposition forces and noncombatants, and human and organization behaviors. Within each of these areas, specific subtopics or needs are identified.

The second stage is the evaluation of the proposals by select subcommittees of the Executive Committee (ExCom). The criteria focuses on the critical issues of feasibility of approach, supportability of data requirements, relevance to MOUT research plan, and reasonableness of timeline and cost estimation.

The third stage consists of suggesting improvements to the proposals, identifying possible collaboration between agencies, and directing further literature review to the sponsoring agencies of the down-selected proposals. The proposing agencies then submit their revised proposals.

The fourth stage consists of presenting the prioritized list and research plan to the senior decision-makers responsible for the funding. The MOUT FACT will monitor the progress of the projects to ensure milestones are satisfied and the deliverables match the original proposals. In FY03, the MOUT FACT will simultaneously monitor progress on FY02 selected projects while setting the conditions for successful execution of stages 1-3.

Requirements and Milestones:
Call for Proposals (CFP) (3Q03)
Accept Phase I proposals (3Q03)
Review and Evaluate Phase I (4Q03)
ExCom Meeting (Phase I) (4Q03)
Accept Phase II Proposals (4Q03)
Review and Evaluate Phase II (4Q03)
ExCom Meeting (Phase II) (4Q03)
Announce funded projects (1Q04)
Receive management plans (1Q04)

Products and Deliverables:
MOUT M&S Research Plan
MOUT FACT website
Prioritized list of MOUT M&S proposals

Points of Contact:
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Success Criteria:
The first element, which defines success for this project, is the identification and prioritization of shortfalls in the representation of urban warfare and its associated environments in both legacy and emerging models and simulations. Second is the development of an effective web-based proposal management system that permits both the submission and evaluation of urban M&S project proposals. Next is the creation of a ranked list of recommended projects for funding based on the objective evaluation of a qualified field of experts. Finally is the development and execution of an effective project management and oversight system.

References:
https://www.moutfact.army.mil

Acquire-Based Modeling for MOUT Environments

Sponsoring Agency:
TRADOC Analysis Center-WSMR, Attn: David S. Dixon, Bldg. 1400, White Sands Missile Range, New Mexico 88002-5502. 505-678-4510 (DSN 258-4510)
Dixon@trac.wsmr.army.mil

Problem Statement:
A significant problem facing US forces engaged in military operations in urban terrain is the detection of the threat. An example would be in determining how many, and who in a crowd of people pose the greatest threat to friendly forces.

This task may be accomplished by adapting the Army standard target acquisition model Acquire to this new environment, subject to certain constraints and conditions.

Previous work showed how this can be done in the IR spectrum for certain threat situations, and indicated that Acquire was quite robust in detecting threat situations. The objective of the project is to produce a Windows program based on Acquire that predicts the probability that a human threat can be identified within a crowd, or within an urbanized scenario.

Technical Approach:
Earlier work focused on determining the cycle criteria to be used in Acquire to identify if a person presents a threat to the observer by identifying objects the person is carrying. This was done only for hand held thermal sensors, for which limited experimental data was available.

To provide a more comprehensive tool, this work will be enhanced in the thermal domain and extended to the visible domain, covering the type of sensors appropriate to it, e.g. image intensifiers, binoculars, TVs and the human eye.

A review of what limited test data is available will be undertaken, and the appropriate cycle criteria determined. When completed, this should cover most observation sensors used in a MOUT scenario. The basis for this test data is the 1996 NVESD report "Recognition of Human Activity using Handheld Thermal Systems" authored by O'Connor, O'Kane, Royal, Ayscue, Bonzo and Nystrom.

The results will be incorporated into a stand-alone predictive tool that may then be added to larger scale simulations, such as Combat^{XXI}, that require threat detection probabilities.

Requirements and Milestones:
Identify and review data for visible spectrum (2Q03)
Test model; identify cycle criteria (2Q03)
Prototype model; test and document (4Q03)

Products and Deliverables:
Report on methodology for threat identification in MOUT
Stand alone tool implementing the methodology

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Success Criteria:
Success for this project is the completion of a review of test data and a determination of cycle criteria for the visible domain in urban/complex environments followed by incorporation of these results into a stand-alone predictive tool that may be added to larger scale simulations that require threat detection probabilities.

Movement Planning in Urban Environments (Footprint to Pathfinder)

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027. Point of Contact: Mr. Michael F. Bauman, SES, Director, TRAC, Fort Leavenworth, KS 66027. 913-684-5132, (DSN 552-5132). baumanm@trac.army.mil

Problem Statement:
Current state-of-the-art technology offers the ability to develop doctrine through the use of modeling and simulation platforms that support multi-echelon warfighting scenarios. The newest emerging simulated warfighting environments such as COMBAT^{XXI} and OneSAF will allow opposing forces to engage and fight with operator-in-the-loop scenarios and experiment with new tactical doctrine using conceptual equipment and organizations. These experiments are developed in an environment that presents the users with real life operational situations and allow the user to evaluate the applied doctrine. Each operation can be conducted numerous times in the simulated environment until the best techniques are developed. The interaction between the simulated environment and user should be at a level that allows users to modify operations on the battlefield as they see fit.

As the future battlefield will most likely contain complex urban settings, emerging simulations will have to model these environments at a much higher fidelity and resolution than is currently available.

