Simulations During Operations

Major John R. Surdu, US Army
Lieutenant Colonel John M.D. Hill, US Army

ABSTRACT

This paper discusses ways in which simulations can support commanders and staffs in command posts of the future. The paper discusses uses for simulations in decision support. The importance of simulation technologies in the (military) operational context is described. The paper describes how simulations can be integrated into command posts of the future to assist in the conduct of planning, rehearsals, operations, and after action reviews. Finally the future of simulations in command posts of the future is discussed.

OVERVIEW OF THE IMPORTANCE OF SIMULATION TECHNOLOGIES

A large number of tasks performed by commanders and staffs can be facilitated during operations by the application of simulation technologies. Traditionally the focus of simulation in the Department of Defense (DoD) has been on analysis and training. Currently, there are no *operationally focused* simulations, built specifically for use during operations. Simulations designed to facilitate course of action (COA) development and analysis, rehearsal, and operations monitoring will enhance the effectiveness of staffs and commanders.

The Army Modeling and Simulation Office (AMSO) recognized the importance of simulation in command and control, and they identified five voids in current modeling and simulation technology for the Army After Next [1]. Three of them were automated decision aids, COA tools, and tactical information aids. The methodology proposed in this paper, originally described by Surdu and Pooch [2], intends to fill these three technology voids. The Defense Advanced Projects Research Agency (DARPA) has also recognized the importance of simulation in command and control activities. A DARPA concept briefing for the Command Post of the Future (CPOF) project provides a list of several tools that will provide input to the *Battlespace Reasoning Manager*, Among these are "Planning and Analysis Applications" and "3D Models and Simulations." In another part of the briefing, DARPA notes that "Battlespace Reasoning, Analysis, and Simulation” assist the commander’s perception and understanding of the battlespace. Finally, Bunker described one form of information to be gathered and protected during information operations as behavior information, the "three-dimensional simulation that will predict the behavior of at least physical objects, ultimately being able to ‘wargame’ courses of action.” [3] While there seems to be wide recognition of the eventual usefulness of simulations, there seems to be no proposed methodology for using them.

Even in this DARPA CPOF program, the program seems to be focusing on kludging existing, legacy simulations into the command post, rather than rethinking the manner in which simulations can assist commanders and staffs. [4]

Essentially the planning techniques and command and control processes used by the Army date from when US staffs were reorganized to integrate more easily with French staffs during World War One. Billions of dollars have been spent automating a process that is more than eighty years old. Despite all this money and the infusion of numerous automated systems into command posts, the technology that has had the most significant impact on the way we do business is the Post-It™ note.

Clausewitz, in his discussion of *friction,* and elsewhere in *On War*, talks about the *feel of the battlefield and* how great commanders have this ability to deal with friction and see through the fog of war. He also notes that this feel of the battlefield only comes with experience. Unfortunately this experience must be gained at the cost of human life. The U.S. Army developed a number of facilities (like the Combined Arm Training Centers (CTCs)) and training simulations (like CBS, BBS, JANUS, ModSAF, JTS, and WarSim) [5-7], which attempt to build this experience at relatively low cost. With severely constrained budgets and short-duration wars, the Army has limited means to identify those officers who have this feel of the battlefield. The simulation methodologies described in this paper provide a means of augmenting the commander’s and staff’s ability to feel the battlefield. Simulations explicitly designed to support operations vice training and analysis are referred to in this paper as *operationally focused*.

Operationally focused simulations are important because they leverage simulation technology to improve situational awareness, prevent information overload, and help the commander stay inside the enemy’s decision cycle. Large Army-wide efforts at improving situational awareness are underway. An operationally focused simulation provides the ability to look at an operation in the present, predict the future, and analyze what has occurred in the past. An operationally focused simulation provides more than just a view of the battle; it facilitates real-time analysis of the implications of friendly and enemy decisions. An operationally focused simulation, like a computer chess analyzer, simulates courses of action into the future and provides information to the commander and staff in a time efficient manner. This information helps the commander make the right decisions at the right time.

One way the use of an operationally focused simulation will help with situational awareness is by helping to prevent information overload. Bateman described the problem of the various digitized tools feeding the commander and his staff with more information than they can process [8]. Operationally focused simulations, as part of the larger system described below, draw the commander's attention to aspects of the current operation that may lead to failure. This helps the commander and staff to focus on important information and to screen out data that is unimportant to the decision-making process. Ultimately, this will help the commander keep his decision cycle faster than that of the enemy. [8]

Simulations Used in Decision Support Systems

Various research efforts have demonstrated the efficacy of simulations in decision support systems. Anecdotally, in 1995 the Australian Army used an American constructive simulation, Janus, to facilitate battle staff training. Two battalions were allowed to use Janus to conduct their planning and rehearsals, the third battalion was not. The battalion that did not use simulation failed to complete the mission, while the other two battalions accomplished the mission while taking significantly fewer casualties. Some recent examples of simulation for decision support are described below.

