THREAT SIMULATION: TRADEOFFS BETWEEN TACTICAL REALISM AND TRAINING VALUE

Samuel F. Bass
AAI Corporation
Hunt Valley, MD

ABSTRACT

Threat simulation in electronic warfare training requires both signal fidelity and tactical realism. These aspects of simulation are generally not in conflict. However, as tactical realism is increased -- through the use of autonomous tactics models responsive to simulated ownship position and crew countermeasures -- training value can be compromised. Specific problems can include: inability to "schedule" the hostile signal environment to avoid trainee overload or to present very specific signal combinations; loss of insight into exactly what situation confronted the trainee at any given moment; and loss of repeatability in a given mission, hence loss of the ability to deliver equivalent, objective-oriented training to successive trainees.

Modern training systems must balance these issues to assure the development and maintenance of superior skills in the electronic combat community. This paper describes the tradeoffs to be considered in the design of threat libraries, selection algorithms, and tactics models. It further indicates approaches to be considered as a function of purpose of the simulation and the level of training to be delivered.

About the author

Mr. Bass is the lead human factors specialist at AAI Corporation, Box 126, Hunt Valley, MD 21030 (410-628-3902). He has been responsible for the definition of instructional, performance measurement, and user/computer interaction features for surface/subsurface ASW and electronic combat trainers and flight simulators.

THREAT SIMULATION: TRADEOFFS BETWEEN TACTICAL REALISM AND TRAINING VALUE

Samuel F. Bass
AAI Corporation
Hunt Valley, MD

INTRODUCTION

Threat simulation in electronic warfare training requires both signal fidelity and tactical realism. These aspects of simulation are generally not in conflict. However, as tactical realism is increased -- through the use of autonomous tactics models responsive to simulated ownship position and crew countermeasures -- training value can be compromised. This paper will examine several potential sources of training effectiveness degradation and present strategies for avoiding their detrimental effects.

REQUIREMENTS FOR COMPETENCY IN ELECTRONIC COMBAT

Competency in electronic combat requires more than the relatively straightforward ability to read computer-generated presentations of threat activity. It demands excellent cognitive and associative skills, which the specialist must apply in a time-critical, often high stress environment. Training of these higher level cognitive skills requires high fidelity, highly interactive simulations. These high fidelity simulations are mandated by the following factors.

- The enemy does not cooperate. There is no peacetime environment or training range which presents sufficiently dense and interactive hostile conditions to allow training in real-world conditions.

- There is no way to reliably train or test personnel and their systems utilization skills in the absence of a realistically interactive environment, and have any faith in their ability to handle the workloads and stresses they will meet in the real world.

- Reduced fidelity, part-task or "most-task" training experiences do not train or test electronic combat processes in the context of actual mission performance, with its additional requirements for crew coordination, navigation, communications, safety of flight, or ordnance delivery.

This situation is not peculiar to electronic combat training alone. It applies to all sensor-intensive combat domains, such as surface naval warfare and the training of submarine attack teams. The complexity of high fidelity simulations for these combat domains stems from the need to (1) replicate the relevant portions of the physical environment, whether RF, acoustic, etc.; (2) choreograph both friendly and hostile sensor evolutions; (3) model and automate the sensor environment's complex responses to inputs made by personnel in training; and (4) maintain sufficient control of the training exercise to assure the delivery of a valid training experience with sufficient data collected to provide timely and effective post-training debriefs.

The Three Aspects of Threat Simulation Fidelity

In the context of electronic combat training, simulation fidelity has three aspects: signal fidelity, equipment fidelity, and environment fidelity. These are discussed below.

Signal Fidelity. Faithful signal simulation in terms of parameter fidelity is an absolute requirement if students are to learn to recognize signals by aural and visual analysis. It is also an absolute requirement if the simulator must stimulate operational receiver processors. Relationships among all parameters and all signals must be correct, particularly as an emitter transitions from mode to mode. These transitions, while often difficult to accurately simulate, are important for the cues they offer the electronic warfare specialist.