Cognitive or situational awareness modeling and human factor performance is lacking in many areas of the warfighting M&S environment. Maneuvering through urban terrain with the ability to recognize urban operational situations as they occur is limited and simple in design and application in current M&S. The ability to determine the effects of conventional weapon attack on an urban terrain is lacking and the ability to recognize obstacles and make complex decisions for alternative maneuvers around obstructions is all but absent. With these very critical concepts missing from the simulated warfighting environment, it is difficult to evaluate the effectiveness of new urban tactical doctrine or realistic consequences of battlefield decisions.

Technical Approach:
The approach involves three major tasks, each producing fundamental algorithms needed for portrayal of MOUT in M&S: urban footprint characterization, structural damage footprint characterization, and pathfinder algorithms. The urban footprint characterization effort will involve determination of typical urban landscapes and methods and materials for construction. This information will be used in the structural damage effort. The pathfinder algorithm will use the results of structural damage footprint characterization.

The structural damage assessment model will predict damage and the associated debris from an attack of conventional weapons on the urban area. Algorithms will be developed for the damage assessment of typical structural types and construction materials (e.g., concrete) subjected to a limited set of conventional weapons. The algorithms will be developed based on structural response calculations and experimental data. Probabilistic algorithms quantifying rubble from structural debris will be developed based on structural response to weapon effects. The algorithm developments will directly feed into the mobility models for maneuver over structural debris and rubble in urban terrain and for damage assessment simulation models of fixed facilities on the battlefield including urban areas.

The pathfinder model will determine GO and NOGO areas through an urban environment, incorporating urban restrictions, structural debris, consideration of engineer effort to reshape routes, and incorporation of threat potential. Both the GO and NOGO areas will be determined by the location of structures and buildings and will consider urban terrain attributes such as path width, military load classification of bridges, and other restrictions to vehicle movement. In the GO area predictions, new algorithms will be developed to determine the ability of a vehicle to override non-standard obstacles created from the effects of collateral damage from conventional weapons attack.

This project is a three-year effort with FY02 representing the start. Significant progress has been made and will allow ready improvement in MOUT to be realized and expanded. This proposed research would address the near and far term technology voids in logistics and cognitive behavior modeling as well as MOUT. The development of algorithms for assessing structural damage in urban terrain including the encroachment of structural debris into possible mobility corridors will assist Army M&S in the areas of lethality calculations and in mobility predictions where rubble is created in the urban terrain.

Requirements and Milestones:
Modification and expansion of urban templates (4Q03)
Development of rubble footprint (4Q03)
Characterization of threat overlays (4Q03)
Development of urban mobility modeling for rubble and craters (4Q03)
Development of dynamic urban terrain network capability for use by movement model (2Q03)
Creation of routing or pathfinder algorithms (w/ STNDMobAPI) (4Q03)
Integration into COMBAT^{XXI} (4Q03)

Products and Deliverables:
Seven additional urban templates
Algorithms for predicting cratering and generating a crater field
Algorithms for handling overlap of debris and crater fields
Incorporation of engineer effort/bypass for mobility
Expanded mobility model to include multi-vehicle, multi-lane movement
Methodology to modify urban terrain network from original data created for urban templates (to account for dynamic changes to the debris field, environmental conditions, etc.)

Interface between environment, STNDMobAPI Pathfinder API to accommodate expansion
Route selection algorithms (objective function and constraints) for dynamic conditions
Methodology to insert urban templates into COMBAT^{XXI} SNE
Expanded architecture for calling Urban Mobility related APIs from COMBAT^{XXI}
Dynamic state implementation with ongoing and cumulative effects

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Mr. Dave Durda, TRAC-WSMR, Bldg 1400 Martin Luther King Dr, WSMR, NM, 88002-5002. (505) 678-3217(DSN 258-3217), FAX (505) 678-8379 durda@trac.wsmr.army.mil

Success Criteria:

Success for this project will be defined as the integration of engineering-level models for structural response and route planning algorithms through an urban environment replete with impediments to movement and cognitive processes into COMBAT^{XXI}. The structural response model will provide damage assessments for typical structures from the effects of a specified set of threat weapons. Generalized footprints for the rubble from structural damage will result. The pathfinder model will include new obstacle override capabilities that will predict the ability of a vehicle to override collateral damage from weapon effects in urban areas.

Extensible Terrain Representation Authoring for the Synthetic Natural Environment (EXTRA SNE)

Sponsoring Agency:
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Problem Statement:
Challenges of modeling complex environments include rapidly generating (visual) complex structures and terrain in simulations, accurately representing (describing) these features, accurately modeling the result (physics-based) of entity interactions with the environment, and rapidly communicating attribute and visual changes to the user and state changes to the simulation database.

Simulation databases typically do not have all the information needed to calculate physics-based results of entity interactions. Entity interactions are often generalized or statistically predicted from computations conducted externally from the simulation. The results of these interactions are typically aggregated to a status or score (e.g., percent of structure damaged). Additionally, file formats used in creating, manipulating, and calculating entity interactions are usually not compatible or interchangeable, especially between simulations.

Technical Approach:
XML will be used to describe the visual attributes needed to represent structures in a simulation as well as physical attributes needed to calculate interaction results using a variety of physics-based algorithms.

