# Lessons Learned Using Tactical Software in Maintenance Training Simulations

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## ABSTRACT

As the US Army strives to reduce logistical costs, more and more functions traditionally performed by the maintainer with plug-in test and diagnostic equipment are being performed by diagnostic software executing on computers embedded in the weapons system. This approach is critical to reducing the "logistics tail" of test equipment and the complexity of maintenance tasks. The role of the system maintainer is being redefined as working with the embedded diagnostic software to troubleshoot problems, isolate faults to line replaceable units, and repair systems through remove and replace operations or by performing adjustments guided by the system under test. This means that maintenance training must focus on teaching the maintainer how to use the diagnostic software effectively.

The Army is using simulations to provide maintenance training at its schools as a way of minimizing the acquisition and maintenance costs of weapon systems that are not deployed. A key decision for the maintenance training simulation developer is whether to use tactical diagnostic software as opposed to emulations of that software in a maintenance simulator.

This paper presents lessons learned during the successful development and fielding of the Diagnostic and Troubleshooting (DT) Trainer for the M2A3/M3A3 Bradley Fighting Vehicle System (A3 BFVS). The A3 BFVS DT is currently fielded at Fort Knox and Fort Benning and has been used to successfully train eleven Maintenance classes to date. This desktop maintenance trainer uses the tactical vehicle software to replicate the system's operational and diagnostic behaviors. It also uses interactive two-dimensional and three-dimensional A3 BFVS components as the soldier-machine interface to the virtual A3 BFVS.

## ABOUT THE AUTHORS

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## INTRODUCTION

In an effort to minimize the acquisition and maintenance costs of weapon systems that are not deployed, the US Army has provided simulation based training devices at its schools to train maintainers of these systems. As the complexity and quantity of software in military vehicles and systems increases, there is the desire to further reduce development and life-cycle costs of trainers by reusing the tactical software in the trainers themselves. A key decision for the program manager is whether to use tactical software as opposed to emulations of that software in a maintenance trainer.

This paper presents lessons learned from the design and implementation of the M2/M3A3 Bradley Fighting Vehicle System (A3 BFVS) Diagnostic and Troubleshooting (DT) Trainer. The DT Trainer utilizes A3 BFVS tactical vehicle software to replicate the system's operational and diagnostic behaviors. It is currently fielded at Fort Knox and Fort Benning and has been used to successfully train eleven maintenance classes to date.

## OVERVIEW OF THE A3 BFVS DIAGNOSTIC AND TROUBLESHOOTING TRAINER

### A3 BFVS Maintenance Concept

The A3 BFVS DT is primarily designed to support training for the 63M Military Occupational Specialty (MOS) Program of Instruction (RTI, 1999). The 63M Soldier is a unit mechanic responsible for the maintenance of the M2/M3 Bradley series vehicles. The maintenance training at USAARMS for the M2/M3A3 is an Additional Skill Identifier (ASI) course for selected soldiers being assigned to units with the M2/M3A3 vehicles. The A3 BFVS DT is also being used at Fort Benning to support ASIJ3 BFVS Master Gunner training (Fort Benning, 2003).

The A3 BFVS is a major upgrade from the A2 BFVS, based on experience gained in Operation Desert Storm. The primary changes from the A2 to the A3 are the complete redesign of the turret fire control system, Second Generation FLIR, and the digital command, control, and communication capabilities. The A3 BFVS has a network of digital processors supporting fire control, sensors, command and control, communications, operational modes, and maintenance. This network is connected by a dual redundant 1553B bus. The digital processors on the network are controlled by real-time software created by multiple manufacturers and communicating over the 1553B bus.

A major change for operator and unit maintenance in the A3 is the extensive Built-In Test (BIT) capability. The new and modified hardware and software for the A3 BFVS has a built-in diagnostic capability to monitor, detect, and isolate failures within the turret. The Vehicle Diagnostic Management Software (VDMS) is hosted on the A3 BFVS Turret Processor Unit (TPU). VDMS diagnoses and troubleshoots the subsystems by initializing the appropriate BIT test, directing and gathering test results, and coordinating follow-on interactive fault isolation testing as necessary.

### A3 BFVS Maintenance Training Devices

A combination of devices provides a cost-effective mix of live, virtual, and constructive training for A3 BFVS maintenance training (RTI and UDLP, 2000).

Live training is the most realistic but also the most expensive in terms of student-teacher ratios, training support costs, and exposure of the student to a potentially hazardous training environment. Furthermore, the requirement to maintain the tactical vehicles in an operational condition limits the types of faults that can be injected. Live training on tactical vehicles is used at Fort Knox, but only after the

students have demonstrated their proficiency with virtual training.

