# Simulations During Operations

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**ABSTRACT**

This paper proposes a methodology for applying simulation technology to the command and control of operations, focusing on the use of intelligent agents to provide feedback and advice. This methodology is designed to leverage simulation technologies to improve situational awareness, prevent information overload, and help the commander stay inside the enemy's decision cycle. Intelligent software agents monitor the course of the real operation and compare it with the near-real-time simulation of that operation. When these agents detect significant differences between the planned operation and the real operation, they explore the discrepancies to determine the impact on the desired outcome of the operation. These agents can launch additional simulations or other tools to make this determination. It is the job of these agents to highlight significant differences between the plan and the operation. In cases in which the success of the plan is threatened, the agents advise the commander.

**INTRODUCTION**

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]. These include 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 portion of the briefing, DARPA notes that "Battlespace Reasoning, Analysis, and Simulation" assist the commander's perception and understanding of the battlespace[3]. 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."[4] While there seems to be wide recognition of the eventual usefulness of simulation, there seems to be no proposed methodology for using them.

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[5]. 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 Army developed a number of facilities (like the Combined Arms Training Centers (CTCs)) and training simulations (like CBS, BBS, JANUS, ModSAF, JTS, and WarSim)[6], which attempt to build this experience at relatively low cost. With severely constrained budgets and one-hundred-hour wars, the Army has limited means to identify those officers who have this feel of the battlefield. The simulation methodology described in this paper provides a means of augmenting the commander and staff's ability to feel the battlefield.

Surdu, Haines, and Pooch[7] discussed the uses of simulation for COA development and analysis and for conducting rehearsals. This paper elaborates these uses for simulation, and it discusses the use of simulation during an ongoing operation as a tool to help the commander and his staff track the progress of the operation and anticipate problems. This paper proposes a methodology in which simulation technologies support commanders and staffs during actual operations. Finally this paper discusses the technical issues and operational implications arising from this methodology.

## WHY OPERATIONAL SIMULATIONS ARE IMPORTANT

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, or 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 he 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.[9]

## 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 an 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[10]. Each phase of the operation is analyzed according to *an action-reaction-counteraction* paradigm. This *ad hoc* method has numerous problems, some of which will be addressed in turn.

The effectiveness of the wargaming 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 an *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 to the group[11].

Finally, the same officers who develop the COAs are the ones who analyze them for strengths and weaknesses and determine the criteria used to 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*[12], 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, this group think can be countered only by a forceful commander, assistant commander, or chief of staff.

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 simulation 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 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.

It is true that the use of a simulation is not a panacea. The parameters used to initialize the simulation can be biased. The attrition model can be inaccurate[13]. The staff can still propose "straw man" plans. The adaptive nature of the proposed system will help ensure that over time the simulation's parameters will tend toward "reality." Given these potential pitfalls, however, an operationally-focused simulation would still provide a more accurate, rigorous assessment of COAs than the current, manual process.

The problem of straw-man plans is more difficult. Currently a staff usually proposes two valid courses of action and one "throw away," since the commander usually wants three choices; therefore, the staff only considers two viable COAs. This is due to time constraints; there is usually insufficient time to adequately analyze three COAs. A staff, armed with a valid[14] 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.

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.

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.

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 sure that everyone fully understands the plan. A simulation that can be halted at will could facilitate a rehearsal just as large 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 other 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.

## UNSUITABILITY OF TRAINING SIMULATIONS

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[15] 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 for 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 must 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™ [16]terrain databases 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.

One government-developed simulation that does not currently have all the properties described but which might be appropriately modified to do so is ModSAF[17]. 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, and 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.

## PROPOSED METHODOLOGY

The proposed methodology, described more fully by Surdu and Pooch[18], is summarized in Figure 1. The methodology involves the interactions of a number of packages and tools, including the operationally-focused simulation (OpSim) discussed in the previous section of this paper, intelligent agents, combat attrition models, path-planning algorithms, etc

*Operations Monitors (OMs):* The OMs are the heart of this methodology. They perform two important functions. They take information from the real world (WorldView, described below) and update the state of entities in the simulated world (OpSim, also described below) seamlessly re-synchronizing the simulation to the real world. More importantly, they monitor the progress of the simulation and compare it to that of the real operation. When they discover significant deviations between the real world and the simulated world, they launch one of a number of tools to explore the ramifications of these deviations.