The supporting software must provide convenient access to the details of signal parameters, so that (1) multiple examples of the same emitter types (not exact copies) can be presented; (2) complex pulse trains (various jitters and staggers, frequency modulation on pulse, coded data pulses followed by CW blasts, etc.) can be tailored; and (3) so that signatures can be kept concurrent with the latest signal intercept data.

Equipment Fidelity. Simulation of control operations and display formats is not enough. Electronic combat specialists must learn to recognize and cope with the aberrant behaviors and deficiencies of their equipment and the signal environment. Some of the effects of interest here are ambiguities and anomalies arising out of receiver processor software; noise that rides on received signals; improper antenna selection; and changes in observed pulse shape and width as a function of receiver saturation, bandwidth changes, or off-tuning. Of course, the specialist cannot be exposed to these effects unless excellent correlation is maintained across both simulated inputs and audio and video presentations on all simulated equipments, such as receivers, DF and omni antenna systems, analysis displays, pulse and spectrum analyzers, etc.

Environment Fidelity. A comprehensive simulation of the electronic combat environment is needed to train higher level electronic combat tasks. These include decision making, maintenance of situational awareness, ability to anticipate, task prioritization, and resource allocation under the stress of combat. To close the training loop, however, the specialist in training must also see the results of his activities. The integrated electronic combat environment must respond to the combination of changes in applied countermeasures, changes in the trainee's platform position or activity, and changes in the position or activity of other simulated entities, such as friendly strike packages.

Thus is mandated the requirement for tactics models for each sensor system in the environment. These tactics models emulate the performance of both the sensor and its human crew. If they are not included in the simulation, the training experience becomes a series of disconnected episodes from which the dynamic nature of real world combat is missing.

TRAINING PITFALLS IN TACTICS MODELING

Tactics models, however, must be implemented with due regard for the limitations of the students who will face them. The following attributes of tactics modeling used for training can lead to degraded training effectiveness.

- Real-world tactics models, as do real world sensor and weapon systems, do not forgive student errors.
- Real-world models do not support specific training objectives.
- Real-world models lead to rapid changes in the student's instantaneous combat situation.
- The randomness of real-world models can destroy the repeatability of training.

Each of these pitfalls is discussed below.

The Unforgiving Nature of the Models

Real-world weapon systems -- and their operators -- are expected to inexorably push for victory and exploit every weakness in their adversaries. However, it is not appropriate to subject students to such models in the skill acquisition and early skill demonstration phases of their training. To do so leads inexorably to student overload, as each misstep provides the simulated environment with incremental advantage. In short order, the environment has "ganged up" on the student, his training session is beyond his control or comprehension, and he has failed. He is demoralized, and he has learned virtually nothing.

Failure to Achieve Specific Training Objectives

Tactics models generally include built-in elements of randomness, so that a threat does not behave in exactly the same way every time it is encountered. This randomness may affect time spent in a given operating state; whether a specific state is even entered; responses to student countermeasures; probability and nature of terminal engagements; time delays in transmitting targeting data throughout a threat network; and so forth.

The pseudorandom nature of the models is designed to provide "realism" for the student. Unfortunately, the tactics models pay no heed to training objectives. They are not interested -- as training developers and instructors should be -- in presenting specific tactical situations for which desired student behaviors can be defined and observed. In many training applications, the models have wrested control of the specifics of threat mixes, signal activity, and engagements, away from the instructors. The consequence is often hodge-podge training evolutions in which instructor feel for student performance is substituted for objective measurement.

Rapidly Changing Combat Environment
The situation is exacerbated when multiple threats and multiple platforms are operating under autonomous models. The instructor/ evaluator might then work even harder than the student. While the student must maintain situational awareness, analyze the environment, and make equipment utilization decisions, the instructor must do all this, plus note (and quite often, remember) what the student did that was suboptimal or plain incorrect. Thus neither the student nor the instructor can reliably maintain good insight into the details of a complex encounter and how the encounter was handled. When numerous encounters are presented in an extended training session, debrief and remediation are quite often cursory and lacking in the crucial detail which the student needs to understand and correct his behavior.