Baldwin, Eldabi, and Paul used simulation to support making healthcare management decisions [9]. Using simulation to analyze Adjuvant Breast Cancer (ABC) trials, the researchers were seeking to "determine the cost effectiveness of the various treatment combinations by comparing the additional resource use with the survival gains and quality of life effects." Baldwin, Eldabi, and Paul asserted that simulation's major contribution to this work was in identifying key variables early and assisting in treatment decisions.

Chokshi described work at AT&T Labs to simulate call centers [10]. This simulation was used to simulate and test new processes in the call centers or to test changes to existing processes. Chokshi asserted that the performance of these what-if analyses permitted the effective and accurate assessment of alternatives. In addition developers and call center managers better understood their information flows as a result of the simulation.

Mastaglio described simulation research designed to support decision-making by top-level decision makers rather than analysts [11]. Mastaglio's enterprise simulations were "used directly by decision-makers to observe the dynamics of the system as it responds to stimuli introduced by the user or a set of stochastic model inputs. We are notionally eliminating the analyst as a middleman; in actuality the role of the analyst changes from one of developing and running the simulation as a tool to support his or her work to having technical responsibility for developing and validating the models used." (This is more like the kinds of support systems needed by battlefield commanders, discussed later in the paper.) Importantly, Mastaglio notes that good mathematical techniques have been developed in many problem-solving domains; however, those techniques provide little visibility of the cause-and-effects relationships of the system. His simulations "directly support the decision-maker who is the end user, resulting in decision that are either easier to make or better informed."

Simulations have been effective at supporting decision-making in non-battlefield situations. The question remains about how simulations might support battlefield decision-making. Mastaglio's approach [11], simulations designed for use by the decision maker, is the right approach.

HOW SIMULATIONS CAN HELP THE COMMANDER ON THE BATTLEFIELD

Uses of Simulation During Operations

The conduct of military operations generally consists of planning, rehearsal, execution, and after action review. These are not distinct phases, since most of these actions occur concurrently and continuously. It is helpful, however, to treat each as a distinct and separable phase for purposes of discussion. Simulation technology can be applied in each of these phases.

Planning: During the planning phase, staffs develop courses of action (COAs). The current method, as outlined in ST 100-9, is an *ad hoc* process involving members of the staff discussing the various COAs [12]. Each phase of the operation is analyzed according to an *action-reaction-counteraction* war-gaming paradigm. This *ad hoc* method has numerous problems, some of which will be addressed in turn.

The effectiveness of the war-gaming process is highly dependent on the skill of the commander and the individual staff members. As discussed earlier, it is doubtful that a large percentage of members of a planning staff have the feel of the battlefield that Clausewitz described. There are a large number of time and space relationships that must be considered when going through the *action-reaction-counteraction* drill, and there are no tools to help staff members do this well.

The effectiveness of *action-reaction-counteraction* analysis of COAs is also dependent, to a large extent, on the interaction between the various members of the planning staff. The reality of our current personnel management policies is that a staff rarely has time to coalesce. Except for *lock ins* and *ramp-ups* for deployments to the large-scale training exercises, personnel rotations ensure that a fair portion of a planning staff will be new in the group[†].

Finally, the same officers who develop the COAs are the ones who analyze them for strengths and weaknesses and determine the criteria used in evaluate the COAs. Despite the best intentions, the planning staff carries with it personal biases as to which plan is better than others. This notion of the developers also being the evaluators can lead to *group think* [13], in which the decision developed by the group is unduly affected by a desire to conform. Given a bias toward one COA, it is easy to manipulate the criteria, weights on the various criteria, and resultant decision support matrix, to support the pre-ordained "best" COA. This bias may be manifested consciously or unconsciously, but it is clearly a risk associated with this *ad hoc* procedure. In the current planning process, once the formal decision briefing to the commander commences, no one in the staff is likely to openly oppose the staff's COA recommendation. Normally, only a forceful commander, assistant commander, or chief of staff can counter this groupthink. Dealing with straw-man plans is difficult. Currently a staff usually proposes two valid courses of action and one straw man, since the commander usually wants three choices; therefore, often the staff only considers two viable COAs. This is due in part to time constraints; there is usually insufficient time to adequately analyze three COAs. A staff, armed with a valid[‡] simulation with which to conduct COA analysis, will be able to adequately analyze more viable COAs -- and do a better job of analyzing the COAs -- than under the current, manual, *ad hoc* method. While the manual method was appropriate in an industrial age Army, it is no longer appropriate for an information-age Army in need of staying inside the enemy's decision cycle.

