*Modeling and Simulation Support for Answering Commanders' Priority Intelligence Requirements*

Christian J. Pizzo[1]
Gerald M. Powell, Ph.D.[1]
Chester F. Brown, III[2]
Jacqueline May[1]

[1]U.S. Army RDECOM CERDEC I2WD
McAfee Center
Fort Monmouth, NJ 07703

[2]Electronic Warfare Associates, Inc.
Herndon, VA

## Abstract

A critical element of Command and Control decision-making support in the battlespace is answering the commanders' priority intelligence requirements (PIRs) in a timely manner and with adequate accuracy. In 2003, the Army initiated a science and technology objective (STO) program entitled Fusion Based Knowledge for the Future Force to conduct the R&D necessary to provide automated support for answering PIRs at the Unit of Action (brigade-level force). The FBKFF STO program has discovered that the modeling and simulation capabilities of today fall short in numerous key areas underlying the required realism, scope, richness and complexity of battlespace scenarios of today and of the Future Force. This paper: (a) identifies and describes these shortfalls in detail, (b) describes the software development and manual workarounds we have carried out to address some of them, and (c) explains why these capabilities are needed to support R&D targeted at solving problems involving information analysis, interpretation, and gathering that underpin the ability to answer PIRs. We also present our current view of what a sophisticated modeling and simulation environment would have as capabilities to adequately support such data fusion R&D. A subset of the requirements and capabilities that will be addressed in this paper include: the ability to simulate aggregations of entities into units and units into higher level units; the ability to simulate realistic behaviors with respect to ground movement, action/reaction/counter-action, threat actions, communications; the ability to replicate battlespace reporting as it exists today and how it will be used in the future operational environment; the ability to efficiently provide scenario-specific human-generated observations in a format that can be integrated into an automated simulation environment; the ability to generate, and adjust, the volume of reports to reflect the severe information overload on analysts; and interoperability with the current and future force intelligence and other Army Battle Command System processors.


## Introduction

In 2002, the Intelligence and Information Warfare Directorate (I2WD) of the Communications-Electronics Research, Development and Engineering Center (CERDEC) in collaboration with the Computational and Information Sciences Directorate of the Army Research Laboratory (ARL) proposed a Science and Technology Objective (STO) program entitled Fusion-based Knowledge for the Objective Force (FBKOF). The purpose of the FBKOF STO [1,2] was to conduct research and development (R&D) to create software solutions that would provide assistance to Army intelligence analysts in the tasks required to answer commanders' priority intelligence requirements (PIRs) at the level of the Army's Unit of Action (brigade-sized force). (More recently the program name was changed to Fusion Based Knowledge for the Future Force (FBKFF), and Army Technology Objective (ATO) replaced Science and Technology Objective). The present paper reports issues and activities pertaining to R&D carried out by I2WD (the FBKFF lead organization). Our focus here is modeling and simulation (M&S).

By providing a set of M&S capabilities that are unclassified, we encourage participation and innovation from many sectors, including academia. To achieve this objective, the M&S software needed to support our program has to provide unclassified data sets, specifically intelligence reports, for data fusion technology and application development under FBKFF research, development and evaluation. M&S is considered to be a critical component of the experimentation-based approach of FBKFF. After what we believe was a thorough investigation of current technology, we have concluded that a set of critical M&S shortfalls exist that prevent adequate generation of intelligence reports from simulated scenarios. In this paper, we present these shortfalls as a set of

M&S requirements with the hope that the M&S community will recognize this as an important area of work. It is not clear to us from the documentation available, that M&S environments planned for the near future have included these needs in their requirements sets. We have also presented a subset of these deficiencies at a number of M&S workshops and symposia [e.g., 3, 4] and they have been recognized as critical deficiencies by the U.S. Army Intelligence Center & Fort Huachuca (USAIC&FH). We would like to re-emphasize that in this paper we are addressing M&S deficiencies we have found in the *unclassified* realm.