The A3 BFVS DT trainer uses commercial-off-the-shelf (COTS) workstation technology to provide important cognitive training at much lower cost per student hour and with greater safety for novice students than either live or constructive training. The A3 BFVS DT uses a combination of trainer-specific software and tactical software to provide the training functions needed by the instructors with the realism of the vehicle software.

### User Interface for the A3 BFVS DT

The A3 BFVS DT trainer uses two displays (McMaster 03), one for the 3D virtual A3 BFVS (shown on the right in Figure 1), and a high-resolution touch-screen display for 2D displays (shown on the left in Figure 1), including:

- The Commander's Tactical Display, which is the primary mechanic's interface for running Built-In Test (BIT) and Fault Isolation Test (FIT) functions
- The Commander's Remote Biocular Display
- The Gunner's Biocular Display
- The Gunner's Direct View Optics Display
- Position indicators for turret azimuth and gun elevation positioning and alignment during exercises
- External test equipment and workbench
- The Squad Leader's Display
- Form 5988E

## EVOLUTION OF THE A3 BFVS MAINTENANCE TRAINING CONCEPT

### Analysis Showed that DTs Could Save Money

In 1999, US Army Simulation, Training and Instrumentation Command (STRICOM, now PEO-STRI) awarded a contract to provide a quantitative assessment that traced training device requirements to specific training tasks and student loads to vehicle fielding plans. The study compared three options representing different combinations of Training Aids, Devices, Simulators, & Simulations (TADSS) for the A3 BFVS against a common set of criteria:

- Option 1: Tactical Vehicles and Hands-On Trainers (HOTs)
- Option 2: Tactical Vehicles, HOTs, and DTs
- Option 3: Tactical Vehicles only

The findings of the analysis showed that Option 2, a combination of vehicles, HOTs, and DTs as training devices, was the TADSS option that could provide effective training with minimum development and life-cycle costs (RTI, 1999). This finding resulted from estimating the acquisition costs for the different elements. This analysis ranked tactical vehicles, HOTs, and DTs in descending order of cost. The same rank order applied to life-cycle costs. The COTS hardware for the DTs made the difference in life-cycle costs considerable, even for a classroom of DTs as compared with a single HOT or tactical vehicle.



**Figure 1**. User Interface of the A3 BFVS DT.

**Why use Tactical Software?**

There are two primary reasons for reusing tactical software in a Maintenance Trainer:

- To provide greater fidelity in the simulation,
- To reduce life-cycle costs resulting from maintenance trainer upgrades to keep the trainers current with tactical software upgrades.

**Provide Greater Fidelity in the Simulation**
If the maintenance trainer properly generates the inputs to the tactical software, and correctly interprets the outputs from the tactical software, then the Maintenance Trainer will behave the same way that the tactical system does. At face value, the use of tactical software will reduce the test and verification efforts required for the maintenance trainer software. Use of tactical software should also provide more "free-play" options, allowing the student to explore a wider range of the tactical software functions than a simulation designed specifically for maintenance training.

**Reduce Life-cycle Costs of Maintenance Trainer Updates Due to Software Upgrades**
A key issue for training is keeping the software in training devices current with the weapon system software version in the field. This is a serious problem, since upgrades to the tactical software are frequent. During the 18-month development of the A3 BFVS DT, there were three upgrades to the tactical software released. Rarely does the funding for a tactical system upgrade include the cost of upgrading the software on the maintenance training devices. Reuse of the tactical software in the training device should reduce the cost of maintaining concurrency between tactical systems and maintenance trainers as long as the interfaces and interactions between the simulation and the tactical software do not change.

**Maintenance Training has proceeded using DTs and Vehicles**

As of the date of this writing, the A3 BFVS DT has completed:

- One two-week MOS63M ASIB9 User Validation, involving ten students
- Eight MOS63M ASIB9 classes, with a total of 39 students. (Personal communication, June 4, 2003)
- Three A3 BFVS Master Gunner classes with a total of 26 students. (Personal communication, May 30, 2003)

The DT has proven to be a very effective training device. Among the findings of the User Validation (Fulkerson and Talbort, 2000) were:

- "The DT trainer functions as an efficient training tool, increasing student to instructor ratio from 2:1 [on the vehicle] to 6:1 [with six students on the DTs]"
- "The DT trainer serves well in its recommended capacity - as a tool for familiarization and introduction of cognitive skills."

Additional findings are contained in later sections of this paper.

## THE A3 BFVS DT TRAINER ARCHITECTURE

**Hardware Configuration**

The DT Classroom consists of an Instructor/Operator Station (IOS) networked with up to 12 Student Stations over a dedicated classroom local area network.