Loss of Repeatability of Training
The random elements of threat modeling can make it impossible to precisely compare multiple students to a performance standard. No two students are confronted with exactly the same situations, even though both are exposed to the same environment. The student skilled in the early phases of engagements may earn himself a "milk run" and not even be thoroughly tested in the more stressful later stages. The student who is inattentive early in the game will have to work harder to "pass." Neither student can be considered fully trained.

POTENTIALLY POOR OUTCOMES

Typical of the undesired results of these problems are those below.

- The student becomes reactive rather than responsive to the environment, as simulated threats take advantage of his mistakes and press him ever more closely. He may carry excess anxiety from training session to training session, becoming progressively less effective as his training proceeds.

- The student becomes "focus trapped," attending only to those portions of his equipment and the environment which arrest his attention, and resorts to stereotypical behavior when he should be maintaining a disciplined, ongoing analysis of the environment and offering well thought-out responses to his situation.

- Random aspects of modeling are particularly problematic in early training, because specific student actions can elicit an assortment of threat responses. The student cannot reliably identify cause and effect, a situation leading to ineffective reinforcement of lessons learned.

- The instructor cannot reliably connect student action with the specific precipitating event. More important, the instructor has no record of other simultaneous events which may have mediated the student's thought processes.

- The instructor cannot conveniently arrange engagements which will either demonstrate specific points to a student or which will require the student to make known responses at known times.

- It becomes very hard to demonstrate that all students have been trained to a specific performance criterion.

SPECIFIC PALLIATIVE MEASURES

These problems can be avoided or mitigated during scenario development, the actual running of the scenario, or post-scenario debrief, as discussed below.

Scenario Development Measures

To prevent purely numeric overload -- both of the student and certain simulated receiver processors -- provide the capability to limit the number of threats which can populate the environment at any moment. Limiting parameters can include the following:

- maximum number of simultaneously active threats

- maximum number of simultaneously active threats in a given class, e.g., early warning radars, acquisition radars, IFFs, antiaircraft artillery, surface-to-air missile (SAM) fire control radars, etc.

Care must be taken, however, in developing the prioritization scheme used to select from the available entities. For example, selection by range and lethality alone will not work, because the environment can become overloaded with short range SAMs, and all early warning radars will be discarded. A better method might be prioritization based on the order in which the most astute tactician would choose to bring the threats into the problem. All methods have their drawbacks, and customization for the specific training and simulation application is highly recommended.

After a satisfactory method of threat selection is adopted, the problem becomes one of choreographing the moment-to-moment interactions with the student. Several features should be implemented, the first of which is to include the ability to inhibit or delay the initiation of an engagement. Simply specifying a time for activation or inhibiting activation is usually sufficient. A second feature would be to provide for the delay or inhibition of critical phases of an engagement, such as entering a tracking or shooting state. Delaying or prolonging these phases gives the student more time to detect, observe, and respond to these events. Inhibition capabilities can be implemented in any number of ways, such as:

- limiting the number of simultaneous tracking or shooting evolutions;

- limiting the number of such evolutions requiring the same equipment for countering;

- limiting the number of evolutions occurring in the same quadrant around the student's platform;

- inhibiting engagements requiring contradictory responses on the part of the student, such as evasive maneuvers in opposite directions, release vs withholding of expendables, and so forth.

This last item presents a quandary, in that decision making training requires that students be presented with seemingly conflicting situations. The intent is to control these situations such that there exist one or more clearly discernible correct responses and such that each potential student error can be used to deduce the nature of the student's deficiency, e.g., book learning, signal recognition, or misunderstanding of a specific aspect of the tactical scene.