The purpose of this paper is to specifically identify the shortfalls regarding M&S supporting research and development in answering commanders' PIRs . Current software workarounds, while limited in functionality, are also presented as steps taken to make progress in spite of these M&S deficiencies. In order to provide the context of how M&S supports higher-level fusion research, an operational perspective is also presented. Finally, we present the characteristics of an ideal M&S environment that supports research and development in solving higher-level fusion problems such as those associated with answering PIRs. In particular, we are referring to levels 2-5 of the Joint Directors of Laboratories (JDL) Data Fusion Model [5]. Although the present paper discusses M&S deficiencies and capabilities in terms of conducting research and development under the FBKFF ATO program, we believe that any project desiring to use M&S to develop and evaluate higher-level (i.e., 2-5) fusion solutions will likely identify the same M&S gaps and desired capabilities.

**Modeling and Simulation Shortfalls**

This section identifies and describes in detail the modeling and simulation shortfalls as discovered in the first two years of the FBKFF ATO. The specific software applications listed are those the FBKFF team initially investigated when determining applicable M&S technology. These software applications have been evaluated in the context of providing data or intelligence reports needed to drive software prototypes developed to support answering commanders' PIRs.

*Ground Truth*

Ground Truth, as expressed under the FBKFF ATO refers to the state of the scenario during execution regarding the environment, entities, and their battlespace behaviors, which are accurate and timely. When dealing with ground truth simulators (force-on-force, entity level), the level of detail of entities modeled is critical. Entities in a ground truth simulator can be any individual object that interacts with other objects and the environment including people, vehicles, weapon and sensor systems, radar and communication emitters, etc. The level of detail pertains both to the physical characteristics of the entities as well as the behaviors exhibited during the course of a scenario involving the entities. Physical characteristics of entities requiring a high level of detail include size, weight, armor thickness or equivalent rating (i.e., main battle tank vs. human skin), onboard systems, armament, camouflage, etc. Examples of battlespace behaviors include ground movement, action/re-action/counter-action, threat actions, force protection, communications and others. The behaviors, tactics and rules of engagement for entities should change over time, as in a real operational environment, and must be configurable in an M&S environment. Also important is the ability of the simulators to allow for the user creation of new entities, or modification of existing ones, to reflect the changes of an adversary's equipment and usage over time. The two popular ground truth simulators evaluated by the FBKFF team consist of the Joint Conflict and Training Simulator (JCATS) and One Semi-Automated Forces Test Bed (OTB). Note, other simulators were evaluated based on their documentation or assessments made by other organizations. Both JCATS and OTB have a set of strong, positive attributes relevant to our needs and that is why we have relied on them more than any others. Nonetheless, after scenario implementation and testing, it was concluded that neither simulator could operate stand-alone and provide the level of detail necessary to portray complex battlespace maneuvers and other key behaviors. In OTB, vehicles in columns would veer off course, or not maintain a constant velocity when they should. Instead of crossing at bridges, entities would attempt to cross water, stopping at the edge and ending their maneuvers. OTB also demonstrated the inability to simulate more than 200 entities before the computing resources on a standard high-end workstation were overloaded. JCATS uses more simplistic entity and aggregate models, and moves aggregates of entities in a scenario as a single object located at the center of mass of the group. This behavior causes entity warping when the aggregate turns to change heading, as the entities are rotated about the center of mass. This is especially troubling when trying to provide continuous ground truth, because the entities will teleport unrealistically into their new position within the aggregate. JCATS, however, was able to simulate the number of entities required to provide enough reports to overload analysts during experimentation. Although this attribute of JCATS is very useful, JCATS falls short in providing an adequately high-level of detail. These deficiencies in adequately modeling detail regarding battlespace entities, entity volume, maneuvering of aggregates, and other combat behaviors prevents either of the applications used in stand-alone mode or together to fully meet the requirements of the FBKFF ATO. In the section below (Workarounds), we list some of the workarounds developed to address the deficiencies of these ground truth simulators.