**Student Stations**
To avoid potential performance problems associated with running complex tactical and graphics software on one computer, the tactical software and the graphics/training software were physically separated on two different computers. This solution reduced development cost and performance risk with a cost increase for the student workstations. Figure 2 shows the A3 BFVS DT Student Station computing configuration. Each Student Station consists of all COTS equipment: two PCs (Graphics PC and Simulation PC), each with network connections to the classroom LAN, two monitors, a keyboard, a mouse, a KVM (keyboard, video, and mouse) switch, and a UPS.



**Figure 2**. A3 BFVS DT Student Station Configuration.

## MAJOR SOFTWARE COMPONENTS

The major software components of the DT are depicted in Figure 3.

### Instructor/Operator Station Components

The IOS software components, shown in Figure 3 as the DT-IOS, support an instructor's ability to create and delete classes; add, delete, and transfer students; assign and delete exercises for students; and print, backup, archive, restore class and student records, and remotely monitor and control student session progress.

### Student Station Components

### Graphics PC Components
The Soldier-Machine Interface software, which resides on the Graphics PC, is comprised of the user interface for the A3 BFVS DT. The subcomponents of the user interface include 3D representations of the A3 turret and hull environments, 2D representations of several of the interactive LRUs and TMDE, and the exercise-control/student-monitoring module.

### Simulation PC Components
The software that resides on the Simulation PC is comprised of the core vehicle tactical software and high-fidelity A3 component simulation models. The operating systems of the Graphics and Simulation PCs are Windows 2000 Professional(TM) and Windows NT 4.0,(TM) respectively.

### Communication Protocol
A custom interface was developed so that the graphics/training software could communicate with the tactical software and the simulation models. The communication takes place via a modified version of the 1553 bus protocol used on the actual vehicle.

## A3 BFVS DT DEVELOPMENT APPROACH

### Integrated Product Team

The A3 BFVS DT Integrated Product Team (IPT) consisted of:

- Program Manager, Bradley Fighting Vehicle System (PM-BFVS)
- Product Manager, Ground Combat Tactical Trainers (PM-GCTT)
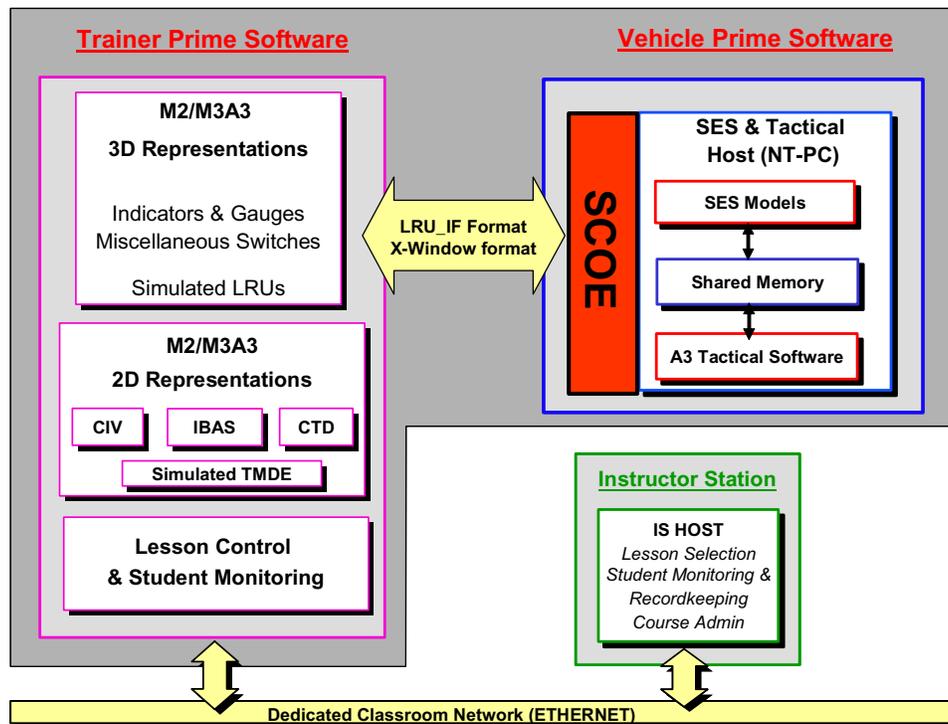- US Army Armor School (USAARMS)



**Figure 3**. A3 BFVS DT Software Component Block Diagram.

- The training system prime contractor, Research Triangle Institute (RTI)
- The vehicle prime contractor, United Defense Industries (UDI)

Going into the project, the training system prime contractor had significant experience in developing effective, virtual reality based Maintenance Training Systems (MTSs) for the M1A2 Abrams, the M270A1 Multiple Launch Rocket System (MLRS), and the M1A2 System Enhancement Package (SEP) Abrams. The vehicle prime contractor had extensive knowledge of the A3 BFVS and the supporting high-fidelity A3 component simulation models. This combination of skills, combined with the input and guidance from the Government IPT members, proved invaluable during the project.