It is important to note that OMs do not take actions with regard to the plan; rather, they explore the ramifications of differences between the real operation and the planned operation. The job of OMs is to help human commanders manage information[19]. OMs should be

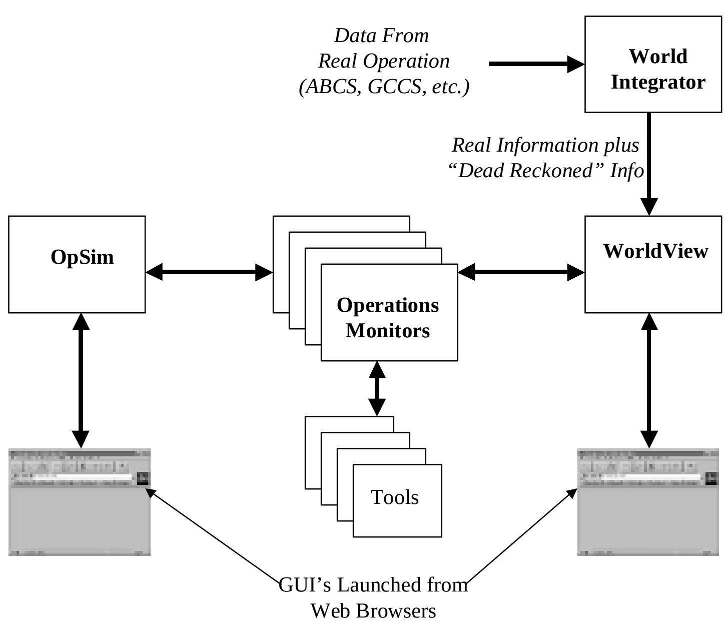


**Figure 1: Proposed Methodology**

considered part of the team, not a replacement for commanders[20]. OMs make some judgement about the seriousness of any differences and issue advisories to the commanders.

Also, it is important to note that OMs must be proactive. It is not sufficient, for example, for an OM to inform commanders that some planning timetable has been broken. In this way the OMs do not provide a bunch of data, they analyze and synthesize data to provide relevant information in a timely manner. The OMs must look ahead and inform commanders in advance if some goal is unlikely to be met. For instance, if some future even requires three of five preconditions be met, the OM must determine whether these preconditions are likely and assess the probability that the eventual goal can be accomplished. When this probability becomes "low enough" the OM must inform the commander.

*WorldView:* The WorldView module is a representation of the real operation. In order to make the job of the OMs easier, the representation of the state of the real operation and the simulated plan should be as similar as possible. WorldView receives information about the state of the real operation through a series of APIs. WorldView then transforms this information into a form that the OMs can easily interpret.

*WorldIntegrator:* WorldIntegrator has the onerous task of monitoring the real operation, processing that information, and passing it to WorldView. In some systems, such as the Global Command and Control System (GCCS) or Army Battle Command System (ABCS), this may involve querying a database. In other system, this may require "eavesdropping" on the network. The reason for this intermediate step is that in real operations, reports on some entities may be intermittent. It is the job of WorldIntegrator to "dead reckon" these intermittent reports and pass them into WorldView. Clearly, when an entity has been "dead reckoned," this must be reflected in the information that WorldView gives to the OMs.

The issue of WorldIntegrator and WorldView involves sensor, data, and information fusion. WorldIntegrator must determine when an entity has been unconfirmed long enough that its actions must be dead reckoned. When some sensor reports a similar unit, WorldIntegrator must determine whether this is merely the lost unit reappearing or a different unit. These and other issues regarding sensor, data, and information fusion are open research issues.

Note that normally OMs do not make tactical decisions. The purpose of an OM is to explore differences and report findings. The autonomy of the OM lies in its ability to decide when and if to launch other tools. As noted in the DARPA CPoF concept, battlefield visualization tools should be decision-centered. Among other things, this means that these visualization systems "show decision-relevant details, highlight relevant changes, anomalies, [and] exceptions, and portray uncertainties”[21]. These are exactly the pieces of information that our proposed methodology is designed to provide. Visualization is not a tool to show the battlefield in a unique way; visualization is a process that occurs within the heads of the commander and his staff[22]. Our proposed methodology provides additional support for this process.

**SYNCHRONIZING THE REAL OPERATION WITH THE SIMULATED OPERATION**

In order for the OMs to adequately compare the real operation with the simulated operation, the two representations must be "close." An axiom in military planning is that no plan survives the first rifle shot. Once the operations commences, the plan will certainly diverge to some extent from the real operation. The job of the collection of OMs is to identify when this divergence has become so great that the success of the operation is in jeopardy. The OMs report this concern to the decision maker (probably with some rating of certainty attached to this conclusion).