Operationally focused simulations provide powerful new tools to the planning process. As part of this process, the staff can enter enemy and friendly COAs and then simulate them to assess their effectiveness. The results of these simulations experiments can then be used as an evaluation criterion for the staff and commander to evaluate, and eventually choose, a course of action. The use of simulations will provide better feedback with higher granularity than current

---

[†] The purpose of this paper is not to attack current U.S. Army personnel management policies. This discussion is meant to describe one effect of current policies.

[‡] Here the use of "valid" is in the loose, non-technical sense. It may not even be practically possible to fully validate *any* combat simulation.

procedures. It will highlight problems, especially synchronization issues, within the proposed COAs. The end result is a timely, more accurate assessment of the effectiveness of the proposed COAs.

If time permits during military operations, the planning staff explores possible alternative actions during the operation (branches) and follow-on operations (sequels). Simulation of the plan makes it much easier for the commander and planning staff to explore more branches and sequels, in more detail, and with greater fidelity. There is little time to conduct analysis of branches and sequels in the current procedure. As a result, only the most likely, and maybe the most dangerous, branches and sequels can be explored -- and that analysis is often superficial. With the operationally focused simulation, these branches and sequels can be quickly simulated to provide feedback to the planners**.**

An additional advantage of a simulation-based process is that the commander can conduct experiments in parallel with his planning staff. Later in this paper, requirements for the operationally focused simulation are described. One of these is that it be capable of being operated by a single user on a single workstation. The commander can experiment with one or more COAs, conducting mission and COA analysis himself, while his planning staff works on the same ones or others.

Finally, having the operationally focused simulation at multiple echelons will speed the planning cycle. Once a Division headquarters has completed the plan, they could transmit the plan file electronically to each of the subordinate Brigades. The Brigade planning staff can then cull out entities that are unlikely to affect them, partially disaggregate the entities in the Division plan to be appropriate at brigade level, and begin to flesh out the Brigade plan. Once again, this aids in our forces staying inside the enemy’s decision cycle. If lower level headquarters need to spend less time recopying overlays and redrawing plans created at higher headquarters and more time conducting mission and COA analysis, the planning cycle of U.S. forces can be compressed without degrading the effectiveness of the process.

Rehearsal: Once a COA has been chosen, it is developed into a full plan and that plan is rehearsed. The simulation will facilitate this detailed rehearsal. Certain rehearsals (e.g., fire support, close air support NBC, and mobility/counter-mobility/survivability) are difficult to conduct over sand tables and maps. Clearly simulation would be an asset for these types of rehearsals as well as for the traditional, maneuver-centric rehearsal. The real purpose of a rehearsal is to identify synchronization issues and to make sue that everyone fully understands the plan. A simulation that can be halted at will could facilitate a rehearsal just as huge sand tables and map boards do today.

A significant advantage of a simulation-based rehearsal is that it could potentially be distributed geographically. With a number of distributed graphical interfaces to the same simulation, the commander and operations officer could control the execution of the playback of the plan while the subordinate commanders and the staff members watched at remote locations. The rehearsal could be conducted without all the key players getting within grenade burst radius of each other.

Execution: After the plan has been chosen, refined, and rehearsed, and the operation commences, the proposed methodology can be used to monitor the progress of the simulated plan and the real operation. Intelligent software agents, referred to as Operations Monitors, compare the progress of the real plan against the simulation of that plan. When significant deviations from the plan occur, the Operations Monitors launch tools that explore the impact of these deviations. Finally the commander is advised if the Operations Monitors determine that the success of the plan is in jeopardy. The remainder of this paper focuses on the use of simulation during the execution of an operation.

After Action Review: After action reviews are important - even during a war. The course of the real operation could be recorded and archived for later review. As time permits, the operation can be "played back" for the key leaders. This would give the commanders and staffs the opportunity to identify synchronization problems or other errors that lead to the final outcome of the operation. During training exercises there are often observer/controllers to dispassionately observe the conduct of planning and operations and provide feedback afterwards. This capability is unlikely to be available during real operations. The use of an operationally focused simulation could help fill this void.

Attributes of Operationally Focused Simulations

Training simulations have been used to facilitate course of action development and analysis in isolated incidents and experiments [1, 3, 4, 8, 14-17]. The worth of a “scientific” method of creating and assessing the value of courses of action during planning is well recognized [1, 3, 4, 8, 15-17]; however, no simulation focused solely on this task has been developed. The military community has developed a large number of simulations for training and analysis, such as the Corps Battle Simulation (CBS), Brigade/Battalion Battle Simulation (BBS), JANUS, and Modular Semi-Automated Forces (ModSAF). While many of these are excellent products, most are unsuitable for use during an operation for a number of reasons, including large pre-exercise preparation, specialized hardware, large numbers of required participants, and large numbers of required workstations.