The results of structural weapons effects calculations will map to multi-state objects (MSOs) and will dynamically change the characteristics of the physical attributes. Vehicular movement rates will be altered based on calculations derived from interacting with the terrain attributes. These modifications can be communicated among participants via web-centric approaches, such as Document Object Model (DOM) and Simple Object Access Protocol (SOAP). This approach is also conducive to mapping to a multitude of present and future models and especially large/diverse datasets.

Requirements and Milestones:
1. Import and view DTED information on the web and develop a XML schema for the physical attributes needed for movement rate calculations. (2Q03)
2. Develop a XML schema for representing building components (features and attributes) and damage algorithms from munitions. (3Q03)
3. Construct three buildings with features and attributes to support visual and physics-based models. Export these buildings to the developing Environmental Database for OOS and represent on the web with XML/X3D. (4Q03)
4. Integrate appropriate physics-based entity interaction algorithms. (1Q04)

5. Demonstrable product viewed on the web and integrateable in OOS. (2Q04)
6. Develop Structural Weapons Effects API (SWE API) interface. (3Q04)
7. Develop a GUI to efficiently create structures with visual and physical attributes for physics-based interaction in web-based simulations. (4Q04).

Products and Deliverables:
Technical report to STRICOM for inclusion into the knowledge acquisition process for OneSAF Objective System consideration
Demonstrable prototype of vehicle movement rates altered by terrain on web
Improved Structural Weapons Effects API (SWE API) w/multiple weapons
Demonstrable prototype with SWE API
Frame damage calculations integrated for structural collapse
Library of generic building types for future use
Demonstrable prototype including structural collapse functionality

Success Criteria: Demonstrable prototypes on the web and in OOS (as being developed) using improved SWE API and vehicular movement impacted by terrain.

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Rapid MOUT Database Generation System Development

Sponsoring Agency:
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Problem Statement:
The US Army test facility at Ft. Hunter Liggett, CA (FHL) had a high fidelity battlefield replication system known as Pegasus. This system provides the capability to generate a 1 meter terrain data base and a 1cm target view data base for use in weapon substitution, command and control applications, and after action test review. The system has been relocated for operation at other sites such as Ft. Hood, TX, and has been used to build new data bases at Yuma Proving grounds to support the Rotary Pilots Associate (RPA) Test.

An ongoing project has taken the functionality and algorithms from the original Pegasus system and rewritten the code to operate in a commercial PC environment. The system is now known as Perspective View Nascent Technologies (PVNT). In recent years the PVNT has been used to test emerging concepts for rapid terrain database generation utilizing an image feedback approach.

Technical Approach:
An operator can be provided interactive editing tools to view and modify the terrain database. This operator performs the process of capturing interactive operations into automated and time saving programs. Once an operation is understood and capable of being performed interactively by an operator, it can be automated with a much higher degree of success than algorithms which are performed manually.

The proposed project will concentrate on the construction of urban models and operator interactive tools that allow the rapid placement and adjustment of such models to the urban environment. Using point and click technology the operator is expected to perform the following functions: identifying features; selecting an appropriate feature model; scaling and adjusting the model to fit the signatures; performing 3d view quality control; adjusting placement and model parameters to attain the best fit; and storing the information in the database.

Once the interactive feedback loop is working. The operations are automated through the use of command sequence capturing, automated feature recognition, automated feature adjustment tools and operation scripting. The application of PVNT to the urban environment will require the analysis and modification of algorithms which have, in the past, been tailored to the rural environment.

This project will extend an existing rural terrain database generation system to rapidly analyze aerial photo, high resolution satellite image, LIDAR and other high resolution raster scan sensor sources in order to identify and model urban terrain features. Such a system will provide a metrically accurate database of urban terrain. An urban terrain database will provide the information required to generate mobility, weapons effects, and line-of sight calculations in an urban environment.

Requirements and Milestones :
Feasibility Demonstration (4Q03)
Prototype One Feature Demo (2Q04)
Prototype Multi Features Demo (3Q04)
Final Delivery (4Q04)

Deliverables:
Theses, dissertations, published papers, code and documentation manuals.
A summary of research findings will be provided as interim reports upon the conclusion of each task and summarized in a final report upon the conclusion of this project.

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Modeling MOUT Target Acquisition and Loss with Graphs

Sponsoring Agency:
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Problem Statement:
Emerging Army organization and operational concepts are increasingly dependent upon multi-sensor collection of information across the battlespace, robust networks to transmit information, rapid assimilation and understanding of information obtained from a variety of sources, uninterrupted satisfaction of the priority information requirements of commanders and soldiers, and precise delivery of effects at the desired time and place. Today's models have iteratively evolved to their present state as the Army's legacy C4I systems have matured through their acquisition and fielding. These legacy systems and legacy models are inadequate to address the C4I and fusion requirements of FCS and Objective Force or assess the potential solutions offered by future technologies. Legacy models also are inadequate to address MOUT.

The outcomes of military operations are highly correlated with target acquisition capabilities. Current Target Acquisition modeling focuses on the detection, recognition and identification (or misidentification) of vehicle platforms and personnel using their signatures. This is inadequate for the combat simulation of MOUT scenarios since there may be no target signature distinction between friendly forces, threat forces, and non-combatants. The Urban Acquire project is adding models of the perception of target activity and situational awareness in order to discriminate among friendly forces, threat forces, and non-combatants.

