Research on the Cost Effectiveness of Embedded Simulation and Embedded Training

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ABSTRACT: *This paper describes the cost and operational effectiveness analyses to be conducted on the Embedded Simulation (ES) to support Embedded Training (ET) and Embedded Operations (EO) being developed on the STRICOM Inter-Vehicle Embedded Simulation Technology (INVEST) program. The basic approach is to determine the goal capabilities of ES, compare these goals to the estimated performance improvements of simulation hardware/software in the future and estimate when each of the ES goals can be achieved in a cost effective manner. The first task will be to determine the design driver cues and responses that ES must provide to the warfighter. We will then determine alternative approaches for ES to provide those cues and responses. From that information, we can also determine the weapon system and environment modeling requirements. We will then collect data from example current simulation systems to aid in estimating the hardware and software performance requirements that ES must achieve to match or exceed fixed-base non-embedded simulation capabilities. We will document these capabilities as the end goals of ES as the technology matures. We will then obtain future cost/performance curves for hardware and software. Based on these performance curves, we will estimate when each of the ES performance goals can be met. We will also estimate when intermediate ES performance goals can be met. Finally, we will estimate the cost effectiveness of ES in the INVEST program relative to the cost of live vehicle training.*

1. Background and Objectives

There are a number of reasons that Embedded Training (ET) has become the preferred approach for training Army personnel:

1. Shortages of maneuver range space and costs to travel to maneuver ranges in a period of declining budgets lead to rationing of realistic training exercises and reduced readiness,
2. Forces deployed in a peace keeping mission or in preparation for an invasion are unable to practice their mission due to cultural or environmental sensitivities or operational security concerns,
3. ET allows the Army to shift more training to the operational units and reduce the equipment and personnel costs associated with the school pipeline.

ET was a major initiative in the late 1980's but lost favor because: (1) concerns surfaced about the effects of ET exercises on the RAM of the vehicles, (2) the limited power of small, portable computers and the high costs of image generators, raised concerns about the realism of the training, and (3) Army systems made limited use of microprocessors and computer displays, requiring special instrumentation or electromechanical components in order to sense trainee responses.

Since that time, there has been a revolution in the power of small computers, and workstations have developed the ability to simulate realistic warfighting environments and display realistic 3D worlds at very affordable prices. Plus, the addition of DIS/HLA capabilities allows us to conduct training exercises that encompass the coordination efforts of large combined arms and joint forces. Finally, increased use of microprocessors and electronic instrumentation in operational equipment makes it much easier to sense operator actions and vehicle state as well as to inject signals into electronic displays. Consequently, ET is a technology whose time has come.

1.1 INVEST Program

The power projection Army of the 21st Century will require a flexible go-to war on-board training capability. Individual, crew and unit training currently conducted in stand-alone simulators will not meet the needs of rapidly deploying forces and geographically dispersed Reserve Component units. Emerging technologies and miniaturization are advancing at such a rapid rate that embedded autonomous trainers can soon replace stand-alone exogenous trainers. The symbiosis of embedded simulation technologies can also be exploited to support the operational capabilities of our ground combat vehicles. The Inter-Vehicle Embedded Simulation Technology (INVEST) is a technology exploration program with the goal of identifying those key technologies that have the highest pay-off. This program will set the course for a totally embedded training (ET) and embedded simulation (ES) system for ground combat vehicles.

The goal of the INVEST program is to develop and demonstrate the technology that will lay the foundation for incorporating embedded simulation into future as well as legacy combat vehicles. This simulation capability will support training that spans from individual training, through crew training, to force-on-force training exercises. Along this continuum, however, there are many technological challenges. These challenges range from the injection of artificial terrain into the driver's viewport for individualized training, to the intermixing of live and virtual images in the commanders and gunners display on the battlefield. This includes all possible types of interaction, e.g., live on live, live on virtual, etc. Finally, there is the need to integrate "command and control" in order to provide complete and productive training. Figure 1 below shows the relationships between the Training, Operations and Combat Development/Testing arenas [1].