A largely ignored aspect of scenario development -- even if many of the preceding recommendations are followed -- is the implementation of user interfaces that simplify the developer's task. In many cases, the developer must "prefly" the mission, make notes regarding problem areas, rescript, recompile, and refly to see if the problems are alleviated. This is incredibly time consuming. Given increasing customer desires for rapid scenario implementation, future system specifications will not accept such methodologies.

A better level of implementation consists of providing the developer with an interactive graphic preview of the scenario, showing the positional and temporal relationships among all platforms and threats. Positional relationships are usually shown in a PPI-type format on a combat situation display. Temporal data is perhaps best depicted in a timeline format, with the use of color coding and symbology to indicate the status of each entity in the scenario. The developer then inspects the displayed data by requesting the instantaneous combat situation as a function of student platform location or scenario time. He is then provided graphic and tabular data detailing simultaneous threat activity, relative position, and so forth. Given this data, he can then edit (both graphically and in text) the scenario file to create the required training situations.

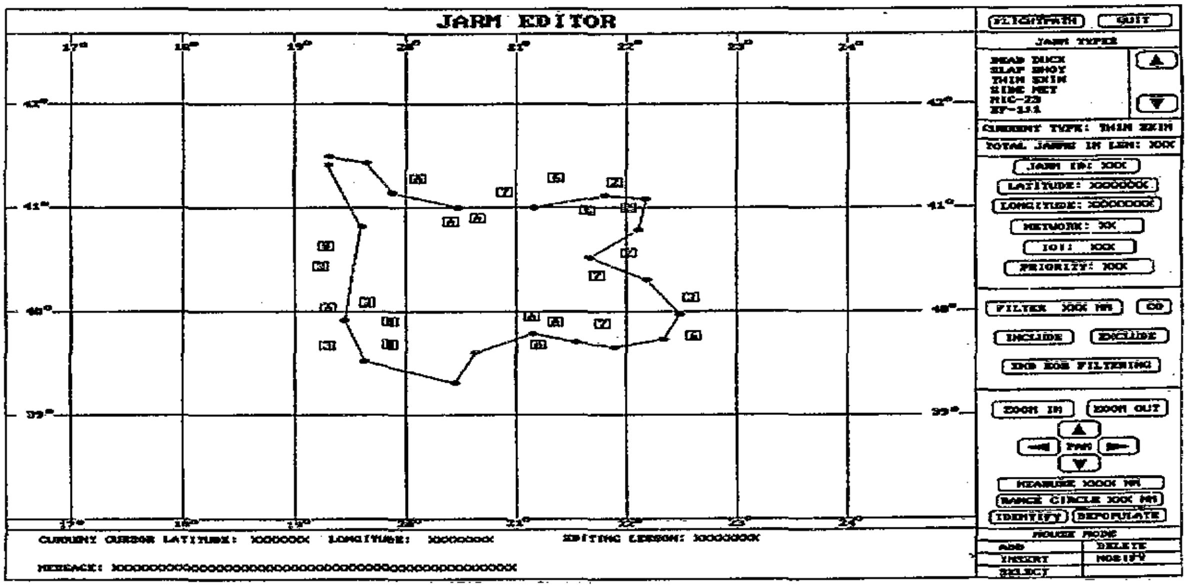

FIGURE 1: Sample PPI Display. Allows selection, positioning, and filtering of threat types, and their position relative to ownship's flight path. Lists and allows editing of all threats simultaneously active at ownship's current position.