Surdu, Haines, and Pooch [18] enumerated the desirable capabilities for an operationally focused simulation to be used during operations, and they include:

- The simulation must be runable from a single workstation by a single user during ongoing operations. Operations centers are crowded, bandwidth is limited, and contractor support is limited. A simulation that cannot be run by a single person on a single workstation would represent a significant burden to an already-busy staff.
- The simulation must be runable on low-cost, open systems, multi-platform environments. While the methodology proposed in this paper concentrates on military applications, an operationally focused simulation is also well-suited far emergency management disaster relief, fighting forest fires, etc. Often the local police and fire units tasked with handling these types of emergencies only have low-end hardware.
- The simulation most be capable of running in multiples of wall-clock time (i.e., real time and much faster than real time). The simulation must be capable of running very fast during planning and rehearsals and running in near real time during operations.
- The simulation must be able to receive and answer queries from external agents. This capability allows external software agents to use the operationally focused simulation to help monitor the current, ongoing operation for deviations from the plan.
- If needed, multiple simulations should be capable of operating together. While there is no immediate need for multiple, cooperating simulations, this simulation should be compliant with known, accepted protocols so that this capability is not precluded if it is needed.
- The simulation should be based on an aggregate-level model. In military operations, the basic rule of thumb is that commanders fight with units two levels below them; brigade commanders fight with companies; battalion commanders fight with platoons; etc. This level of abstraction is sufficient for the users of the simulation; therefore, in a desire to be able to run much faster than real time, the simulation need not be entity-level.

Surdu, Haines, and Pooch described a prototype simulation implementation that meets these requirements. In addition, their use of VMAP 2^{TM} [19] terrain database addresses the issue of exercise setup time and cost. This methodology does not rely on the simulation developed by Surdu, Haines, and Pooch; any simulation that meets these requirements could support this proposed methodology for using simulations during operations.

Blais and Garrabrants echoed many of these desirable characteristics of operationally focused simulations [14]. They described an exercise in which an aggregate-level Marine Corps simulation was used to support mission planning in “a major staff exercise.” Their list of lessons learned from this experiment is similar to that proposed by Surdu, Haines, and Pooch. Blais and Garrabrants asserted that high levels of aggregation were necessary in order to make the simulation usable by a single operator on a single workstation. The requirement that the simulation be capable of running much faster than real time was confirmed. They also discussed the interaction of the planning staff with the simulation run, and their description seems very rehearsal-like. Other issues raised by Blais and Garrabrants not discussed by Surdu, Haines, and Pooch were rapid scenario design and flexible, pre-defined measure of effectiveness by which to judge a plan.

In addition, it is essential that an operationally focused simulation is capable of interfacing directly with Army command and control systems. This capability has been kludged into a number of system and has been demonstrated in several exercises. For instance, the Corps Battlefield Simulation (CBS) was linked to the Army Battle Command System (ABCS) as part of Army Experiment 4 in 1998 [20] and again for Prairie Warrior 98 [21]. The fact that this integration had to be done more than once is evidence of the *ad hoc* nature of this linkage. The need for simulation as part of ABCS was recognized in the Capstone Requirements Document for ABCS [15]. To be useful in the operational environment, a simulation must be designed to interface with real command and control systems.

One government-developed simulation that does not currently have all the properties described but which might be appropriately modified to do so is ModSAF [22]. While ModSAF and its proposed follow-on product, OneSAF, are entity-level simulations, their Distributed Interactive Simulation (DIS) and Persistent Object Protocol (POP) protocols could be wrapped in an "agent" to manage the receipt of subscriptions and queries and their answers. ModSAF is not inherently cross-platform, but it has been ported to a variety of platforms. The GUI (which communicates with the simulation via UDP/IP messages) might be rewritten in a language like Tcl/Tk or Java to provide this capability.