*Sensor Models*

Tied to the ground truth simulators as either internal elements or external applications are sensor models representing the sensor systems either currently deployed or in development for the Army. The purpose of these sensor models is to process the ground truth information fed by a simulator and produce an output similar, if not equal, to the data produced by the real sensor systems they represent. In order to replicate the future operational environment in simulations, the FBKFF team identified those sensor systems that would provide the most important information to an Army intelligence analyst. Without identifying specific sensors, they consisted of signals intelligence (communications and radar), image intelligence, measurements and analysis intelligence (unattended ground sensors, UGS), and ground moving target indicator (MTI) radar. The few available models representing those sensor systems were then evaluated using implemented ground truth scenarios. The models evaluated were deficient in a number of ways including the lack of physics-based calculations, unrealistic/optimistic sensor data, and non-standard message formats. Sensor models that are based on statistics are deficient with respect to physics-based models as the former rarely takes into account all of the environment characteristics including: the terrain, weather, vegetation, elevation and location of the entities, buildings, subterranean features, and building rubble, all of which become particularly important in urban scenarios. The FBKFF ATO requires physics-based models that take the above into account, including line-of-sight calculations, as results evolve toward greater levels of realism. Statistical models tested and evaluated also produced very optimistic results due to the failure to take error into account when determining sensor "hits." In addition to the above, many of the reports generated did not correspond with any standardized message format. For the purposes of sensor data exploitation and analysis, this is valid output, but for intelligence reasoning, a standard message format provides the detailed information up front that an analyst needs to determine the importance of a report. In developing scenarios representing the future operational environment, certain sensors will play an important role in providing actionable intelligence (intelligence providing commanders and soldiers a high level of shared situational understanding, delivered with speed, accuracy, and timeliness necessary to operate at their highest potential and conduct successful operations) to Army analysts.

One of the sensor systems of key importance to the Future Force of the Army is signals intelligence, or SIGINT. It is necessary to incorporate models that can generate and detect communications and radar emissions and output standardized military messages. One application evaluated by the team had a very strong foundation for generating realistic signal scenarios and tying them to ground truth maneuvers resulting in timely battlespace communications. An analyst examining these simulated communications could form hypotheses as to the adversary activity based on the pattern or content of a series of transmissions. Unfortunately, more development will be required in order to integrate the application with the ground truth simulators. Other SIGINT models evaluated used simple distance calculations to determine if emitters were within range of the sensor platform and would skew the data based on user-defined error variables. While the skewing of data in order to reflect receiver sensitivity and other characteristics addresses the limitations of the real systems, a single numerical value is inadequate for representing all the environmental characteristics that prevent optimal sensor operation. Environmental characteristics such as the effects of elevation (terrain masking), weather, urban environments (buildings) and vegetation have no effect on these primitive sensor models. Clearly more effort must be dedicated to working on detailed and realistic SIGINT models before they can be trusted as valid input to higher level fusion processes. Note, we realize an unclassified model will not reveal actual sensor performance. Of use, in an unclassified setting, would be models where researchers can create their own variables and manipulate values of variables in any way desired.

*Human Intelligence*

While not a source of physical-sensor data, human intelligence is proving itself a critical source of information regarding enemy location, activity, and behavior in recent conflicts. Current evaluation of M&S technology has demonstrated a shortage of human-generated reporting models that tie into ground truth simulators. This deficiency is currently met by hand-generated reports that are time-consuming to generate, and correspond to only a single, static scenario. The requirement for modeling HUMINT and human-generated reports has been iterated by a number of sources and most recently at the Unit of Action Intelligence Surveillance and Reconnaissance Map Exercise (UA ISR MAPEX) and the accompanying meeting of the Fusion M&S Working Group in August, 2004 [4]. Without understanding the importance of human-generated intelligence, which may be the only actionable intelligence provided to an analyst operating in an urban environment, we are limited to portraying a world in M&S that in many important ways fails to represent operationally-salient characteristics of reality.