Once the commander has been notified that the currently running simulation no longer accurately reflects the state of the actual operation, the simulation should be updated. If the simulated plan is allowed to continue to diverge from the real operation over time they will become almost completely unrelated. Any analysis the OMs would perform at that point would be meaningless. This updating also allows OpSim to better predict where the operation will be at some future time. The problem, however, is to define a synchronization mechanism which is feasible and adaptive. The proposed approach is best illustrated through two examples.

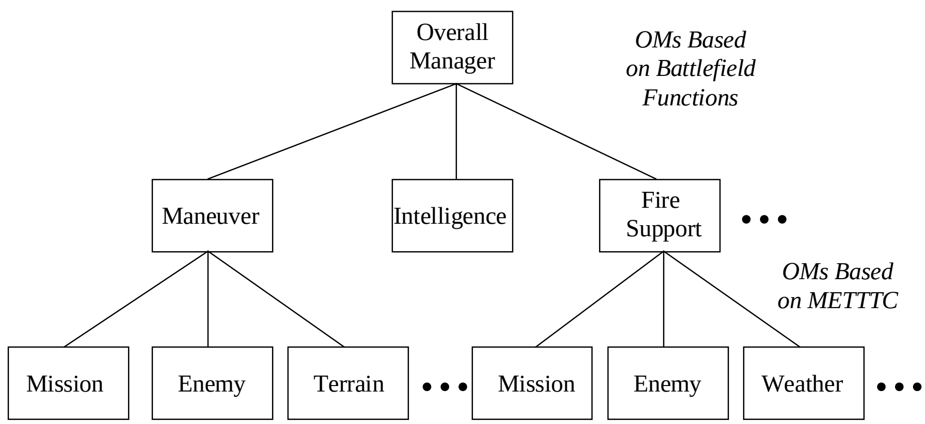


**Figure 2: A Possible, Partially-Expanded Hierarchy of OM's**

The combat effectiveness of entities (units) in the simulation is characterized by some probability distribution(s), such as the well-known Normal Distribution (or bell curve). These probability distributions (which might be different for different classes of entities) are used in the analysis of the various COAs during the planning phase, and they are also used to simulate the interactions between the various entities as the simulation was paralleling the operation in near real time.

At the time the OMs determine that the real operation and the planned operation are significantly different, they have a body of historical data on the actual effectiveness of the classes of entities. The OMs must do two things: update the current state (e.g., the number of casualties, number of vehicle losses, number of key weapons lost, etc.) and update the future performance of the entities within the simulation. An OM tries to refit the historical data to the family of probability distribution described for that class of entity.

Another, less-technically interesting update of OpSim would occur when the number of entities was significantly different. If, for instance, the plan assumed that the enemy would have three tank battalions, but WorldView indicates the enemy actually has four, OpSim would need to include this additional unit in the future. Adding this unit automatically would be difficult, since an intelligence officer would have to provide OpSim with an estimated plan for this new entity.

The basic idea, therefore, is for one or more OMs to analyze the performance of the simulation with respect to the real operation. The OMs can make small updates in the parameters of OpSim automatically. For larger deviations they query the users for help. The amount of data that needs to be gathered before the differences are significant is unclear. One problem with analysis of military operations is that the experiments are not reproducible, much of the area of operations is destroyed in the process, and many of the witnesses are killed. One approach to dealing with this issue is for the threshold (used to determine whether to update automatically) to be adaptive. The OMs can use the performance of the simulation after an update to help it adjust the threshold.

As stated earlier, OMs focus on a narrow domain. This makes their design and implementation more tractable. When the system is first launched, a manager OM creates the first layer of OMs in the hierarchy (Figure 2). The overall manager is responsible for synthesizing the reports of the agents below it in the hierarchy. The first layer of OMs in the hierarchy compares the current situation with the plan, each looking at the operation from a particular, narrow perspective. One such taxonomy for OMs in this first layer is the use of the Combat Functions (as defined in FM 100-5): maneuver; fire support; air defense; command and control; intelligence; mobility, counter-mobility, and survivability; and combat service support (logistics and personnel)[23].