HOW SIMULATION TECHNOLOGIES RELATE TO COMMAND POSTS OF THE FUTURE

Work with On-Line Simulations

Davis has been researching the use of simulations during the operation of manufacturing systems [16, 23-25]. Andersson and Olsson proposed a very similar use of simulation during the operation of a customer order driven assembly line [26]. The use of simulation during military operations was echoed recently by Ferren: "When much-faster-than-real-time simulation becomes practical, the warfighter would have a predictive tool available, online in the field, and integral to their weapons, mobility, and communication systems." [27]

Davis distinguished between on-line planning and off-line planning. In off-line planning, the goal of the analyst is to predict the performance of some system given a set of design parameters (inputs and/or initial conditions). The analyst uses a validated simulation to experiment with different values for the design parameters to determine the best configuration of the system. Then the analyst computes statistical estimates of one or more performance measures[16, 28]. All of the analysis is done before the real system is configured; it is off-line. In most non-trivial applications, there are a large number of design parameters and performance measures. Conducting detailed analyses of multiple values of numerous design parameters can quickly become intractable. There are a number of techniques designed to decrease the volume of the search space [29]; however, "determining the optimum set of values is not a trivial task, and optimality often represents a property that simply cannot be established or verified." [16] Due to the coarse nature of off-line analysis, Davis proposed on-line simulation as a method of improving the performance of real-time systems [23, 24].

Davis has been pioneering on-line simulation as a technique to facilitate flexible manufacturing systems (FMS). As in the command and control domain, which is the focus of this dissertation, an FMS must specify a control policy in addition to state variables and state transitions. This control policy is selected from a number of possible policies, and it can be thought of as a possible course of action. Some of the inputs to a simulation are exogenous, but others are endogenous. These endogenous inputs are generated by the control policy. In open-loop systems, the control policy is specified *a priori*. In closed loop systems, the endogenous inputs are determined by the control policy *and the current state of the system* [16].

Control policies are analogous to courses of action (COAs) in military operations (described below). Once the COA is chosen (with the help of off-line simulations), the selected

COA can be thought of as the control policy for the upcoming operation. Davis asserted that the operating characteristics of FMS change constantly with time. Similarly the shape of a battlefield changes constantly with time.

Davis also discussed a concept called *autovalidation.* Autovalidation is a process that compares the result of the on-line simulation over time against the real operation of the FMS and updates to simulation to improve its accuracy [16]. Davis admitted that there are no theoretically sound methods of performing autovalidation and asserted that this is an open research issue. Surdu and Pooch discussed the need for such a feedback mechanism and one proposed approach [30].

Ideally in a proactive on-line simulation environment, the system should be constantly simulating each of the possible control policies to determine which one the real system should adopt. Clearly these simulation experiments must be generated and conducted much faster than real time in order for such a system to be useful. It takes some amount of time, *t*, to launch each of the *N* simulations (where *N* is the number of control policies to be evaluated). Between the time that experiment *n* is launched and *n+1* is launched, the state of the real system has changed. It is desirable that experiment *n+1* consider all the available information. Since *t* can never be zero, all of the *N* experiments may have different initial conditions. This places the comparison of their results on a shaky statistical foundation [16].

A research issue described by Collier [31] is the automated generation of courses of action for the system to consider. Fiebig and Hayes [32] and Fiebig, Hayes, and Schlabach [33] described a system for generating courses of action in the military domain. Their system generated many courses of action using genetic algorithms. In each generation, the courses of action were evaluated by a coarse, low-fidelity simulation. They also used a scheme to ensure that new courses of action generated through crossover and mutation were in fact different than existing courses of action.

There is some controversy over how many iterations of a simulation are necessary in order to reach useful conclusions. Davis asserted that thousands of runs of an on-line simulation are necessary [16]. On the other hand, Law and Kelton asserted that ten to fifteen repetitions give sufficiently reasonable confidence intervals and that increased numbers of iterations gives a false sense of accuracy not justifiable in most simulations [34]. In Davis' prototype on-line simulation systems, he maintained a running average of the last 50, 100, 250, 500, 1000, and 2000 most recent trials. Ideally, the confidence interval of the larger sample sizes should be contained in the confidence intervals of the smaller sample sizes, but this will not be true if the system is in a transient mode (i.e., not in steady state). As the sample size is increased, when the confidence interval of a larger sample size was not contained in that of a smaller sample size, the smaller sample size was used to estimate the measure of performance. While Davis admitted this was an *ad hoc* technique, he has built a number of prototype systems that demonstrate the success of the approach [23, 24, 35].

Gilmer and Sullivan have proposed a technology they call multi-trajectory simulation [36-38]. This technique is used to explore multiple decisions in parallel. When a decision point is reached, the simulation is "split," and each decision is simulated until the next decision point is reached. The simulation is split again. The results of these multiple simulation trajectories are then rolled back and the results presented statistically. Based on these results, the decision maker can choose a course of action at the point of the first split.

Operationally Focused Simulation

Surdu, et al., developed the *OpSim* (short for operationally-focused simulation) system to examine the feasibility of using operationally focused simulation, software agents, and various artificial intelligence technologies in the operational environment [39]. The idea is to conduct operations monitoring, predict outcomes, determine the significance of any deviations of the actual operation from the planned operation, and inform the decision-maker when there is a significantly different projected outcome from what was initially planned.