The Acquire algorithm focuses on target detection, recognition and identification for individual sensor-target pairings. Solving the many difficult problems associated with the Acquire algorithm in an urban environment is necessary, but not sufficient. Further research is needed to model fusion of sensor data from suites of coordinated sensors and from networks of sensors.

Technical Approach:
This research builds on the Urban Acquire project and complements that effort by providing analysis tools for OF/FCS and by suggesting aggregate models for future simulations. Using an approach similar to the model-test-model approach, this research will experiment with aggregate models of sensor suites and sensor networks with the intent of providing analytic approaches. As the Urban Acquire model matures, data from this model will be used for validation and refinement of the graph models. In a similar manner, as the FCS concept matures, data from systems under test can be used for validation and refinement of the models. The models and analysis techniques based on graphs will evolve and mature with FCS.

Initial work will identify high-resolution data and models under development and scheduled for use in COMBAT ^{XXI} and OneSAF. The Acquire model is the de facto Army standard and the Urban Acquire project will produce the standard for urban areas; however, other aspects of these future simulations will be relevant for developing graph models. The factors that influence target loss will be examined to select parameters for the graph models, as will factors relating to coordinated sensors and networks of sensors. During this phase, the problem will be scoped and shaped for maximum return on investment and relevance.

In the second phase of the research we will develop candidate graph models for various aspects of the problem and identify graph theoretic approaches that provide insights for the candidate graph models. Potential approaches include methods from the theory of random graphs that may allow us to make assertions about the collective effectiveness of the sensors. For example, there may exist a threshold probability function (for edge connectivity probability) that ensures information dominance. Also of particular interest when structuring the sensor network are results related to graph structures including those about cliques and graph components.

In the final phase of the research we will develop techniques to analyze the graph models and write the technical report. As an example, if a threshold probability function exists, then parameters related to edge probabilities can be varied to examine their effect on information dominance for various quantities and types of sensors. We will brief the emerging and final research results to COMBAT^{XXI} and OneSAF developers and members of the FCS study team.

Throughout the research, models and data will be documented to facilitate verification and validation. Any software prototypes will be verified using automated testing procedures. Any models developed using commercial software tools (e.g., spreadsheet models) will be validated with test data and the test methodology and results will be documented. This research will also propose future validation tests to improve both the data and the models as the OF and FCS concepts mature.

The models developed might be incorporated into other simulations that will be High Level Architecture (HLA) compliant; however, these models will not serve as federates in an HLA federation. The underlying models and data will be documented sufficiently to facilitate inclusion of their relevant aspects in the simulation object model (SOM) of any federate that incorporates the models.

Requirements and Milestones:

Identify available data and models from current research and simulation development programs like COMBAT ^{XXI} and OneSAF. (1Q03)
Develop candidate graph models for various aspects of the problem. (2Q03)
Identify graph theoretic approaches that provide insights for candidate graph models. (2Q03)
Develop techniques to analyze the models using random graphs. (3Q03)
Write the technical report. (3Q03)

Products and Deliverables:
Technical report to TRAC and to AMSO for inclusion in the MSMR describing the research including documentation of data, models and analysis techniques used and developed.
Briefings, conference papers and prototypes to the FCS study team, and the COMBAT^{XXI} and OneSAF development teams.

Success Criteria:
The project will be complete when the graph models are sufficiently defined to allow for analysis to support OF/FCS sensor studies.

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Cyber Terrorism of Water Supply Infrastructure

Sponsoring Agency:
Department of Justice: Homeland Security Research & Technology Initiative
Attn: Dr. Paul Stockton, Naval Postgraduate School, Monterey, CA 93943, 831-656-3038, pstockton@nps.navy.mil

Problem Statement:
The President's Commission on Critical Infrastructure Protection (PCCIP) conducted a study concluding that cyber threats are a clear danger (risk) to all infrastructures. Among these critical infrastructures are the nation's water supply systems. A 1996 survey assessed that water supply control systems are vulnerable to cyber-intrusion with the most likely culprits being hackers, disgruntled employees and terrorist elements. The consequences of such attacks can range from information corruption/disruption to denial of service (shutdown of water supply).

Water utilities are becoming increasingly interconnected, interdependent, and moving toward common protocols like Transmission Control Protocol/Internet Protocol (TCP/IP). This research effort seeks first to survey the types of control systems in use by water suppliers and their vulnerabilities. Additionally, this work will include fault tree and event tree analysis in order to demonstrate information filtering and its applicability in combat simulations and force protection models.

Technical Approach:
The first effort will consist of a formal survey of water suppliers (military installations, cities, etc.), methods of access to control systems (LAN, dial-in, etc.), the potential threat sources, attack tools, and potential consequences of cyber attack. Next, we will conduct fault tree and event tree analysis in order to demonstrate information filtering and its applicability in combat simulations and force protection models. Event tree analysis asks "what if" to determine the sequence of events that lead to consequences. From the event tree one can construct a probability density and exceedance probability. The exceedance probability for the current system and comparison to future policy options can serve as a useful model to understand measures of outcome. Event trees help to understand how an outcome occurs as it transitions through mitigating events. The consequences are conditioned on the occurrence of the initiating event and subsequent mitigating events (e.g., hacker intrusion through a firewall and disgruntled employee accessing through a dial-in connection).