**Maximize Software Reuse**

The project made maximum reuse of previously developed software. This included the A3 BFVS Tactical Software, Simulation-Emulation-Stimulation (SES) Models, which were used in the development and integration of the A3, and maintenance training software architecture. The proven nature of the reused software components reduced schedule and cost risks.

**Stable, Well Documented Interfaces**

From the beginning of the program, the importance of stable and well-defined interfaces was stressed. A proven interface, internal to the tactical and simulation software components, was reused. A new, 1553B-like interface between software components provided by training system and vehicle prime contractors was well documented and maintained.

## A3 BFVS DT DEVELOPMENT CHALLENGES

There were multiple challenges the DT IPT had to overcome. Several of these are listed below.

**Tactical Software Cannot be Changed to Support Training**

The training system developer cannot change the tactical software. Even when the tactical software developer is part of the training system development team, the tactical software will not be changed by the training development, which is typically scheduled several months behind the tactical software development cycle.

The training system developer has to treat the tactical software as a "black box" in terms of debugging the training system software. Again, having the tactical software developer as a member of the training system development team mitigates this problem, but the tactical software was developed by a variety of companies that were not members of the training system IPT.

These requirements were key cost drivers of the project. The most important program management decision made early on in the development cycle to reduce this risk was to ensure that the tactical system developer was part of the maintenance trainer development team. Without this IPT organization, the project would have been much more costly and time-consuming.

**High-Fidelity Real-Time Simulation Models**

The Maintenance portion of the Tactical Software, VDMS, required high-fidelity simulation models with real-time interfaces in order to operate properly. These models were required to provide support for:

- Real-time message traffic between the simulated subsystem components and the tactical software host computer.
- Timely and accurately simulated responses from operational subsystem components.
- Timely and accurately simulated responses from faulty subsystem components.

Reuse of SES models developed to test and verify the tactical software reduced this development effort, but this still required significant effort by the team.

**Tactical Software States**

In previous maintenance trainers developed by the training system prime contractor, all weapon system behaviors were simulated and all system states were known and settable by the training simulation software. This gave an instructor the ability to let a student make errors, go off the chosen diagnostic process path, and be put back on the correct path.

The A3 BFVS tactical software was not designed to be reused as part of a training device. Therefore, it had no mechanism available through which an external entity – the training portions of the DT software – could reset or even examine the internal state of the Tactical Software. Therefore, since the state of the tactical

software could not be reset – except by starting an exercise for its beginning -- the student could not be allowed to commit any errors. Furthermore, no errors made by the soldier could be allowed to reach the tactical software.

For the current state of the tactical software to be known and the correctness of a student's action judged in advance of the action being taken, software had to be developed to track tactical software states through pattern recognition of the tactical-software-provided CTD display content. This software provided state information to the training software based on student actions combined with all possible transitions resulting from, and system responses to these actions.

Additional software was developed to prevent messages resulting from erroneous student actions from reaching the tactical software, which would result in a deviation from the desired diagnostic path. This software allowed the student to learn by experimenting without having to reset the tactical software when the student made an error.

### Tactical Software Problems Revealed

Thorough testing of the Maintenance Trainer revealed problems with the tactical software that had not been previously reported. These problems were reported by the prime contractor to the Government. When corrected, this will result in a better product for the soldier.

### Tactical Software Upgrade

Addition challenges to using tactical software were uncovered during discussions regarding upgrading the tactical software version to match that of the vehicle. Namely, use of tactical software is not a guarantee for maintaining concurrency between training devices and tactical systems. This is true for at least the following reasons.

Software developed to track the tactical software's state, transitions, and student actions, and to constrain erroneous student actions must be modified to "fit" the new software version.

In addition, new vehicle software may have improved diagnostics that invalidate the methods by which faults were modeled in the simulation models. If this is true, the simulation models must be altered to accurately present symptoms of the same fault(s) to the improved software. If this is not possible, selection, implementation, and documentation of another fault of

equal educational value must be executed, while changing all appropriate training system documentation and, if necessary, the corresponding Program of Instruction (POI).