*Documentation and Interoperability*

In addition to the very specific details that the current breed of Army M&S applications are lacking, there are some general properties, normally associated with good software engineering, that are inadequate as well. Documentation and interoperability are two critical elements of any software application, but even more so for modeling and simulation applications. Without comprehensive user-guides and other documentation such as application programming interfaces, software change logs and bug fixes (to allow the user to understand what has been fixed and what may still be broken), and quick references (to aid in quick scenario implementation), the full capabilities of these applications cannot be exercised. This becomes important for implementing ground truth scenarios that require the user push the limits of the embedded behavioral models in order to portray an intelligent adversary. Interoperability for M&S applications refers to the ability to generate output that can be processed by a wide number of applications, and provide a simple interface for creating new applications. In the case of tested M&S applications, both OTB and JCATS provide a very nice interface via Distributed Interactive Simulation (DIS) Package Data Units (PDUs). The PDUs allow for other applications to receive and process ground truth information and are used by the FBKFF team in order to develop situation awareness, described in the next section. These PDUs, however, reflect the lack the detail inherent in the applications evaluated, which is required by higher-level fusion processes. A more effective means for simulation communication and reporting should be incorporated.

These deficiencies in M&S regarding lack of detail in entity characteristics, shortage of physics-based sensor models, absence of human-generated reporting models, inadequate user documentation, and interoperability problems, must be addressed. We believe that failure in meeting the M&S requirements above will severely limit advances in higher-level fusion research and development sought to enable future Army intelligence analysts to gain information superiority over intelligent and increasingly unconventional adversaries.

**Workarounds**

Due to the deficiencies identified above, in modeling and simulation applications to meet numerous key requirements of higher-level fusion processes, we have developed a set of workarounds in an attempt to provide intelligence reports for the R&D ongoing under FBKFF. The workarounds listed below are only temporary solutions implemented in order to perform higher-level fusion R&D despite current M&S application limitations.

The PDUs generated by both OTB and JCATS are currently the driving force for the scenarios used by the FBKFF team. The two most important PDUs for generation of intelligence reports are the "Entity State" and "Spotted" PDUs. The "Entity State" PDU contains all the information regarding an entity including geo-location (Latitude, Longitude), kinematics (velocity vector), unit status (Healthy, Firepower Kill, Mobility Kill, Destroyed), internal application designation, and unit identification (callsign), at regularly updated intervals (i.e., every 5 seconds). An application reading in a stream of "Entity State" PDUs can keep a log of the status and location of every entity in relation to the terrain and each other over the entire course of the scenario. It is our goal to use ground truth information, such as the "Entity State" PDU as an element of valid metrics for analysis of experimental higher-level fusion applications. While currently useful to provide position and status information, it would be beneficial to also provide updates of the local intelligence of each entity (all the other entities that are currently known to the highest level of target acquisition). This local intelligence would aid the scenario operator in gaining insight into the reason behind an entity performing a specific action ( e.g., what caused the entity to pull off the highway and take cover in heavy vegetation?). The "Spotted" PDU is also important to FBKFF, as it provides a means of determining the enemy situation via spot reports in order to represent friendly forces identifying hostile targets on the battlespace. Information of importance contained in the "Spotted" PDU includes level of acquisition (unknown, detection, recognition, etc.), target identification (possible equipment types), geo-location, and target status (minimal battle damage assessment). Far from meeting the required level of detail expected in future force reports, "Spotted" PDUs are used to meet a critical gap in automatic generation of intelligence reports from a ground truth scenario. Raw sensor model data can also be used to a minor degree in order to provide low-level intelligence reports.