One of the premises of that work is that it is inappropriate to apply training simulations to real-time operational planning and execution. Rather, a new generation of simulations specifically tailored to operations is required. Planning systems could then launch software agents that make use of this new class of simulations to make predictions about future states of the operation. These software agents operate in a dynamic hierarchy that allows each agent to look at just a narrowly focused aspect of the operation. The findings of these agents are combined and analyzed through the use of fuzzy logic and expert systems in order to determine whether the plan is in jeopardy.

Anticipatory Planning

For quite some time the military approach to planning has followed a strict process. First, an analysis of the enemy's capabilities and intentions is used to decide on a few enemy courses of actions (COAs). Against these enemy COAs, several friendly COAs are produced and analyzed. The commander then chooses the friendly COA that will be fully planned. The result is a detailed plan based exclusively on information known at the time of planning and predictions about what will happen during the operation. Unfortunately, most plans never survive the first hour of execution and the commanders, aided by their planners, transition into a reactive planning mode.

With the advent of increased situational awareness, however, the planners ought to be able to better anticipate the flow of the battle. This anticipation can only occur if a different planning paradigm is used that treats planning and execution as a continuous process. Brigadier General (retired) Huba Wass de Czege has proposed an approach that supposes planners can continuously feed battle information into a simultaneous planning and execution process [40]. His anticipatory planning and adaptive execution approach will be a necessity in the dynamic and information-rich battlefield of the future. It will enable U.S. forces to achieve the option dominance that allows them to identify future favorable options early enough to shape the battle in support of those options.

Hill, et al., designed and implemented the *Anticipatory Planning Support System* (*APSS*) to investigate the anticipatory planning approach [41]. Human planners use this prototype system to define several initial reasonable branches to the plan. Once the operation begins, *Actual State* information from the *World View* is used to continuously produce new branches to the plan. Simultaneously, invalid branches are pruned away, allowing the planning effort to focus ahead of the more likely branches.

THE FUTURE FOR THE COMMANDER AND COMMAND POSTS OF THE FUTURE

Building Operationally Focused Simulation

A number of technical challenges remain in the construction of operationally focused simulations. The representation of the plan space, one that includes many possible, future courses of action, is difficult. Experiments are ongoing at the United States Military Academy, West Point, to determine the feasibility and efficacy of two technologies: using a database as the internal state representation and the notion of concept-based simulation.

The idea of the OpSim [39] and Anticipatory Planning Support System [41], both described earlier, require that numerous software agents have asynchronous access to the current and future states of the plan. For this reason, it has been postulated that it would be more effective to have the simulation(s) operate on a database, rather than having each one maintain proprietary representation schemes. This will allow the various software agents to query the state of the plan at any time. The use of a commercial database management system could then be used to ensure the integrity of the database through numerous updates and queries.

In order to facilitate communications with the human decision maker, *Concept-based Simulation* has been proposed. Rather than the human decision maker having to stipulate in fine detail the movements and actions of the various units and subunits in the plan/simulation, it would be easier if the human could use concepts instead. This would be like drawing large wide arrows on the map to indicate the movement of several battalions, rather than drawing the routes of each of the battalions, specifying intermediate locations, etc. The use of concepts, rather than tasks, will also facilitate the computer describing the various courses of action available at any give decision point.

Allowing the Simulation Entities to Get Smarter

In order to facilitate rapid simulation of courses of action during operations, simulation entities will have to become more intelligent. Significant work has been done through the U.S. Army's Simulation, Training, and Instrumentation Command (STRICOM), and simulations, such as ModSAF and WARSIM, in which entities display limited intelligence, have been developed [6, 22]. In order to make the simulations better predictors of the outcomes of future engagements, the entities in the simulations should become better simulators of the behaviors of the real units they represent. Over time, the entity that represents a particular friendly battalion should fight and react in a way consistent with the real battalions past performance. In this way, when the commander sends two battalions to accomplish a mission, he will know that the entities in the simulation will fight like the real battalions – and the real battalions are likely to perform in the real battle as the entities did in the simulated battle. As the intelligence community begins to build a picture of how enemy units react to certain situations, it may be desirable for the simulation entities to react in that way – for at least some of the simulation runs. In other simulation runs, it might be desirable to let the simulation entities choose the best option for them, whether or not it is consistent with past behavior.

Modeling the Commander

There has been quite a bit of work in user modeling. Recently, Corker showed how human performance modeling of air traffic controllers helped in the redesign of air traffic control systems [42]. Maes described the use of software agents to model users in an attempt to create intelligent assistants [43-45]. Ruvini and Dony used agents to learn and repeat tasks performed by humans [46]. Each commander has a different way of making decisions. Different commanders want different information presented in different ways. Over time, the decision support system should model the commander (or any habitual staff user) in order to present information in the best way for the user. As commanders and staff officers move from assignment to assignment, they should be able to take their “profile” with them. Certainly officers in new assignments will need different information; however, the system could start learning the officers’ preferences from the officers’ profiles, rather than starting with no knowledge.