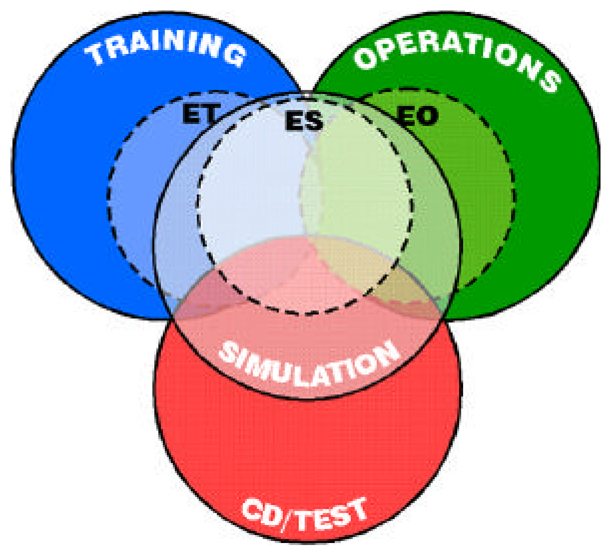

Figure 1 Simulation Relationships Between Training, Operations and Combat Development/Test

Simulation plays a central role in all three of these arenas. ES is the subset of the simulation arena that will be fully integrated into the combat vehicle. ES will play a role in Army XXI and play a key role in the Army After Next (AAN). ET is all embedded training technology, including those not requiring simulation, and will be an integral part of the training arena. Embedded Operations (EO) which include the operational enhancement functions of situational awareness (SA), battlefield visualization (BV), mission rehearsal (MR), command coordination (CC), critical decision making (CDM) and course of action analysis (COAA) will be an integral part of combat operations. That portion of ES where ET and EO overlap is when training moves from the motor park into the field. The INVEST program ES will permit commanders to seamlessly migrate from ET into EO and vice versa. The target vehicles for the INVEST program are the M1A2 System Enhancement Package (SEP) and Future Scout and Cavalry System (FSCS).

1.2 INVEST Cost Effectiveness Analysis

The basic approach for the cost effectiveness analysis is to determine the goal capabilities of ES, compare these goals to the estimated performance improvements of simulation hardware/software in the future and estimate when each of the ES goals can be achieved in a cost effective manner. In this analysis, we will (1) determine the design driver cues and responses that ES must provide to the warfighter, (2) determine alternative approaches for ES to provide those cues and responses, (3) determine the weapon system and environment modeling requirements, (4) estimate the performance end goals of ES as the technology matures, (5) obtain future cost/performance curves for hardware and software, (6) estimate when each of the ES performance goals can be met, (7) estimate when intermediate ES performance goals can be met, and (8) estimate the cost effectiveness of ES in the INVEST program relative to the cost of live vehicle training. Each of these steps is discussed below.

2. Design Driver Cues & Responses

The objective of this task is to define the cues and responses that ES must provide and sense in order to support cost effective embedded training and embedded operations. The first step is to get the tasks for training on the target vehicles as derived from the Universal Joint Task List. Then, we will develop the EO tasks likely to be supported by ES. We will classify each task or subtask by learning subcategory and criticality.

The tasks listed below are presented in order from lowest to highest skill degradation rate:

- Attitude Learning (slowest kill degradation rate)
- Gross Motor Skills
- Steering & Guiding Continuous Movement
- Positioning Movement
- Detecting
- Making Decisions
- Recalling Bodies of Knowledge
- Situational Awareness (Classifying-Recognizing Patterns)
- Recalling Procedures
- Voice Communicating For Coordination (fastest skill degradation rate)

There is a great deal of research literature available on which types of tasks have the highest skill decay rates. See [2, 3] for a summary of research findings and list of references. The slowest skill decay rates are for tasks that involve attitude, gross motor skills, and steering and guiding. This finding tracks with the old saying that "You never forget how to ride a bicycle". The fastest skill degradation rate is for recalling bodies of knowledge, recalling procedures, and coordination tasks. Note that increased automation of Army systems has moved the tasks of most warfighters into the fast skill degradation area. Procedural tasks that require the recalling of information and coordination with other team members have the fastest skill decay rates and this fact explains the current emphasis on team training in the military. The second consideration is task criticality. Naturally, priority in ES should be given to tasks that have the greatest impact on mission success and safety. This initial rating of skill decay rate and criticality helps to alert us as to which tasks should receive the greatest consideration for ES. However, the rest of the analysis below is required to determine the required fidelity and cost effectiveness of ES on each of these tasks.