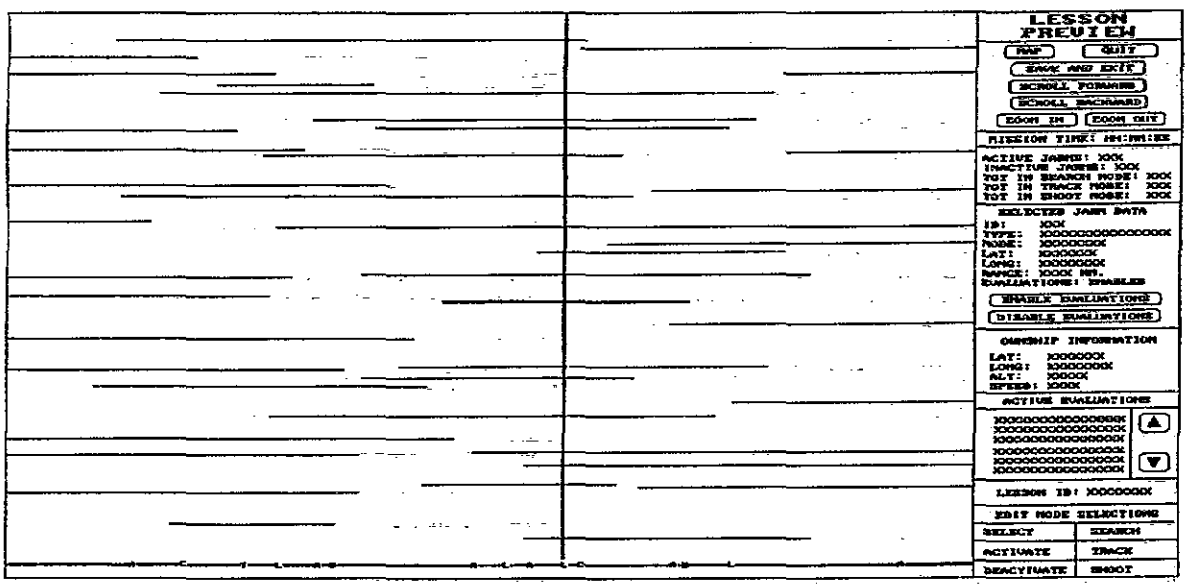

FIGURE 2: Sample timeline display. Shows active time for each threat in relation to all other threats. Allows same editing capabilities as the PPI display. Correlation of time and ownship position is provided by crosshair symbology on the timeline display and highlighting ownship symbology on the PPI display. This allows immediate determination of the student's instantaneous workload.

While this graphic interaction method is a vast improvement over "fly and fix," *it is still relatively* cumbersome and time consuming, in that the developer has to review the scenario on a moment-by-moment basis, maintaining his own awareness both of the tactical situation and of the training objectives. A more advanced solution consists of implementing "watchdog" software. Such software has the following characteristics:

- it is "taught" the capabilities and capacities of the simulated sensors and countermeasures equipment;
- it is "taught" an assortment of logical relationships regarding acceptable tactics, e.g., an aircraft cannot simultaneously break away from two threats when one is on either side of the aircraft, or a manual jammer may not have its bandwidth spread greater than some number of MHz;
- it monitors the instantaneous tactical environment for signal presence and activity (searching, tracking, shooting, etc.);
- it examines the environment in accordance with rules and queries set up by the scenario or curriculum developer;
- it alerts the developer to undesirable situations based on its own logical rules and special developer-inserted rules and queries.

The developer's rules and queries are important for creating scenarios most appropriate for given levels of training. They might take the following *forms:*

- alert when more than three SAMs are simultaneously engaging the student;
- alert when 10 direct threats are simultaneously active;
- alert when several threats requiring different modulations must be countered by the same manual jammer;
- alert when all search radars have been pushed out of the environment due to the insertion of higher priority signals;
- alert when three signals all must be countered *by the same piece of equipment;*
- in conjunction with the threat selection algorithms, **do not permit** some or any of the above situations to develop.

This last capability is invaluable. It greatly reduces scenario development time, because the developer need not search for nor fix these problems. The scenario almost builds itself, and the level of difficulty is appropriate for the student, as dictated by the curriculum and training objectives. No situation is presented which is beyond the (presumed) capabilities of the student or the simulated equipment, yet all possible realism and tactical responsiveness are maintained.

Measures Applied During Mission Run

After the student has nested in the simulator, three approaches are suggested for improving training value: careful limitation of instructor features for control and modification of the scenario; appropriate presentation of integrated environment and student performance data to the instructor; and methods of alerting the instructor to critical problems outside his immediate purview.

