A CONCEPTUAL ARCHITECTURE FOR INTEGRATING TACTICAL ENGAGEMENT SIMULATIONS (TES)

James T. O'Connell, Jr.
O'Connell and Associates, Norfolk, VA
Larry L. Mengel
LL&M Associates, Elizabethtown, KY
Dr. Thomas A. Mastaglio
***PAIDEIA,* Virginia Beach, VA**

ABSTRACT

In this paper the authors' suggest a conceptual architecture for achieving the high level of integration required to insure fidelity and tactical realism in the environment of a synthetic electronic battlefield. The architecture focuses on the concepts associated with the development of a family of knowledge-based software modules that populate the battlefield. These modules, ACTORS, AGENTS, and Filters provide the capability required to implement the full range of functions inherent in modern tactical warfare. The approach maintains strict adherence to all of the salient features of the Army's collective training strategy. Flexibility is provided to ensure implementation consistent with current doctrine Modification can accommodate doctrinal, weapons systems and other external changes. The architecture provides an innovative design that applies current and emerging technologies to satisfy the training community's vision of a capability to integrate, in an electronic environment, the full range of tactical engagement simulations.

THE AUTHORS

The authors of this paper, all graduates of the United States Military Academy and retired Army officers, have had extensive experience in the design, development and implementation of Tactical Engagement Simulations (TES). They offer a unique understanding of user requirements and the technical foundation essential to leverage emerging technology to enhance training effectiveness/combat readiness.

Jim O'Connell received his Masters Degree in Operations Research at the Naval Postgraduate School. His military career as an Infantry officer included assignments in support of the development of tactical simulations, training and training related systems. His most recent efforts have been in support of continued development of the Army's Combat Training Center (CTC) instrumentation systems and training devices.

Larry Mengel holds a Masters Degree from Lehigh in Industrial Engineering. His active duty career as an Armor officer included command, staff, and research and development assignments . He served as TRADOC Systems Manager for the Army's Combined Arms Tactical Trainer (CATT) program. He currently serves as a consultant to industry and government on advanced applications of simulation capabilities to support training needs and other functional areas.

Dr. Tom Mastaglio received a PhD in Computer Science at the University of Colorado in 1989. His military experience includes more than 20 years in both Field Artillery and training development assignments. Tom worked as an independent consultant and research analyst prior to assuming his current position as the Deputy Program Manager for Training Effectiveness on the Close Combat Tactical Trainer (CCTT).

A CONCEPTUAL ARCHITECTURE FOR INTEGRATING TACTICAL ENGAGEMENT SIMULATIONS (TES)

James T. O'Connell, Jr.
O'Connell and Associates, Norfolk, VA
Larry L. Mengel
LL&M Associates, Elizabethtown, KY
Dr. Thomas A. Mastaglio
***PAIDEIA*, Virginia Beach, VA**

INTRODUCTION

The conceptual architecture presented in this paper provides a focal point for accelerating needed development of a *technology leap-ahead to integrate tactical* engagement simulations (TES) into an effective and efficient system. The overall concepts discussed herein apply to current simulators and simulations deployed in support of combat arms training today and the more technically advanced training systems currently under development. The fundamental motivation for such an architecture is to encourage the timely development of a robust, effective, and efficient electronic environment to support collective training needs.

The overall approach addresses the following needs: an expanded capability to "Train As We Fight;" enhancements that support multi-echelon training ; and, integrated linkage to a sophisticated real time After Action Review (AAR) process.

We advocate satisfying these needs through the development of an overarching computer and networking architecture that exploits application of advanced technologies to enhance system effectiveness, fidelity, and tactical realism. We submit that a computational architecture based on an object-oriented system design (OOD) is essential and we provide one in this paper. The design we advocate incorporates an engagement-based adjudication of combat and provides for the seamless integration of weapons system and other simulators, simulations and TES used on instrumented ranges. *Attrition-based combat calculi cannot seamlessly support requirements to model entity level combat elements and support higher formations which are aggregates of those elements.* Representation of combat elements as knowledge-based entities is key to achieving a technology "leap ahead" in replicating ground combat for the multi-echelon simulation we envision. We clearly recognize that additional *computational resources are required to* implement the concept we advocate. We believe, however, that technology growth will overcome this limitation and that the performance needed to support the computational architecture described herein will be affordable within 5 years.