Fault-tree modeling adds insight into how mitigating events fail. This is accomplished by starting with a mitigating event as the top event and enumerating through the use of Boolean logic all the possible failure modes attributing to the ultimate mitigating event failure.

Milestones:
Conduct water supply survey (2Q03)

Conduct event and fault tree analysis (3Q03)
Demonstrate the use of trees in information filtering for combat simulations and force protection (4Q03)

Deliverables:
Water Supply Survey
Vulnerabilities, access, threats, attack tools, and consequences of attack of control system

Success Criteria:
Development of complete Event Trees and Fault Trees of water supply systems and the associated analysis of their application to information filtering in support of combat simulations and force protection.

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Elements of Combat Power

Sensor Mix Study

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Problem Statement:
The Objective Force Unit of Action's effectiveness and performance relies on a pervasive, robust C4ISR network that provides a Common Relevant Operating Picture (CROP) to most platforms. Without a robust C4ISR network, Future Combat System (FCS) lethality, survivability and mobility will decrease or may be significantly degraded[1]. Manned and unmanned aerial, vehicle-mounted, and ground sensors are essential components of the C4ISR network. Given the existence of various (often competing) factors such as available sensor types, target types and densities, terrain, and sensor characteristics (cost, latency, survivability, logistical requirements, etc.), a quantitative method for determining the optimal sensor mix that allows the UA to detect, recognize and identify the Contemporary Operating Environment threat – while accounting for uncertainties in sensor performance and threat array – is required.

There are two aspects to this requirement: operational and M&S. The operational aspect addresses the need for a tool to assist decision makers with such issues as: force structure (how many/what types of sensors should be organic to the UA?); mission planning (what sensor array should the UA be equipped with for a specific mission); mission execution (how should a given sensor array be employed?); and risk assessment (what risk is associated with deploying a UA with a sub-optimal sensor suite?). The M&S aspect addresses the need for a methodology for rendering such operational phenomena in existing and future models and simulations. Of all FCS sensors currently being considered, *which* should be employed in a given scenario? *How many* of each should be employed, and *how* should they be employed? The goal of this project is to determine the optimal sensor mix that allows the UA to detect, recognize, identify and track the Contemporary Operating Environment Threat.

Technical Approach:
This project will be conducted in two phases:

Phase I will involve modification of an existing mathematical programming model (developed by TRAC-FLVN) to more closely track sensors and their possible deployment in a scenario. These modifications will include:

[1] FCS Unit of Action Systems Book, AMSAA Version 1.2, July 2002

1) The addition of a grid reference system to allow sensor missions to be assigned to specific locations in the AO. Currently, sensor missions are evaluated over all possible range bands to which they could reasonably be assigned. Targets are allocated to range bands, but not given any locations on the map.

2) The explicit inclusion of random outcomes in sensor performance, target location, and target density, so as to encourage the use of a more robust mix of sensors for a given scenario.

3) Various model enhancements/corrections including accounting for over/under detections and modifying the objective function.

Phase II will involve a Masters student at NPS, and will result in a thesis for that student. It is based on modeling a time-phased deployment of sensors into specific grid locations in the AO. This may require the development of a new model that extends the decisions made in the Phase I model (how many of each type of sensor to put in each grid location) to include a time component (how many of each type of sensor to deploy to each grid location, in each time period). The constraints of this model will be much more complex than in Phase I, as the problem takes on a scheduling character, as opposed to the assignment character of Phase I. Primary activities in this phase will include:

1) Development of basic Phase II modeling approach. This model will have aspects of vehicle routing (especially for UAVs and other long range, highly mobile sensors), scheduling (limited resources have to cover a time-varying workload), and assignment (sensors will be allocated to specific locations in specific time periods).

2) Integrating Phase I model with Phase II model. This will involve two main steps: using Phase I solution/output as input to Phase II; and using results from Phase II to modify the solution to Phase I.

Requirements and Milestones:
Elimination of the concept of "retask time" for Phase I model (1Q03)
Penalization of over-detection (1Q03)
The addition of a grid reference system to allow sensor missions to be assigned to specific locations in the AO (1Q03)
Creation of unclassified test data for model development/testing (1Q03)
Review of objective function (goals, weights, etc.) (2Q03)
The explicit inclusion (in the optimization) of random outcomes in sensor performance (2Q03)
Prepare report on Phase I model (2Q03)
Development of time-phased sensor deployment model (3Q03)
Integration of Phase II model with Phase I model (4Q03)
Testing, modification, and results analysis (4Q03)
Prepare report for Phase II (4Q03)

Products and Deliverables:

A mathematical programming model and supporting code (Phase I in the GAMS modeling language, Phase II in GAMS or another appropriate system), including appropriate (unclassified) test data to demonstrate functionality.

Sufficient documentation to enable future users to develop their own data and adapt the model to different scenarios.

Success Criteria:
Success is contingent upon the ability of resultant model(s) to efficiently and effectively determine optimal or near-optimal initial sensor arrays for the Unit of Action, as well as optimal employment strategies for this sensor array. Additionally, these models will have the capability to interface with other tools/models as appropriate.