Limitations on Instructor Control and Modification Features. Instructors traditionally want the ability to change or control everything in a training scenario. They will add threats, initiate unscheduled attacks, introduce malfunctions, increase the noise added to comm channels, and *generally do things intended to keep students on* their toes. As a result, criterion referenced training goes out the window. Students are not trained to an objective set of standards, but to the internalized -- and often unverbalized -- standards of the instructor who happens to be on the console that day.

Minimization of these adverse effects requires careful attention (1) to what instructor capabilities are provided, and (2) to the careful integration of those capabilities with the simulator's system for monitoring and recording student performance. The second point is addressed first.

Student Performance Monitoring and Recording. The essence of the problem here is separation of the wheat from the chaff. It does no good to record everything for replay, because instructors rarely will have time to use a replay feature. The simulator is overbooked, and the instructor usually is as well. It is similarly inadvisable to rely completely on the instructor's memory and predilections regarding critical student behaviors. It is possible, however, to collect relevant data on individual engagements, sort them as to degree of student success, and if desired operate statistically on the results. The following are possible data collection categories.

- number of threats responded to within a certain time criterion (measures student situational awareness)

- types of threats responded to within a certain time criterion (differentiates situational awareness from threat recognition and prioritization);

- numbers and types of threats countered using incorrect equipment techniques, e.g., wrong modulations, etc. (highlights either student's lack of understanding of acceptable threat counter, or his lack of facility with his equipment);

- numbers and types of threats misidentified (depending on available simulated equipment, identifies inability to interpret display symbology, inability to correctly measure parameters, or deficient book learning, leading to incorrect association of threat parameters with threat identification);

- in a reconnaissance setting, number and type of parameters logged with incorrect equipment setups (attempting to identify a scan type while receiving the signal through a rotating direction finding antenna, indicating failure to follow proper procedures).

The list of such categories is endless. The point, however, is that such data can be collected. It can be stored for a very efficient post-mission debrief with the student. It can be used to identify required remedial training. And it can be presented in real time to the instructor to direct his attention to problem areas and allow him to counsel the student "on the fly," so to speak. A proper system for alerting the instructor to undesirable levels of student performance further reduces instructor workload and contributes to the efficiency and efficacy of the training session.

Instructor Capabilities for Scenario Modification. In a well-structured curriculum, instructors should be actively discouraged from tampering with carefully constructed training exercises. Nevertheless, it is inevitable that the need for impromptu remedial training, special demonstrations, or the occurrence of unforeseen student ineptitude will dictate that instructors be provided with modification capabilities. The requirement is (1) to limit the capabilities available during formally constructed scenarios, (2) to maintain comprehensible records of changes made, and most important, (3) to be able to interpret the effect of the instructor change on student performance to formally defined criteria.

Potential Application of "Pseudo-adaptive" Training

Adaptive training can be loosely defined as an automatically controlled training evolution in which the problem becomes easier or more difficult as a function of a student's moment-to-moment performance. For the purposes of this paper, pseudo-adaptive training (PAT) is similarly defined, except that adaptations are under instructor control.

Successful implementation of PAT requires that training objectives be defined in a slightly different fashion than is the current custom. Objectives are now stated in the general form of, "....counter all presented threats, within the time criterion appropriate to this level of training, using proper tactics." PAT objectives would require the inclusion of additional "terms" in the equation. For example:

> "At training level "X", counter all presented threats within time criteria and using proper tactics, **where the threat mix and tactical situation shall be defined in terms of level of complexity and tactical competence."**

SEGMENT / BIN NO./TITLE	1	2	3	3R	4	5	6	7	8	9	10	SUM/ COUNT	AVG
1 COMM SET													
1. THRT WARN		18/24	12/24	15/18								30/48	2.8
2. CALL MAN.	--	6/12	3/12	9/12								9/24	2.5
3. EXT. RESP.			8/8	6/8								32/32	4.0
4. INT. RESP.	16/16	8/8											
5. XXXXXXXX													
6.													
7.													
8.													
9.													
10.													
2 JAM SET													
11. TIME ACC													
12. FREQ													
13. BW ACC													
14. MOD ACC													
15.													
16.													
17.													
18.													
19.													
20.													