Train as We Fight

To simulate realistic battle conditions during training exercises, soldiers should perform wartime tasks using their normal operational equipment. This enhances believability and supports the principle: "train as you will fight." It is important for the simulation system to be robust enough to allow all personnel participating in a training event to carry out their respective wartime functions. This is particularly true for support of command and staff training. This factor should be recognized in the design and development of embedded training capabilities in the next generation of tactical equipment.

Multi-Echelon Training Support

Our conceptual architecture assumes an electronic battlefield that supports realistic collective training at all organizational levels. We assert that a Battalion Commander should be able to train his staff in a "stand-alone" configuration or be easily linkable over an appropriate computer network to participate realistically in Brigade and larger formation exercises

Design, development, test, and *implementation of a realistic multi-echelon* capability would not, in and of itself, accommodate all of the requirements of the Combined Arms Training Strategy (CATS). There must be a capability to link related training events, regardless of the configuration of the TES support being provided to the participants, in a coherent and highly credible fashion. This capability must be developed to support unit training focused on a common scenario and characterized by a realistic integration of: (1) players using dissimilar simulations (e.g. CSSTSS, TACSIM, BBS, JANUS); (2) units conducting maneuver training at a Combat Training Center (NTC, CMTC or JRTC); and, (3) commanders and staffs involved in BCTP exercises.

Quality AARs Enhance Training Effectiveness

We advocate comprehensive AARs based on the Battlefield Operating Systems (BOS) and functional structure of the Blueprint of the Battlefield. Developing a high quality *feedback* capability is totally consistent with our overall concept. We would suggest that the best approach here is to build on the previous developments of the AAR processes that support the CTCs.

We anticipate an AAR support capability that provides the results of engagements and events efficiently and without bias. Data will be available to commanders and controllers "on demand" explicitly describing *what* happened and supporting the analytical determination of *why* it happened. This data package will assist in preparing and conducting unit- (e.g. Brigade or *Division level) and functionally-oriented* AARs. Our approach supports both on-site AARs and take-home or electronically delivered products tailored to the training unit's requirements.

FIDELITY TO PRINCIPLES

The conceptual architecture described herein is offered as an approach to enhancing realism in a dynamic, realistic, synthetic electronic battlefield environment. Battles can *be simulated at all echelons of command without* human intervention or system initialization. *Tactical realism within the simulation can be* enhanced by integrating various man-in-the-loop capabilities available in currently fielded and developmental tactical engagement systems (TES).

We based our conceptual architecture on the following principles:

Resolution of engagements is always at the entity level. An entity, defined as a "killable" platform, may be a tank, helicopter, individual soldier, or communications node. *An entity is never an aggregation of platforms.* Entities interact on the battlefield according to behavioral rules, using performance data representative of observable real world actions. Adherence to this principle supports constructing a simulation that is both "intuitively" believable and inherently realistic.

Linked networks enhance the player interaction and control. A set of Local Area Networks (LAN) connect elements residing at a common physical location. Wide Area Networks (WAN) connect multiple LANs, or *even other WANs when necessary.* Our analysis reinforces the observation that not every entity or element on the battlefield (i.e., in the training exercise) needs to "know" everything that is going on in the entire area of operations. Information will be selectively provided to commanders and units depending on their distance from a particular action, their need for the information and the probability of their receiving it.

Players access the simulation using a variety of modes. Computer workstations, manned simulators, tactical weapons systems, and constructive TES systems provide the portals, or electronic gateways, through which soldiers, operating at different organizational levels, can participate simultaneously in supported training exercises. An architecture supporting *seamless* operations, in single or multiple modes simultaneously, is both feasible and practical by the end of this century. We envision entities capable of being both assembled and combined, as necessary, in order to meet tactical requirements. Efficient filtering allows thousands of participants to be linked and interact.

The Blueprint of the Battlefield guides and disciplines implementation. The Battlefield Operating Systems (BOS) enumerated in the Blueprint of the Battlefield support a paradigm for effective management of the simulation and support for AARs. The Blueprint provides a rational, hierarchical structure that ensures that all functions are considered both during operation of the simulation and when AARs are conducted.