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Human Factors Analysis in a C4ISR Experiment

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Problem Statement:
Human factors analysis is critical for FCS and Objective Force command and control systems and decision support tools. Requirements for lengthy tactical commitments (72 hours) and situational understanding dictate the need to study the effects of the future forces on leader and staff personnel. The C4ISR experiment being conducted by TRAC and UAMBL affords the opportunity to study two critical categories of human factors, workload and situational awareness.

A Common Relevant Operating Picture allows shared awareness on the battlefield, but its utility is dictated by the quality and quantity of information presented, the amount and details of the information of the battlespace of which the individuals can be cognizant, and the environment in which they operate.

Technical Approach:
This project consists of three phases. The first phase includes a literature review and selection of performance models to be used during the evaluation phase. Phase two will be training of data collectors, data collection during the experiment, and preliminary analysis and insights. Phase three includes more detailed analysis and documentation of the findings.

Requirements and Milestones:
Assist Human Factors Lead (ARL) in test design and data collection plan for the FCS C4ISR Experiment. (1Q03)
Provide referenced research to Human Factors Lead and Study Director (1Q03)
Assist with data collection and analysis (1Q03)
Provide final report input to the study director summarizing human factors analysis (2Q03)

Products and Deliverables:
Observer forms for situational awareness and workload assessments
Team mental model
Initial insights
Input to the C4ISR Experiment Final Report

Success Criteria:
The FCS C4ISR experiment will provide Milestone B insights. The human factors insights gained from this experiment will be included in the final report. Follow on study requirements will be identified from this study.

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Information Measures of Effectiveness

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Problem Statement:
Analysis for the Objective Force requires the ability to judge the contributions of information to the overall force effectiveness of the units. The underlying paradigm of network-centric warfare puts a premium on the value of information. Requirements documents for the Objective Force state that the cumulative effectiveness of these units is a sum of maneuver, firepower, protection, and leadership raised exponentially to the value of information.

Despite widely held beliefs that information significantly enables a unit's performance, little information is available that actually proves such is the case. Technological challenges will potentially prevent instantaneous promulgation of perfect, fused, and correlated information. Figuring out how much information is enough, judged by qualities of the information, is key to transformation analysis.

Technical Approach:
This project will satisfy a Naval Postgraduate School thesis requirement while providing key insights for the Future Combat System (FCS) analysis of alternatives. Using a simulation-building toolkit, the study team will develop a FCS scenario with assigned sensors using beyond-line-of-site engagement tactics to acquire and destroy threat forces. Information on threat forces is hindered by the presence of previously killed vehicles and decoys.

The independent variables will include the amount of information gathered and an aggregate process, analysis, and transmission value. By changing the levels of these values, which will mirror changes in information qualities such as consistency, accuracy, and latency, insights will emerge as to the value of information. The dependent variable will be the number of rounds required to destroy threat forces.

Requirements and Milestones:
Build model using above described scenario (2Q03)
Conduct runs and analyze data (3Q03)
Provide thesis as written report (3Q03)

Products and Deliverables:
Approved thesis

Success Criteria:
This is one of the few projects that look directly at information gain as a measure of a unit's efficiency. Explicit representation of all the factors associated with network-centric ground combat is beyond the reach of current technologies, so incremental approaches to understanding the value of information is key to understanding the ramifications of transformation. Success is contingent upon meaningful correlations between the quality of information and force efficiency, if such correlations even exist.

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Internetting of Fires

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Problem Statement:
This research directly supports the development of models and simulations for the Objective Force (OF). It will expand the way in which the OF and Future Combat System (FCS) are modeled. The specific goal of the project is a decision support tool that plans fires for future scenarios with the OF/FCS. This project will develop an algorithm that determines the best way to allocate fires for a FCS force and evaluate the ability of the FCS to successfully perform in an urban combat mission.

This effort will lend insights into organizational and operational concepts for the OF and will feed future Army simulations such as Combat ^{XXI} and OneSAF as well as concept definition studies by various system proponents.

Technical Approach:
Simkit, a set of Java classes for creating discrete event simulations will be used for algorithm development. This will facilitate eventual incorporation into OneSAF and Combat ^{XXI}.

The research team will use the simulation engine to identify the best way to allocate fires as well as identify the relevant variables for use in future simulations. Additionally, human behavior representation will be modeled with Bayesian Decision Networks to replicate perception and decision-making.

Requirements and Milestones:
Combine Internetting of Fires methodology with Sensor Mix Study results for sensor-shooting link analysis (3Q03)
Research suitability of employing existing methodology in complex terrain (3Q03)

Products and Deliverables:
Algorithm with documentation that defines FCS allocation of fires provided to Sensor Mix study team.

Success Criteria:
Existing products have already been well received. Several analytical efforts are using the initial internetting of fires methodology as a point of departure in larger Army-wide studies. Future success is contingent upon supporting these efforts.

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Advancements in Simulation

Modeling Natural Decision Making (NDM) for Information Fusion and Military Decision Making (NDM4Fusion)

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Problem Statement:
It is difficult to measure the value of information and the effectiveness of fusion algorithms. However, Objective Force (OF) decision makers must decide and act swiftly and decisively using fused information presented in a common relevant operating picture. Increased reliance on information requires that we model human decision making processes better to support planning and course of action analysis.