As a research project under I2WD, the FBKFF ATO has been able to use a number of M&S technologies including sensor models and sensor report databases as part of our in-house resources. Sensor models incorporated into the experimental laboratory include a ground MTI radar and a SIGINT model that work with OTB/JCATS PDUs, an UGS model embedded into OTB, and an Electro-Optical/Infra-Red (EO/IR) 3-D camera simulator that reads the ground truth from OTB/JCATS as well. The output from these sensor models populates a sensor report database configured to handle various types of messages. Using tailored data visualization tools, an operator can manually correlate sensor events, stored in the database, and determine the enemy's actions, force composition, and possible ground maneuvers. Various single- and multi-intelligence domain tracking applications can be connected to the sensor report database in order to automatically correlate the sensor data into tracked targets. The output of these tracking applications (i.e. the tracked battlespace objects) can be stored back into the database and displayed on the visualizer, giving the operator more detailed information about the enemy situation than the set of raw sensor data. While this type of application serves an operator who is managing ISR assets and correlating sensor data and tracker reports, a future Army analyst will have to process these and other reports based on enemy aggregates, behaviors, and actions as well, which are unaccounted for in most intelligence and fusion applications.

Using the simulated reports captured from the "Spotted" PDUs, sensor data from the models (stored in the sensor report database), and the tracked battlespace objects from the multi-intelligence tracking applications, we can generate extensive logs of reports in a specific format. While the format of these report logs does not mirror any message format standard used in the military, it contains all the important information regarding the time reported, time the information is available to be processed, geo-location, kinematics, quantity sighted, equipment/vehicle type, reporting unit information, types of sensor systems used, and report confidence. With the recommendation from operational community representatives, the log file also draws a connection between the individual reports and the ISR collection plan laid out by the intelligence officer. As improvements to the realism of M&S applications occur, the reports generated will become richer in detail, aiding research and development in providing solutions to context-dependent fusion problems.

**How M&S Capabilities Support R&D in Higher-level Fusion Problems**

Generally, modeling and simulation save the Army, and other DOD organizations, time and money during research, development, testing, and evaluation (RDT&E) of technologies. The need to provide unclassified M&S applications to influence and enable military RDT&E of higher-level fusion problems was expressed at the Fusion M&S Working Group in November 2003 [3] and further emphasized at the Battle Command Battle Lab – Huachuca sponsored Unit of Action (UA) Intelligence, Surveillance, and Reconnaissance (ISR) Map Exercise (MAPEX) on August 23-24, 2004 [7]. As we discovered that current M&S technology falls short in providing detailed intelligence report data sets to stimulate the fusion R&D in our program, we raised these shortfalls as critical requirements. Investigation of the deficiencies identified in the first section, workarounds attempting to provide small levels of functionality, and documentation of the short falls as critical requirements for fusion R&D have been time and labor intensive. More advanced applications will need to be developed that can meet these critical requirements and provide the realistic, unclassified intelligence data sets that were traditionally generated by hand.

In order to provide realistic, unclassified data sets, the reports must either be generated by hand, or in an automated fashion by M&S applications. Hand generation of the reports is extremely time consuming, prone to human error, and the reports generated can only represent a single static scenario. This prevents run-time changes in mission, enemy, terrain, time, troops available, and civilian considerations (METT-TC). What is critically needed to accelerate experimentation-based development and evaluation of robust intelligence-fusion applications are dynamic scenarios where realistic battlespace behaviors can be implemented and modified during run-time to reflect the change of tactics of an intelligent, adaptive adversary. In October 2004, we submitted an AR5-5 proposal [6] for FY2005 Headquarters Department of the Army (HQDA), Army Study Program, attempting to secure funding in order to develop a simulator capable of supporting higher-level fusion R&D. A Level 1 Fusion (JDL Level 1 [5]) Simulator would generate and output large volumes of reports, based on a ground truth scenario, to stimulate intelligence-reasoning fusion applications. Although the proposal did not meet with success, it provided a clear message to attendees that M&S must fulfill the need for realistic sets of intelligence reports based on scenarios representative of current and future operational environments.