FIGURE 3: Sample Performance Data. Data can be presented as score sums, averages, or counts of occurrences.

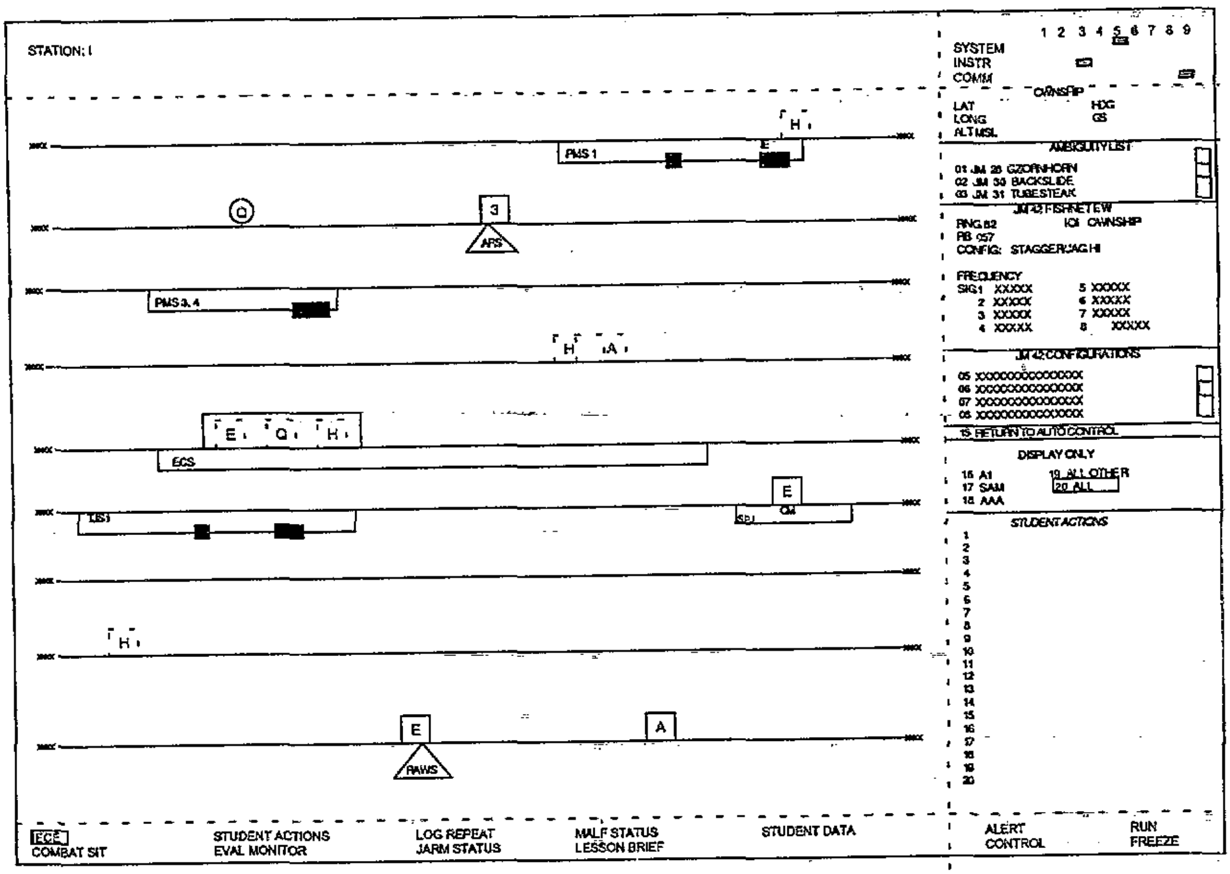

FIGURE 4: Instantaneous Electronic Combat Environment Summary. Data includes active threat type, operating mode, frequency, *assets available, assets used, receiver tuning data, threats being engaged, and currently* running automatic performance evaluations. Color coding, shape coding, and varying line structures assist in rapid data interpretation.