ARCHITECTURAL COMPONENTS

The major components of the architecture described herein are knowledge-based software modules: a set of ACTORs, a set of AGENTs, and a set of Filters. These modules populate a realistic, three dimensional synthetic electronic battlefield. Collectively, the modules support both the simulation of ground combat and an AAR capability. The information required to support AARs is collected by the AGENTs.

Table 1 includes a description of the intelligent modules, their source of knowledge, and the respective role each assumes within the simulation.

MODULE	KNOWLEDGE SOURCE	ROLE OF THE MODULE
ACTOR	Computer Knowledge-Base	Interpret entity actions
Player Entities		
Manned Simulations	Human Intelligence	Execute tasks in a virtual environment
Instrumented Vehicles	Human Intelligence	Execute tasks in an actual environment
Intelligent Autonomous Entity (IAE)	Computer Knowledge-Base	Emulate task execution in a virtual environment
Gross Intelligent Autonomous Entity (GIAE)	Computer Knowledge-Base	Emulate systems in a virtual environment
AGENT	Computer Knowledge-Base	Assess entity actions
Filter	Computer Knowledge-Base	Manage Inter-network data flow

TABLE 1. Intelligent Components of System Level Architecture

The entities are intelligent; some have *computer knowledge-bases, others contain a* human knowledge source. Our proposed implementation consists of the software, databases, and computational tools needed to archive and document the outcomes of the *engagement-based combat actions; ensure* exercise control; and support the evaluation process. It recognizes the constant requirement to provide "near real time" analysis and feedback to exercise controllers, unit commanders and participants.

ACTORS

Our top level approach and architectural design, *features a set of computational objects* which we have labeled ACTORS. ACTORS enable the simulation to use entity level actions generated by: intelligent autonomous entities (IAEs and GIAEs); simulators (e.g. SIMNET,); *and TES devices* (e.g. MILES II, SAWE-RF, AGES II) to interface with one another and have an impact on the outcome of simulated engagements.

ACTORs are knowledge-based. Their purpose is to represent and interpret the behavioral actions of the three types of entities. They have no direct role in the battle and exist only to support the simulation, exchange *information, and enhance credibility. They* receive behavioral actions as input from the entities for which they are a cohort and have the ability to *decide* how to present those activities on the network to other ACTORs in the system. A *suitable architecture for the ACTORS will* allow them to be *tuned* to exercise conditions and modify their behavior over time through machine learning methods.

ACTORs provide the interface between the entities and the rest of the virtual battlefield. They have the ability to modify or degrade the actions and activities of the combat entities they represent. They also provide the capability to model the fog of war based on the "human factors" aspects of a unit's posture and capabilities.

The internal architecture of an ACTOR consists of intelligent software components, required knowledge-bases, algorithms, data sets, process control routines, etc., needed to perform this complex function. Their specific implementation will be developed in more detail during concept development. There are some crucial aspects of their design which can already be identified.

A software component which we call a "tactical equalizer" (analogous to the graphic equalizer in a stereo system) permits tuning the output of the entities prior to their behavior being input to the actual simulation. This tuning process depends on a model of the capabilities and status of the unit with which an ACTOR is affiliated. This guides an ACTOR in modification of the behavior of the subordinate entities of that unit and adds significant realism.

Sophisticated knowledge-bases assist the ACTOR in performing the tactical equalizing role. These knowledge bases are designed to provide an understanding of tactical methods, individual and crew performance factors, and even the effects of fatigue. Our approach uses a set of heuristic knowledge similar to an effects table.

Each ACTOR module must have the capability to make unrestricted distribution of information about the exercise to the controller and receive guidance regarding modifications to *exercise conditions. Requirements for voice* recognition and voice generation software could be algorithmically accommodated at the ACTOR interface.

Player Entities

ACTORs interpret the actions of three types of entities: *manned simulators,* instrumented weapons systems, and intelligent autonomous entities.