The next step is to review the conceptual designs of the target systems and generate design driver cues and responses for ET and EO. In equipment design, there are invariably design requirements that drive the design to a certain level of performance that will subsequently, satisfy all less stringent design requirements. In an ET and EO fidelity analysis, we look for the design driver cue and response requirements for each task listed above. These design driver cues and responses will be the ones used in the subsequent analyses.

In order to define the cues and responses required in ET and EO, we must first define the warfighter cues and responses in the operational vehicle. Consequently, we will review the list of ET and EO tasks and:

- Define Warfighter cues
  - What is seen, heard, felt
- Define Warfighter responses
  - Control actuations, communications

3. Alternative ES Approaches

Now that we know what real world cues and responses must be duplicated, the next task is to look at alternative means for ES to provide the simulated cues to the warfighter and sense the responses. Naturally, the preferred alternative is to use the weapon system controls and displays to provide these simulated cues and responses, but this will not always be possible. There are many ways ES can provide the required cues and responses and they fall along a continuum from lower to higher fidelity. These different levels of fidelity may differ by two orders of magnitude in cost. For each design driver cue and response, we will propose display, control and communications alternatives that will provide the required fidelity to achieve EO and ET objectives. Some of these alternatives will be achievable using near term technology and some will require future development. For alternatives that require long term development, we will propose lower fidelity alternatives to use in the interim. These lower fidelity alternatives will require special techniques such as Simisms to partially achieve the goals in the short term. An example of a Simism is the use of color coding of friendly and threat vehicles in SIMNET because image generators and displays could not provide sufficient resolution to differentiate between threats and friendlies at the required ranges.

Once we have developed these recommended alternatives, we will present them to the INVEST IPT and take advantage of their expertise in making a final list of recommended alternatives. The process for determining these recommended alternatives for fulfilling the EO and ET objectives is discussed below.

- Visual displays fidelity analysis
- Auditory displays fidelity analysis
- Touch feedback fidelity analysis
- Controls fidelity analysis
- Communications fidelity analysis

This process is fairly involved and we only have room to discuss the visual displays, controls and communications fidelity analysis here.

3.1 Visual Displays Alternatives Analysis.

We will select each of the design driver cue requirements for display fidelity (generally in terms of display resolution) based on task requirements per doctrine. Example: For the “Engage Target” task, “Identify a T-72 MBT at XXXX meters”. Then we will list alternative means for fulfilling these visual display design drivers. Possible alternatives are:

- Direct view
- Hardcopy
- Weapon system display (Fully Embedded)
- ES-specific display (Appended)
- ES-specific display (Umbilical)

For ES-specific displays, possible alternatives are:

- Alphanumeric display
- Graphical display
  - Color/monochrome
  - LCD/EL/CRT/ plasma
  - Mounted on head/ panel/external optics

The required resolution of these displays is derived from the ET/EO requirements analysis conducted above.

The signals for these displays must be generated by some means. Possible alternatives are:

- Weapon system sensors
- Weapon system test signal
- Enhanced weapon system test signal
- ES-specific stimulation
  - At sensor
  - In processing
  - At display

For ES-specific stimulation, the image generator requirements will be derived from the required:

- No. of moving targets/friendlies
- Fidelity of targets/friendlies
- Environment size/resolution

4. Modeling Requirements

The next task will be to determine the extent to which the weapon system and environment must be modeled in order to achieve the EO/ET objectives. There are various levels of fidelity for simulating the operation of a weapon system. For example, munition impact point may be simulated using monte carlo techniques or a full weapon flyout model may be used. One approach may be adequate for procedures training but not adequate for advanced skill training. The required size and resolution of the terrain database will be impacted by sensor range and need for free-play maneuver space. Also, EO situational awareness tools may impact the required size of the environment model. In addition, environment models will be needed to simulate terrain and atmospheric effects on RF transmission quality. We will perform an analysis to determine the level of weapon system and environment model fidelity required to achieve the EO/ET objectives.