These OMs in the first level of the hierarchy have a number of tools (and additional agents) available to them to perform their analysis. One possible taxonomy for agents in a second layer of OMs might be along the lines of the Army's METTTC mnemonic (Mission, Enemy, Time, Troops, Terrain and Weather, Civilian Impact). Under this taxonomy, one OM would be looking for differences in the size, strength, and/or composition of the enemy. Another might be looking at effects of terrain and weather. One possible, partial expansion of an OM hierarchy is shown in Figure 2.

## FUTURE WORK

A prototype operationally-focused simulation that allows subscription to information by OMs has been built[24]. It is an aggregate-level, discrete event simulation capable of near-real-time and faster operations. This prototype allows plans to be created for a variety of light and mechanized platoons and companies, both friendly and enemy. Allowing the first plan to be "cloned" and modified eases the process of inputting several plans. (This also aids in the process of exploring branches and sequels.) Figure 3 shows a view of OpSim before experiments have been run, and Figure 4 shows a view of OpSim after an experiment has been run. Once all the plans are created, a number of simulation experiments (runs) can be conducted. Finally, the user is presented with a table that describes the average number of personnel, vehicles, and weapons systems lost during each experiment. This provides the planners with feedback on which course of action is best. This feedback would just be one criterion in the decision matrix used to choose a COA. OpSim can also be run in near real time, along with a real operation.

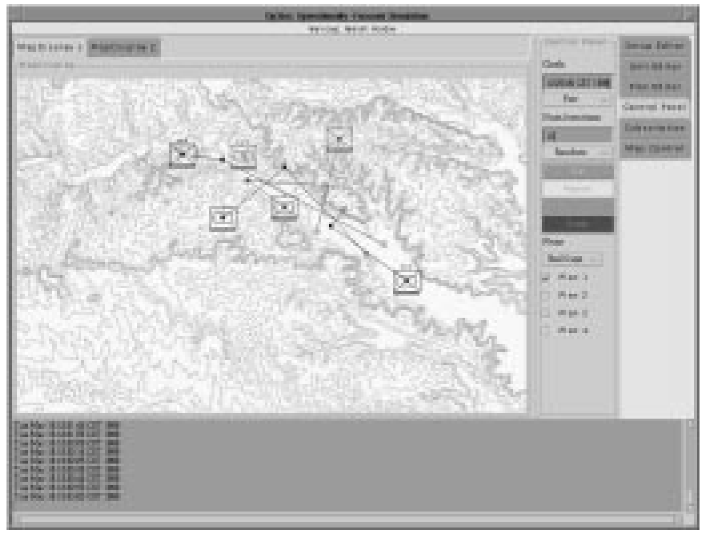

**Figure 3: OpSim Screen before Simulation Run**

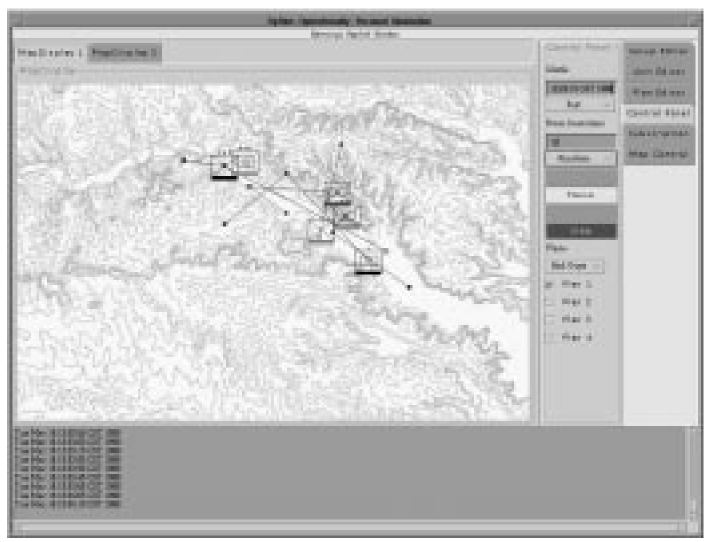

**Figure 4: OpSim Screen after Simulation Run**

In addition to the creation of the OMs, future work on OpSim includes:

- Improving the query response capability of the simulation and permitting one-time queries in addition to subscriptions.
- Creating the ability for OpSim to run different plans at different speeds (i.e. in different threads) so that it could be running the current operation in near real time while running the plan (or a branch or sequel) as fast as possible to predict its outcome. This would also permit planning the future operation to be interleaved with monitoring the current operation rather than treating them as time-ordered, separate processes.