This approach has ramifications both for curriculum and simulator design approaches. Curricula must accommodate the changes, and simulation systems must implement them. The following discussion is confined to potential simulator system impacts. It describes methods of providing instructor control over simulator training experiences, where (1) the methods do not destroy the objectivity of the training, (2) the methods feed directly into formally stated instructional objectives, and (3) instructor-inserted changes can be automatically documented in student records.

Specific Instructor Control Features. First is the capability to limit the tactical "competence" of modeled threats, both before and during the exercise. Limits can take many forms without overtly obstructing the realism or training value of the experience. For example, extend the minimum duration of each phase of the engagement (acquisition, tracking, shooting, etc. This provides the functional equivalent of a less proficient crew or fire control computer, weapon limitations, etc. It increases adversary response time to the student's error or failure to recognize and analyze a situation as quickly as necessary in the real world.

Second is allowing the instructor to increase threat susceptibility to applied countermeasures. This allows the student to demonstrate he has seen the threat and moved to counter it without his having to devote all of his attention to refining his applications early in his training.

Third is the provision of control of unusual engagement sequences. Disable short cut or "snapshooting" engagements (such as launching missiles out of what the student believes is purely an acquisition mode) until the student is prepared to recognize and address them.

Fourth is allowing the instructor to disable the endgame, inhibiting the adversary from launching at or destroying the student platform. This is particularly important if there is no endgame counter to teach the student.

These methods can be implemented by providing proficiency/lethality coefficients under instructor, lesson script, or adaptive control; by allowing instructor input of track inhibits and shoot inhibits for individual threats or threat groups; or by allowing instructors to set delays in data transfer times among members of a threat network. This has the effect of retarding network responses to student intrusion, inactivity, or ineptitude.

Tie-ins to Student Performance Measurement and Record-keeping. If the previously discussed capabilities are implemented, student evaluation or "grading" formats would have to change. In addition to the traditional letter or numeric values in each of the performance categories, stress or difficulty coefficients would be added. Data might appear as in the following tables. The scoring and evaluation system would automatically calculate adaptive scores and make recommendations regarding whether the student should be allowed to advance.

Figure 5: Notional presentation of on-line instructor changes to a scenario

DATA COLLECTION CATEGORY	OBJECTIVE	BASE THREAT MIX	BASE LEVEL OF DIFFICULTY	INSTRUCTOR CHANGES	REVISED LEVEL OF DIFFICULTY
1.					
2.					
3.					
4.					

Figure 6: Notional presentation of student base and adaptive scores

DATA COLLECTION CATEGORY	BASE SCORE	ADAPTIVE SCORE	ADAPTIVE SCORE NEEDED TO PASS TO NEXT TRAINING LEVEL
1.			
2.			
3.			
4.			

CONCLUSIONS

It is clear that customers are demanding more and more realistic training. It is equally clear that with decreasing defense budgets, training must become not just less expensive, but more efficient and effective. The concepts presented in this paper, if implemented, will allow us to proceed toward these goals by (1) providing both the students and instructors with efficient and detailed presentations of student performance, minimizing the time taken to identify exactly where a student is deficient; (2) improving the quality of student debriefs; and (3) identifying with high precision exactly what remediation will do the student the most good. Furthermore, it affords the opportunity to train students to a criterion in a more efficient fashion, in that the use of adaptive techniques can result in a "finished product" -- a student that meets all criteria -- in the shortest possible time. Finally, all this can be accomplished not just in a classroom or computer based training lab, but in the context of a high fidelity, highly reactive, wargaming simulator. This is the potential we dare not ignore.