Manned simulator-entities are man-in-the-loop emulators of combat systems, such as those found in the Close Combat Tactical Trainer (CCTT) system. These are <u>naturally</u>, as opposed to <u>artificially</u>, "intelligent" because the behavior of a simulator entity results from the human reasoning process. The intellects of the crew members are the sources of knowledge and performance. Similar expertise must be embedded in the computer knowledge bases of the Intelligent Autonomous Entities (IAE).

Due to the "clean environment" in which simulators operate, as compared to the "dirty battlefield" simulated, the system must attenuate the actions of simulator entities. This is accomplished by the ACTOR assigned to "cohort" an entity which is responsible for passing information onto the battle network . A simulator exchanges information with an ACTOR using DIS standard Protocol Data Units (PDU). ACTORs not only receive but also comprehend PDUs and are able to, when necessary, modify a message before "broadcasting" it over the appropriate battle network.

Instrumented weapons systems entities are used to integrate subsistent TES. Data will be processed by an ACTOR and forwarded onto the main simulation network where the overall battle is portrayed. Whether this data can be extracted directly from existing range instrumentation systems or adding additional hardware is an implementation design decision beyond the scope of this paper. The ACTOR concept is critical for integrating the engagement-based data from instrumented weapons systems entities into the overall simulation.

The *Autonomous entities* are knowledge-based software modules which can be used as one-to-one replacements for simulator entities to populate the rest of the battlefield. We suggest the following two types: (1) intelligent autonomous entities (IAE) and (2) gross intelligent autonomous entities (GIAE). They could be based on the Semi-automated Forces (SAFOR) approach pioneered in SIMNET or an alternative approach such as the *one which will be implemented in CCTT.* Autonomous entities encapsulate the knowledge required to emulate the appropriate physical and tactical behavior at a system platform level. An IAE emulating an M1 tank, for example, will perform as if a fully trained crew were operating their weapons system. Attenuation by the ACTOR of the actions of an IAE emulating a tank is a major feature of our concept.

The internal software structure of an IAE will encapsulate the knowledge required to insure it acts with believable behavior. Its actions will replicate an actual manned system with sufficient realism to interact in virtual space with a participant in a manned simulator. This knowledge will include proper tactical and crew procedures and human performance heuristics.

GIAEs are a simplification of IAEs. They are used to populate the battlefield in areas of the simulation that do not include man-in-the-loop entities. It is likely that they will contain the same knowledge as IAEs but apply it in a less complex manner. Observation of the portions of the battlefield containing only GIAEs will reveal a less sophisticated image and more stylized behavior. This will not degrade the simulation's ability to produce realistic combat outcomes or to support consistent training at multiple echelons of command.

The long term goal is to replace all GIAEs with IAEs. This will occur when the requisite growth in computational power is cost effective enough to allow the entire simulated battlefield to be completely populated with IAEs. The ACTORs are the most technically advanced feature of our architecture. Further research, development, and testing are required to implement the ACTOR concept.

AGENTS

The second essential component of our architecture is a structured set of knowledge-based AGENTs. The structure is based on the Blueprint of the Battlefield. The Blueprint provides a hierarchical definition of combat functions at the tactical, operational, and strategic levels. This provides an appropriate baseline for analyzing and integrating combat, combat support, and combat service support functions.

At the lowest functional level, an AGENT encapsulates the knowledge to observe simulated combat and infer whether or not a player has adequately performed the function for which the AGENT is responsible. Making this type of assessment requires synthesis of a significant amount of information. Applications of Artificial Intelligence (AI) techniques such as advanced pattern recognition, concept formation, and case-based reasoning will require significant computational processing capability.

Functional level assessments will be passed to the next higher AGENT in the hierarchy. Individual AGENTs fuse and integrate input from subordinate AGENTs within their respective "chain of command." This results in an assessment of a unit's performance at that level. This process percolates up through the hierarchy of AGENTs — one of which is analogous to each Blueprint element — until an overall BOS-based performance assessment can be made.

FILTERS

Filters are the mechanism that allows the networking of technology-supported training without attempting to expose all elements of the simulation to all of the data generated at the entity level. Filters interface lower level networks on which smaller, higher resolution engagement-based battles are played with higher level networks which represent the command and control of these battles.

Filters provide the ability to manage and control data "traffic" both on and between networks. Filters encapsulate knowledge of what information to pass between the networks. On a case-by-case basis, they modify, simplify, or elaborate on messages prior to passing the information to higher, lower, or adjacent networks.