- Improving the statistics gathering and reporting capabilities of the simulation.
- Improving the ability to get information from the terrain database.
- Improving the API.
- Making the simulation compliant with various DoD protocols. As an aggregate-level simulation, it should be compliant with a protocol like the DoD Aggregate Level Simulation Protocol (ALSP), and the intent is that it eventually be HLA compliant with the ALSP Federation[25].
- Making the overall system aware of more than just quantifiable aspects of an operations. The overall methodology must eventually be able to assess the effectiveness of a plan based on attributes other that just numbers of men and systems lost.

The ability for agents to query the simulation is of vital importance to the implementation of this proposed methodology. Consequently this capability is receiving special emphasis. A number of possible methods are being explored.

## SUMMARY

This paper proposed a methodology for using simulations during an ongoing operation to improve situational awareness, prevent information overload, and help the commander stay inside the enemy's decision loop. This methodology includes the use of an operationally focused simulation that runs in real-time, simulating the plan. This methodology also includes the use of intelligent agents, Operations Monitors, to compare the events in the real operation versus those in the plan. These agents query both the representation of the real operation and the simulation to find deviations from the plan. The agents then launch various tools to determine the effects of these deviations.

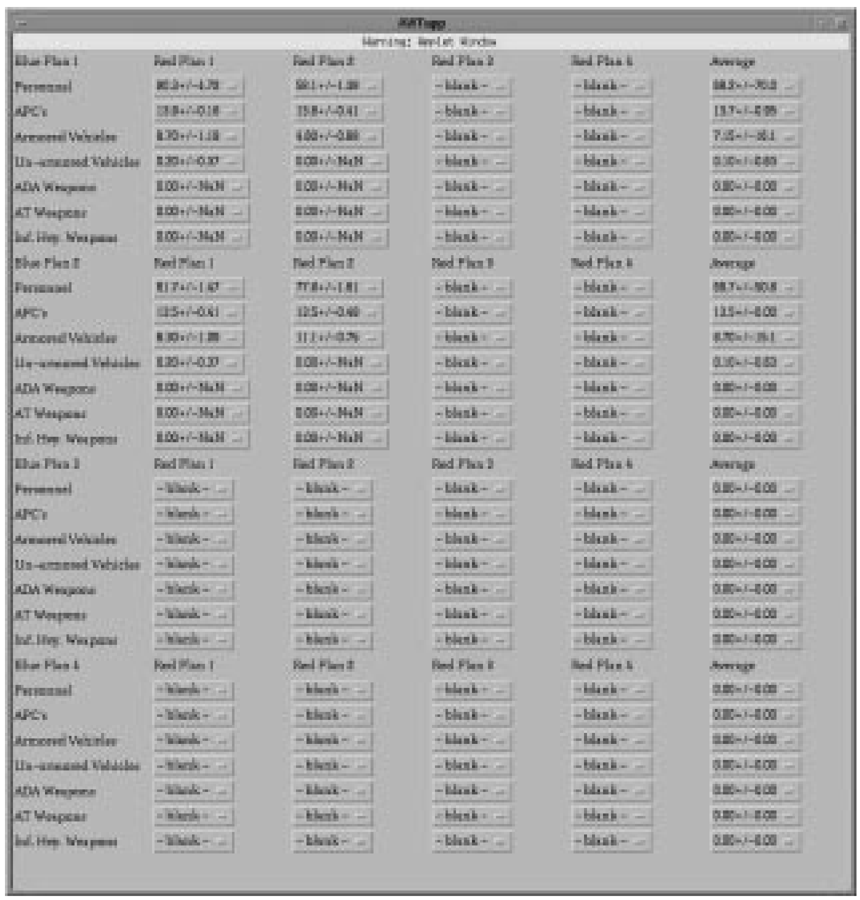

**Figure 5: Sample of Statistical Output from a Series of Simulation Experiments (running Blue Plans 1 and 2 vs. Red Plans 1 and 2)**

If the effects are significant, the agents advise the commander and staff. Operationally focused simulations, as the central part of this proposed methodology, are an important technology for an information-age army, because these simulations improve situational awareness, prevent information overload, and help the commander stay inside the enemy's decision cycle.

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[14] 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.
[15] Surdu, Haines, and Pooch, "OpSim."
[16] VPF™ and VMap-2™ are registered trademarks of the National Imagery and Mapping Agency.
[17] Modular Semi-Automated Forces (ModSAF) was originally built by Loral Advanced Distributed Simulations. It is under configuration control by Simulation Training and Instrumentation Command (STRICOM), Orlando, FL.
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