A commander will need to assess the trustworthiness of his information, possibly as a subjective measure of the quality of his data, before he uses that data to make decisions. Potentially, commanders with imperfect information will make the correct decisions, make hasty, but bad decisions, or be paralyzed with indecision as a result of incorrect quantities or qualities of data.

Modeling these interactions between information and the users of the information is critical in understanding the information-centric paradigm of the Objective Force. Decision support systems, leader development curricula, and joint force plans all require understanding of how humans interact with information and make decisions in a mission context.

Natural decision making (NDM) strategies incorporate intuition and are based on observation of human decision making in the real world while accomplishing real tasks. They compliment the deliberate, rational decision making approach used in the military decision making process (MDMP) and have strong application to the evolving decision environment of the Army's Objective Force. NDM models are needed that: model human decision processes; incorporate education, training and experience; are traceable; adapt and learn; work in an uncertain & dynamic environments; and can be supported with Knowledge Acquisition and data.

Technical Approach:
This project will develop and prototype a natural decision making behavior model to support evaluation of information fusion algorithms and to measure the value of information. This behavior model will support replication, experimentation and simulation of military decision-making processes. This research will produce a framework to evaluate decision-making based on a common operating picture.

Our preliminary research has identified three potential related models: Recognition-Primed Decision Making, Singular Evaluation, and Nonlinear Problem Solving. These models share certain internal representations as well as certain algorithms like recognition and mental simulation.

Knowledge acquisition is critical for behavior modeling. Cognitive task analysis is a set of interviewing, observation and analysis techniques aimed at understanding what goes on inside people's heads as they interact with their world. It unpacks expertise and describes cognitive processes in the context of a task. Cognitive task analysis supports NDM by providing a proven approach to knowledge acquisition for NDM behavior models.

The first phase of the project includes further background research and additional work developing natural decision models for military modeling and simulation. This includes developing models' details, representations, data representations, and supporting algorithms.

Phase two will involve implementing a natural decision model prototype and conducting a proof of principle demonstration. The research team will implement the model and fully document both the model and the implementation. The research team will also document data requirements and provide guidance to military subject matter experts to assist in future knowledge acquisition and behavior development.

Requirements and Milestones:
Preliminary Research (1Q03)
Use Case Development (1Q03)
Model Development (2Q03)
Model Implementation (2Q03)
Proof of Principle Demonstration (3Q03)

Deliverables:
Natural Decision Making Model
Prototype implementation to support experimentation and further research
Proof of principle demonstration

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Agent Based Modeling

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Problem Statement:
Agent based modeling and simulation has attracted considerable attention recently, but little is understood about this emerging modeling methodology, and the utility of this approach for future Army M&S is not known. The fundamental question this experiment is attempting to answer is: are agent based models appropriate for use in OF analysis and FCS AOA?

Agent based models are fairly small when compared to other military simulations. In general, they are only designed to represent a small focused subset of entities and interactions rather than the complete or very large set normally found in traditional constructive simulations. The relative simplicity of current agent based simulation models offers two key advantages. They are quick to set up and they run very fast. From the time a simple scenario is conceived, it may take less than a week for a single analyst to implement the scenario and conduct tens of thousands of simulation runs. This compares to the more traditional constructive military simulations that may take many months to implement and produce only a few runs.

The ability to produce tens of thousands of simulation runs allows the analyst the ability to consider thousands of alternatives. This ability generates many data points, and, coupled with recent advancements in experimental designs, allows the analyst to explore many dimensions of the models' input space and identify critical variables, important interactions, and the ranges of the affected variables. This means of exploratory analysis has the potential provide effective analytical support to the larger traditional constructive simulations.

Technical Approach:
The approach in this experiment will be to develop an urban scenario with guidance from the Dismounted Battlespace Battle Lab (DBBL), Ft Benning, and conduct trade-off analysis across multiple agent based models to determine the appropriateness of these models for OF/FCS analytical support.

Specifically the intent is to use a series of new models and analytical tools developed under Marine Corps Combat Development Command's (MCCDC) Project Albert to explore questions relative to OF and FCS. The particular models that will be used are Pythagoras, Socrates and MANA. We will exploit recent advances in computing power by utilizing the Maui High Performance Computer Center (MHPCC) to implement our design of experiments and conduct thousands of runs to explore questions from the perspective of many data points.

The basic scenario design will be completed with guidance from the DBBL's Chief of Analytical Simulations utilizing the FCS Systems Book version 1.3 as reference. The scenario will be set up with blue forces moving through an urban environment to an objective. The urban scenario will have aggressive red forces that continually patrol the environment. The experiment will conduct trade-off analysis on squad size (9 vs. 12), the number of squads (2 vs. 3), the weapons mix in squads, the use of an FCS vehicle and the weapon and sensor mix on the FCS vehicle. The potential MOEs are blue attrition, optimal weapons and sensor mix for the FCS vehicle and squads, and time to mission completion.