5. Performance End Goals

The best way to estimate the cost effectiveness of ES in the future is to project the costs based on the known hardware/software costs and effectiveness in present systems. Consequently, the approach used in this task will be to take current systems with known levels of effectiveness and document the hardware and software required to achieve that level of effectiveness. We will select fixed-base training systems such as CCTT and COFT with known training effectiveness and document the hardware and software required to achieve this level of effectiveness. We will also pick representative EO systems such as the Inter Vehicle Information System (IVIS) and gather the same data. We will gather the following data on the current systems:

- Lines of Code (LOC), MIPs, RAM, and Mass Memory
  - Instructor/Operator Functions
  - Weapon System Simulation
  - Environment Simulation
  - CGFs
- Image Generator
  - Max Moving Targets/Friendlies (T/F)
  - Polygons per T/F
  - Environment Size/Resolution
  - Update Rate
- Comm System
  - Audio
  - Data
- Simulation Data
  - LAN/WAN
- Unit Support Required
  - Instructor/Operator Functions
  - CGF Control
  - Role Playing

This information will give us a clear idea of how much horsepower will be required to reach our full EO/ET goal.

Based on the above analyses, we will develop the performance that must be achieved by ES in order to fulfill the ET and EO goals. This performance will be documented such that the reviewer can compare it to the known capabilities of current systems.

6. Future Cost Performance Curves

One of the tasks in the INVEST program is to gather data on the future performance curves of various ES technologies, primarily computers, image generators and communications. The main drivers of ES performance are dollars, pounds and cubic inches. Consequently, the following performance curves over time in will be generated.

- MIPs per Dollar/lb/in$^{3/}$
- Memory per Dollar/lb/in^3
- Polygons/sec per Dollar/lb/in^3
- Display Resolution per Dollar/lb/in^3
- MB/sec RF COMM per Dollar/lb/in^3

7. When End Goals Can Be Met

By taking the ES performance goals and comparing them to the projected performance curves, we will be able to estimate when each of the goals can be achieved. We will estimate when these goals can be met with hardware small enough to be mounted in moving vehicles at an acceptable cost. These estimates will be based on the assumption that the full fidelity goals will be met.

8. When Intermediate Goals Can Be Met

As indicated above, ES can be provided at various levels of fidelity. While the ultimate goal is to provide ES at the goal level of fidelity, many of the EO and ET goals can be partially fulfilled at lower levels of fidelity during the interim period before the full goals can be achieved. For those EO and ET goals that cannot be achieved in the short term, we will propose lower levels of fidelity that will fulfill portions of the goal and make ES a useful tool for the Warfighter in the short term. Examples are color coding threats and friendlies and using scenario control of CGFs for procedures training.

9. INVEST vs Live Operations

Finally, we will then compare the estimated cost of ES (at both the end goal and at intermediate times) to the estimated cost of live training using the real vehicles. These live training cost estimates will be based on required hours of operation to match the ES training effectiveness. Target vehicle live operating costs will be estimated based on data from the vehicle design documents as compared to current M1A2 and Scout Vehicle operating costs contained in the DoD

Visibility and Management of Operating and Support Costs (VAMOSC) tables.

10. References

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Author Biographies

BRUCE MCDONALD has been working in the area of Embedded Training since 1988 and has over 25 years of experience in modeling, simulation and training systems. He received his Ph.D. in Industrial Engineering from Texas A&M University in 1973. He has been active in the SIW since its beginning and served as the chair of the DIS Steering Committee. He is the former chair of the SIW Special task group on High Level Architecture. He is currently the chair of the Exercise Management Forum.

HUBERT BAHR is a Decorated Vietnam Veteran with 28 years of Federal Service. He received his BS degree in engineering from the University of Oklahoma in 1972 and his Masters Degree in computer engineering from the University of Central Florida in 1994. For the past 18 years he has been involved with instrumented Force on Force Ranges. He is currently the lead engineer for the INVEST STO in the Research and Engineering Directorate of STRICOM. His research interests are in the areas of parallel processing, artificial intelligence, and computer architecture. He is also pursuing his Ph.D. at the University of Central Florida.