**Ideal Capabilities of a Modeling and Simulation Environment**

From our perspective, an ideal M&S environment would meet all of the deficiencies described in the first section of the present paper to allow a user to implement METT-TC dependent, realistic ground truth scenarios that produce intelligence reports detailed enough to drive higher-level fusion applications. These scenarios could be modified during run-time in order to change the output reflecting changes in tactics, rules of engagement, equipment, etc. In the "ideal" modeling and simulation environment, ease of user implementation would be absolutely critical. Software-interfaces such as wizards, dialog windows, windows displaying Arc Digitized Raster Graphics (ADRG)/Compressed ADRG (CARDG) maps, informative mouse-overs, battlespace object drilldowns, three-dimensional graphics, MIL-2525B Icons (military standard battlespace icons), and easy-access help screens would aid users in creation and implementation of their desired scenarios. Simulated entities would be realistic representations of dismounted infantry, guerillas, vehicles, civilians, organizations, communications networks, computer systems, buildings, utilities, road networks, and any other aspect of the future operational environment. Rules of Engagement could be edited at any point in the scenario, allowing the transition from Offensive to Support and Sustainment operations (SASO). While, the user would have full control over the specific characteristics and behaviors of each entity, the default state would represent a believable individual in actions, maneuvers, and self-preservation. No longer limited to standing and firing at an approaching foe, an entity would take cover in the rubble of a destroyed building, calling for backup if necessary. A terrorist organization would be able to collaborate via ad hoc communications to synchronize attacks on installations. These situations form plausible scenarios that could be effectively implemented in the ideal ground truth simulators that meet all the deficiencies in the first section.

Following the ground truth implementation, the ISR collection plan would then be entered into the scenario drivers to allow for interaction over the course of the scenario with battlespace objects. Ideally, a user could allocate available sensor assets to one or more areas of interest (AOIs) or named areas of interest (NAIs). These sensing assets would be able to provide reports that are directly tied to a specific collection plan designed to answer a commander's priority intelligence requirements. The software modeling the sensor systems would be physics-based and provide flexibility in allowing users to explore a range of error values and other limitations, but without using classified information. Reports generated from the both the sensor assets and entities (normally friendly, allied, or civilian) themselves would be stored in a retrievable database and displayed graphically on a computer map. At any point in the course of scenario execution, the FBKFF experimentation team could modify or change the values of the reports in order to reflect the degradation or inaccuracy of the information provided. Reports could also be time delayed to represent pre-processing of information, network communication latency, adversary jamming, etc. Example scenarios include a pre-specified collection plan linking collection assets with NAIs and AOIs. As enemy forces maneuver across the battlespace, they would be detected by sensor models and spotted by friendly observers. The sensor data generated and spot reports issued, which are both linked to the collection plan, would allow for an analyst test subject to gain insight into what actions the simulated enemy forces are taking.

The goal of an ideal M&S environment supporting R&D in solving higher-level fusion problems is ultimately to generate detail-rich, context-dependent intelligence reports tied to an analyst's ISR collection plan, that can be utilized by software prototypes attempting to aid the analyst in tasks such as answering commander's PIRs in dynamic scenarios.

**Summary and Conclusions**

The purpose of the present paper was to express the findings of our assessment of the current deficiencies in Army modeling and simulation software to produce unclassified intelligence reports capable of driving higher-level fusion RDT&E for purposes such as answering commander's PIRs. Without meeting the identified requirements of M&S supporting R&D of higher-level fusion applications, we cannot be confident of their analytic, interpreted or fused output based on our inability to have fine control over all the independent variables during scenario execution. Variables such as report detail, accuracy, density, and latency, sensor limitations and malfunction, and information degradation, need to be modeled so that test cases in quantities supportive of statistical analysis can be executed in a time efficient and cost effective manner (hand generation of reports is neither). M&S should ultimately allow us the freedom to produce different test cases by modifying these variables in order to stress fusion applications attempting to answer commanders' PIRs and other challenging tasks of upper-levels of fusion. The robustness of these applications to handle different situations expected in future operational environments ultimately rests on the modeling and simulation environment's ability to produce these test cases quickly, efficiently, and with adequate detail.

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