Filters are a necessary feature for allowing entity level combat adjudication under the constraints of near term affordable network and computational resources. At some future point, when computational and network capacities have larger limits, it is foreseeable that the conceptual architecture can collapse into one large network without any filtering modules. This is a long term goal.

AAR Support

We envision an AAR process that provides full support for the feedback and evaluation metrics essential to meet the Army's collective training needs. Computational support would include a suite of integrated computer hardware and state-of-the-art software tools configured to meet the specific needs of the controllers, analysts and support personnel who use them to plan and present the AARs.

Conceptually, the AAR support system generates products based on the assessments made by the AGENTs. Graphical displays and analytical tools will generate summary statistical data. Presentation tools support developing the high quality, multimedia products required.

The AAR process supports the analysis and synthesis of information before, during, and after each appropriate training exercise. We anticipate AARs taking place both during and upon completion of the training event. Replay of segments of battles and other combat events will be available in a visual display. Recreation of the battle is achieved using the stream of Protocol Data Units (PDU) that were generated during the exercise and stored in a relational database component.

SYSTEM LEVEL OVERVIEW

The overall functional relationships among the elements and components of the simulation and the principal information flows and feedback loops are shown below in Figure 1.

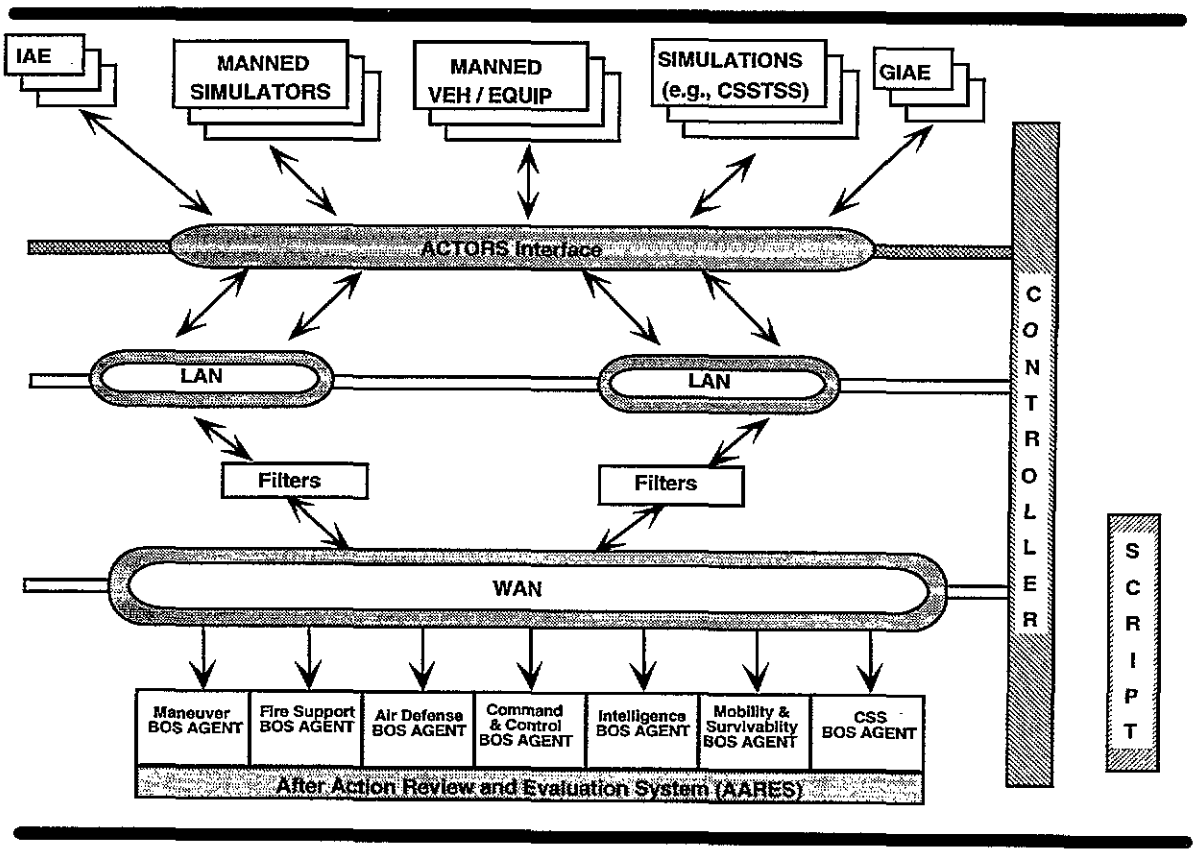

Figure 1. An Overview of the System

Manned simulators such as the Army's Close Combat Tactical Trainer (CCTT), the Air Force's F-16 trainer, or the Navy's Inport Trainer would interface using DIS standard protocols.

Manned vehicles and equipment are tactical equipment with embedded or appended electronic interfaces to the simulation using DIS protocols.

Instrumented weapons systems, such as those at the National Training Center (NTC) facilitates the integration of units conducting force-on-force training. A brigade training at NTC could be "connected" with the constructive synthetic battlefield and actions of individual vehicles and units would be replicated in the simulation in a realistic and credible manner.

Simulations include existing models that support the functionality of various BOS-focused aspects of the battlefield, such as intelligence, maneuver, or combat service support. They add a level of detail and robustness in their functional areas that can be used to "stimulate" the exercise and concurrently enhance training realism.

The ACTORs are knowledge-based software components that populate the *ACTORS interface.* They monitor, analyze, and tune behaviors of player entities.

Local Area Networks (LAN) connect ACTORs within a particular geographic area and through them conceptually link entity level players. The number of ACTORs on a LAN depends on the exercise design, the network traffic load, and the network capacity. Networks also link the controller and AAR support elements to the simulation.