CONCLUSION

This paper proposed a number of ways in which simulations can aid decision makers in command posts of the future. Simulations can be used in all phases of an operations: planning, rehearsal, execution, and after action review. It is important that simulation not be used merely to automate old processes but instead facilitate revolutionary, new processes. In addition, existing and developing technologies to facilitate these uses of simulation were discussed. While many promising technologies have been demonstrated, it remains as future work to develop a fully functional prototype system.

REFERENCES

[1] P. J. Delany, "Army Modeling and Simulation Office Policy and Technology Working Group video teleconference," personal communication, 28 October 1998. Captain, U.S. Army, Army Modeling and Simulation Office

[2] J. R. Surdu and U. W. Pooch, "A Methodology for Applying Simulation Technologies in the Mission Operational Environment," in *Proc. IEEE Information Technology Conference*, Syracuse, NY, 1998.

[3] R. J. Bunker, "Information Operations and the Conduct of Land Warfare," *Military Review*, vol. 98, pp. 4-17, 1998.

[4] D. Gunning, "Command Post of the Future," at http://www.mole.dc.isx.com/cpof, 15 October 1998.

[5] D. Kang and R. J. Roland, "Military Simulation," in *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, J. Banks, Ed. New York: John Wiley & Sons, 1998, pp. 645-658.

[6] M. Rogers, "Warfighter's Simulation," at http://www.stricom.army.mil/PRODUCTS/WARSIM, March 1999.

[7] J. Balash, "Janus," at http://www.stricom/army.mil/PRODUCTS/JANUS, March 1999.

[8] R. L. Bateman, "Avoiding Information Overload," *Military Review*, vol. 98, pp. 53-58, 1998.

[9] L. P. Baldwin, T. A. Eldabi, and R. J. Paul, "Simulation Modeling as an Aid to Decision-Making in Healthcare Management: The Adjuvant Breast Cancer (ABC) Trial," in *Proc. 1999 Winter Simulation Conference*, 1999.

[10] R. Chokshi, "Decision Support for Call Center Management Using Simulation," in *Proc. 1999 Winter Simulation Conference*, 1999.

[11] T. W. Mastaglio, "Enterprise Simulations: Theoretical Foundations and a Pratcial Perspective," in *Proc. 1999 Winter Simulation Conference*, 1999.

[12] U. S. Army, *ST 100-9: Techniques and Procedures for Tactical Decisionmaking*. Fort Leavenworth, KS: U.S. Army Command and General Staff College, 1991.

[13] P. Wyden, *Bay of Pigs*. New York: Simon and Schuster, 1979.

[14] C. L. Blais and W. M. Garrabrants, "Simulation in Support of Mission Planning," in *Proc. Advanced Simulation Technology Conference: Military, Government, and Aerospace*, San Diego, CA, 1999.

[15] J. E. Bessler, "Army Battle Command System (ABCS) Capstone Requirements Document (CRD)," TPIO-ABCS, Ft. Leavenworth, KS Revision 1.0, 10 February 1998.

[16] W. J. Davis, "On-Line Simulation: Need and Evolving Research Requirements," in *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, J. Banks, Ed. New York: John Wiley and Sons, Inc., 1998, pp. 465-516.

[17] P. A. Fishwick, G. Kim, and J. J. Lee, "Improved Decision Making Through Simulation Based Planning," Department of Computer and Information Science and Engineering, University of Florida, Gainesville, FL, Tech. Report 94-14, February 1994.

[18] J. R. Surdu, G. D. Haines, and U. W. Pooch, "OpSim: a Purpose-built Distributed Simulation for the Mission Operational Environment," in *Proc. International Conference on Web-Based Modeling and Simulation*, San Francisco, CA, 1999.

[19] Department of Defense, *MIL-V-89032: Military Specification: Vector Smart Map (VMap) Level 2 (Draft)*. Fairfax, VA: National Imagery and Mapping Agency, 1996.

[20] J. M. Brennan, "The Army Experiment 4 (AE4) Simulation to Army Battle Command System (ABCS) Experiments," STRICOM, Orlando, FL 98-9-1, September 1998.

[21] B. Brown, "RTM Integration Phase I Test Plan," National Simulation Center, Ft. Leavenworth, KS Coordinating Draft, February 1998.

[22] S. Rodio, "ModSAF," at http://www.stricom.army.mil/STRICOM/E-DIR/ES/MODSAF, March 1999.