Requirements and Milestones:

Prepare designs for Agent-Based Model Runs. (1Q03)
Conduct Simulation Runs (1Q03)
Complete Analysis and Report. (1Q03)
Brief Outcome (2Q03)

Products/Deliverables:
Workshop Report. (2Q03)

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Advancements in Experimental Designs

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Problem Statement:

The Department of Defense (DoD) uses simulation models to support its decision-making process by, among other things, testing war plans, deciding what equipment to acquire, determining the best combination of forces, and determining the best combination and use of weapons. Since it is nearly impossible to conduct actual physical experiments to determine the effectiveness of war plans, force designs, or weapon system capabilities in actual conflict, the DoD relies on these simulation models to capture significant insights that enable senior leadership to make informed decisions.

A new and stimulating area of combat models involves complex adaptive systems. The concept is to use multi-agent-based software tools to examine the relationship between numerous input variables and output measures. The self-adaptive nature of these models facilitates broad exploration and permits the possibility of gaining substantial insights into emergent behaviors on the battlefield (Horne and Leonardi [2001]). The major proponent of this current research is the Marine Corps Combat Development Command's Project Albert.

A common characteristic of the above-mentioned models is the vast number (sometimes even greater than 100,000) of variables or data elements present—many of which are uncertain. Conducting a comprehensive experimental design on these numerous variables is prohibitive. Often, a small subset of the variables (usually no more than two or three) is chosen for experimentation. In such a case, the results are necessarily assumed to be invariant to the large number of uncertain variables held constant, but no empirical assessment is made. In addition, even a small, manageable subset does not guarantee that a detailed experimental design will be used. The problem is compounded since, even if a manageable subset of input variables is chosen, determining the appropriate levels or settings of the variables remains an issue. Remembering that the main thrust of the experimentation is to identify significant insights, this goal may be jeopardized when a small subset of variables or inappropriate levels of the variables are used.

Defense analysts need experimental designs capable of efficiently searching an intricate simulation model that has a high-dimensional input space, characterized by a complicated response surface (substantial non-linearities may be prevalent). The experimental designs to be developed can provide the ability to search a comparatively high-dimensional (up to 22 variables) subspace of a simulation model and reliably identify critical variables, important interactions, and the ranges of the variables where these effects occur. Furthermore, the number of runs required is small (e.g., a minimum of 129 runs for 22 variables) when compared to most existing experimental designs.

Technical Approach:
This work will develop experimental designs that provide the ability to search a high-dimensional (up to 22 variables) simulation model and reliably identify critical variables, important interactions, and the ranges of the variables where these effects occur.

The two most important characteristics for these designs are orthogonality and space-filling. Two measures are used to assess the orthogonality of a design matrix, the maximum pairwise correlation and singular value decomposition condition number. The use of both measures provides a better ability to differentiate between the orthogonality of candidate designs.

Number of experiments	Number of variables examined in the orthogonal or nearly orthogonal designs	Number of variables examined in previous orthogonal designs	Percent increase in number of variables examined
17	7	6	17%
33	11	8	38%
65	16	10	60%
129	22	12	83%

Table 1. The designs developed in this work will be able to examine a greater number of variables than similar previous designs in the same number of runs. These new designs still have excellent orthogonality and space-filling characteristics. The algorithm generalizes for an arbitrary number of variables.

Requirements and Milestones:
Prepare designs for Agent-Based Model Runs. (1Q03)
Prepare refereed journal article for submission to *Technometrics*. (3Q03)
Investigate inclusion of factors or variables having a fewer number of levels than required runs. (4Q03)

Products/Deliverables:
Provide runs for Agent-Based Model Runs. (1Q03)
Journal article for *Technometrics*. (3Q03)
Methodology for factors or variables having a fewer number of levels than required runs. (4Q03)

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JANUS versus JCATS Attrition Algorithms

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Problem Statement:

The United States Army modeling and simulation community is currently engaged in a number of high-resolution studies involving Military Operations in Urban Terrain (MOUT). Training and Doctrine Command's (TRADOC) Analysis Center (TRAC) at White Sands Missile Range (WSMR) uses Janus to examine the MOUT environment. The Dismounted Battlespace Battle Lab (DBBL) at the United States Army Infantry School (USAIS) uses the Joint Conflict and Tactical Simulation (JCATS). Both are open form stochastic computer programs that allow participation from a human in the loop. JCATS models complex terrain physically in three dimensions. Both models can accommodate a full suite of sensors, weapons and unmanned vehicles.

The problem is to determine the differences in attrition based on a common MOUT Scenario between the two models and to determine the distinct differences in the adjudication process. This research will provide insight to decision makers who rely on these models as part of their analytic process.

Technical Approach:
This study proposes to design a set of experiments based on attrition and adjudication factors found in Janus and JCATS. A straight comparison of these factors based on sufficient model runs may provide distinct differences in the factors chosen for study. This will include comparison of these factors: Pk values and attrition; munition kill factors; and RSTA factors

If available, the project also proposes to examine the source code to find the distinct differences in the adjudication algorithms and to see what special subroutines are used in the MOUT environment. If these can be extracted, specific experiments could be run using only the subroutines in order to determine the specific differences. This would allow many more experiments to be conducted in a short time.

Requirements and Milestones:
Set up simulation environment with Janus and JCATS. (1Q03)
Choose factors for analysis / design the experiment (1Q03)
Complete experimental runs (2Q03)
Complete technical report on findings. (3Q03)

Products/Deliverables:
Analysis of model runs.
Briefing on initial findings
Technical report on findings

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