Filters are knowledge-based software components that determine what information must be transmitted to, or received from, another network. Filters are transparent to training exercise participants and exist only to maximize the efficiency of the networked architecture. If network capacity was large enough, or if an exercise was small enough, Filters would not be needed.

Wide Area Networks (WAN) carry information that must be shared among LANs. Although the schematic shows only one WAN, several could be linked in a hierarchical structure to support larger exercises.

Exercise control is accomplished through human-computer interfaces. The controller element monitors the exercise to ensure that it runs "fairly," interjects circumstances required by the script, and modifies exercise parameters to ensure training objectives are satisfied. Controller workstations provide a "god's eye" view of the exercise and access to ACTORs which can carry out controller instructions. The control element has the capability to communicate with all other elements in the simulation.

The AAR function, supported by AGENTs that monitor network traffic, collect battle information and analyze that information, is designed with a dedicated AGENT for each element in the BOS hierarchy. Files are built concurrently with the progress of the exercise and are able to provide up-to-date summary information on demand throughout an exercise. At the end of an exercise, this systemic technical support helps a unit commander organize and present AARs.

THE SYNTHETIC THEATER OF WAR

The synthetic environment shown in Figure 2 summarizes how our architecture and approach is intended to replicate elements on a real world battlefield. The schematic portrays the echelonment of forces on both sides -- friendly and enemy -- with the portals (or gateways) they activate for access to the simulation. The synthetic electronic battlefield we advocate is bounded by the Script and Controller echelon to provide exercise monitoring and control for activities and conditions external to the system's capabilities.

A written script provides the necessary definition for each exercise. It is not a "master events list" but rather a delineation of the tactical conditions. It is provided in sufficient detail to describe the who, what, when, and why. It establishes and baselines external factors that will influence the conduct of the exercise.

A compelling feature of our conceptual architecture is the notional use of autonomous player entities. These can be Intelligent Autonomous Entities (IAE) which have the same fidelity as a manned-simulator (e.g., CCTT). IAE can be organized into units, under the control of ACTORs, to portray higher order behavior compatible with unit level operations. ACTORs are allocated to staff work stations where they represent the subordinate units of the headquarters. DIS protocols are the best near and long term methodology for integrating across the spectrum of TES systems. Our architecture also supports integration of existing constructive models, such as CSSTSS, CBS, BBS, and JANUS.