[23] W. J. Davis, "Developing an Intelligent Controller for Integrated Manufacturing Resource Planning," University of Illinois at Urbana-Champaign, Urbana, IL Draft, October 1998.

[24] W. J. Davis, "A Framework for the Distributed Intelligent Control of Advanced Manufacturing Systems," University of Illinois at Urbana-Champaign, Urban, IL Draft, October 1998.

[25] W. J. Davis, X. Chen, A. Brook, and F. A. Awad, "Implementing On-line Simulation with the World Wide Web," *Simulation*, vol. 73, pp. 40 - 53, 1998.

[26] M. Andersson and G. Olsson, "A Simulation Based Decision Support Approach for Operational Capacity Planning in a Customer Order Driven Assembly Line," in *Proc. Winter Simulation Conference*, Washington, DC, 1998.

[27] B. Ferren, "Some Brief Observations on the Future of Army Simulation," *Army RD&A*, vol. 99, pp. 31-37, 1999.

[28] S. Vincent, "Input Data Analysis," in *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, J. Banks, Ed. New York: John Wiley & Sons, 1998, pp. 55-92.

[29] S. Andradottir, "Simulation Optimization," in *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, J. Banks, Ed. New York: John Wiley & Sons, 1998, pp. 307-333.

[30] J. R. Surdu and U. W. Pooch, "Connecting the Operational Environment to Simulation," in *Proc. Advanced Simulation Technology Conference: Military, Government, and Aerospace Simulation*, San Diego, CA, 1999.

[31] K. S. Collier, "Automated Decision Support Systems Enabled by Models and Simulations -- A "Leap-ahead" Technology Recommendation for the US Army After Next Time Frame (2020-2025)," in *Proc. Military, Government and Aerospace 1999*, San Diego, CA, 1999.

[32] C. B. Fiebig and C. C. Hayes, "DAISY: A Design Methodology for Experience-Centered Planning Support Systems," in *Proc. IEEE International Conference on Systems, Man, and Cybernetics*, San Diego, CA, 1998.

[33] C. C. Fiebig, C. C. Hayes, and J. Schlabach, "Human-Computer Interaction Issues in a Battlefield Reasoning System," in *Proc. IEEE International Conference on Systems, Man, and Cybernetics*, Orlando, FL, 1997.

[34] A. M. Law and W. D. Kelton, *Simulation Modeling & Analysis*, 2 ed. New York: McGraw-Hill, Inc., 1991.

[35] W. J. Davis, "On-Line Simulation for Torpedo Avoidance," at http://www-msl.ge.uiuc.edu/~brook/boat, November 1998.

[36] J. B. Gilmer and F. J. Sullivan, "Alternative Implementations of Multitrajectory Simulation," in *Proc. 1998 Winter Simulation Conference*, 1998.

[37] J. B. Gilmer and F. J. Sullivan, "Multitrajectory Simulation Performance for Varying Scenario Sizes," in *Proc. 1999 Winter Simulation Conference*, 1999.

[38] J. B. Gilmer and F. J. Sullivan, "Recursive Simulation to Aid Models of Decisionmaking," in *Proc. Winter Simulation Conference*, Orlando, FL, 2000.

[39] J. R. Surdu and U. W. Pooch, "Simulation Technologies in the Mission Operational Environment," *Simulation*, vol. 74, pp. 138 - 160, 2000.

[40] H. Wasz de Czega, "Discussion of Anticipatory Planning," personal communication, February 1999.

[41] J. M. D. Hill and J. R. Surdu, "Agent Cooperation in Dynamic Plan Building," in *Proc. 5th World Multi-Conference on Systemics, Cybernetics and Informatics (SCI 2001)*, Orlando, FL, 2001.

[42] K. M. Corker, "Human Performance Simulation in the Analysis of Advanced Air Traffic Management," in *Proc. 1999 Winter Simulation Conference*, 1999.

[43] P. Maes, "Agents That Reduce Work and Information Overload," *Communications of the ACM*, vol. 37, pp. 31-41, 1994.

[44] P. Maes, "Situated Agents Can Have Goals," in *Designing Autonomous Agents: Theory and Practice from Biology to Engineering and Back*, P. Maes, Ed. Cambridge, MA: MIT Press, 1994, pp. 49-70.

[45] P. Maes, "Artificial Life Meets Entertainment: Lifelike Autonomous Agents," *Communications of the ACM*, vol. 38, pp. 108-114, 1995.

[46] J. Ruvini and C. Dony, "APE: Learning User's Habits to Automate Repetitive Tasks," in *Proc. 2000 International Conference on Intelligent User Interfaces*, New Orleans, LA, 2000.