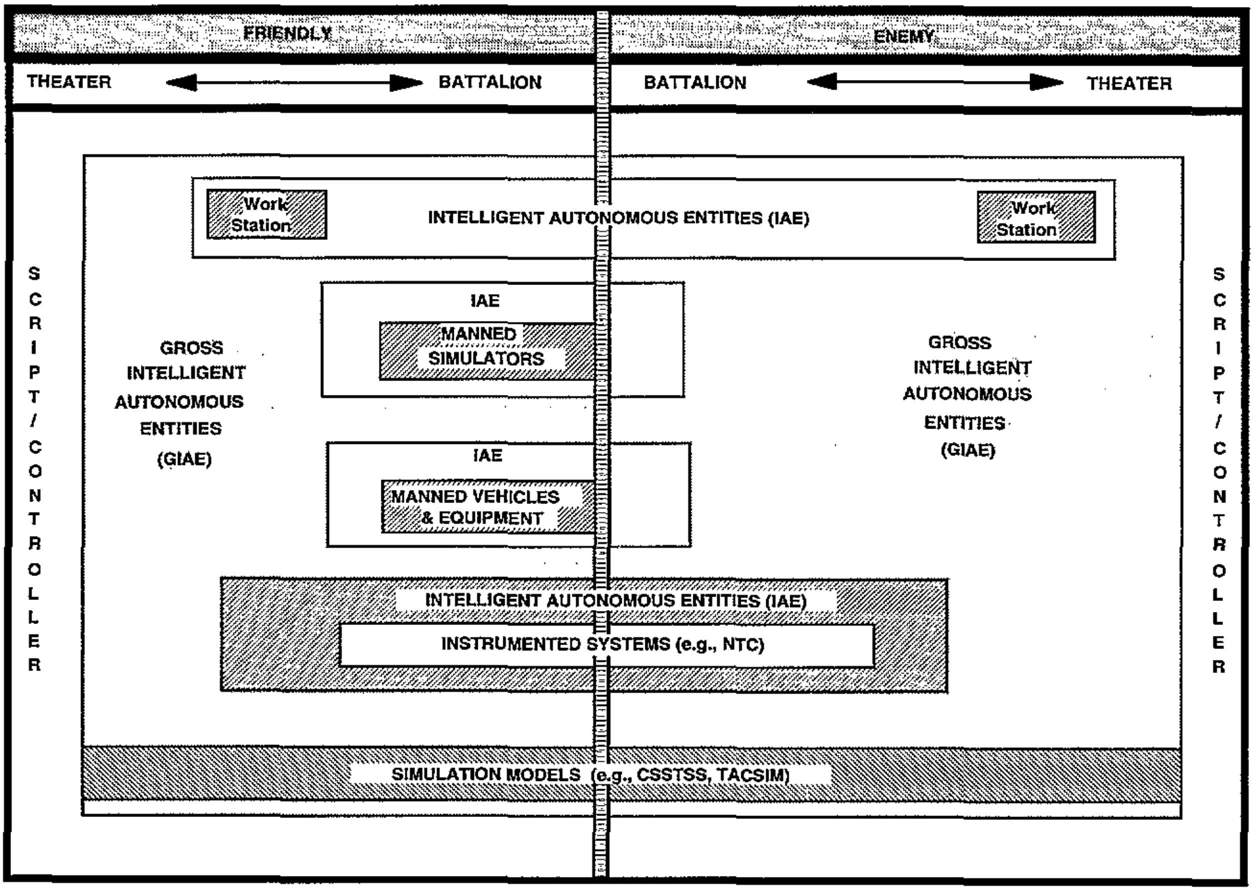

Figure 2. The Synthetic Theater of War

We have offered a conceptual architecture that incorporates many technologies which are evolving and maturing. This paper provides not only a conceptual architecture for integrating TES, but also proposed developmental work in important disciplines along several technical dimensions. We believe that the concepts presented here contribute to a foundation for such an effort. We fully appreciate that important research is ongoing and suggest that a focus along the lines of this paper will offer a high return on investment.

CONCLUSION

The architecture we propose cannot be built without prototyping supported by advanced systems and software engineering. Development cannot be managed as a monolithic system architecture and design which is assembled and then tested. The innovative technical pieces should be developed in parallel, tested using existing government programs and resources, and integrated after they successfully demonstrated.