## EXPERIENCE WITH THE A3 BFVS DT TRAINER

### Money is Being Saved

The use of PC-based DT trainers has saved the Army millions of dollars both in initial acquisition costs and in continuing life-cycle costs for A3 BFVS maintenance training.

### Reduced Acquisition Costs
The DT classroom at Fort Knox can currently support a student to instructor ratio of 8:1. The DT development cost the Army approximately $4M. If vehicles, instead of DTs, were used to train eight students, four vehicles and three additional instructors would be required to support the on-vehicle ratio of 2:1. At approximately $4M per A3 vehicle, the cost of the four additional vehicles would be $16M. Disregarding the salaries of the three additional instructors, the cost difference, counting non-recurring engineering (NRE) costs, is approximately $12M.

### Reduced Life-cycle Costs
With the reduced number of A3 vehicles used for training, there are fewer, expensive tactical components and cables to replace due to damage and wear. Although COTS components that comprise the DTs will require repair or replacement, the cost per component is decreasing, while its quality and performance are increasing. The reduced equipment maintenance costs are important to the school, since the Class IX budgets for replacement parts have not risen as rapidly as the costs of electronic components in the systems. Furthermore, maintenance training puts strains on equipment that were not considered in developing the tactical systems. For example, cables were not expected to be removed 8 or 16 times a day.

### Increase in Student to Instructor Ratio
The historic on-vehicle student to teacher ratio is 2:1. The ratio on the DT is limited primarily by the number of available DT Student Stations. When one student is assigned to each of the eight Student Stations at the Bradley Training Division at Fort Knox, the student to instructor ratio is 8:1. This has allowed the Bradley Training Division to get more training out of its scarce resource of experienced instructors.

**Training Benefits**

**Early Availability**
DTs can be developed in parallel with the tactical vehicles, making them available earlier in the fielding schedule. Fewer tactical vehicles being allocated to train soldiers in the classroom means more vehicles being fielded to active units.

**Quick Learning**
In addition, the DTs are training the soldiers more quickly than the all vehicle, or panel trainer methods. According to the "very satisfied" end users at Fort Knox, the DTs "are doing a very good job of training our soldiers … they are learning very quickly." (Personal communication, June 11 and October 7, 2002). "This new equipment has cut our training time in about half" (Hudson, 2002). This means less time for the soldier in the schoolhouse and more time with his unit.

**Additional Observations**
An Instructional Systems Specialist with the Bradley Training Division at Fort Knox made the following observations about the DT (Personal communication, May 16, 2003):

- "Transfer of learning from [the DT] to the live vehicle is enhanced. Student can perform practical exercise on DT mastering skills and knowledge, which enables them to take skills to a higher level on the actual vehicle."
- The DT "Enables student to troubleshoot at a higher-level then actual vehicle where you can induce actual faults on the DT but not on the live vehicle."
- "Troubleshooting procedures are refined on the DT's because the software identifies student mistakes and provides feedback that keeps them with the task-step guidelines. This reduces the number of safety violations and self-induced faults when they move to the live vehicle."
- "The DT Trainer requires students to learn new 'A3' acronyms which are different from the A2 acronyms along with their location and function."
- "It also requires the student to research troubleshooting procedures with the use of the technical manuals."

**LESSONS LEARNED FROM THE A3 BFVS DT TRAINER**

The following lessons were learned during the development, integration, testing, fielding, and application of the A3 BFVS DT:

1) Tactical software can be used in desktop maintenance training systems. The A3 BFVS DT demonstrates this.
2) Include the vehicle prime contractor and, if possible, subcontractors in the Integrated Product Team (IPT). Their knowledge of the system is invaluable.
3) Maintain a thorough Interface Control Document (ICD) for all communications and control interfaces and protocols.
4) Even though validation of Tactical Software-provided behaviors is not required, validation of event propagation and state representation is required.
5) High-fidelity simulation models with real-time interfaces must be developed, if they do not exist, to enable the Tactical Maintenance Software (TMS) to operate properly. These models must support:
   a) Real-time message traffic between the simulated subsystem components and the Tactical Software host computer.
   b) Timely and accurately simulated responses from operational subsystem components, as well as faulty subsystem components.
6) Mechanisms must exist or be created through which an external entity (i.e., the non-tactical software portions of the training device) can examine the Tactical Software's internal state and either alter the Tactical Software's internal state, or prevent erroneous student actions from reaching the Tactical Software.
7) The tactical software may not be perfect. Be prepared to discover, report, and deal with problems in the Tactical Software.
8) Use of tactical software in training devices does not guarantee easily maintained concurrency between training devices and tactical systems.
   a) If software was developed to track version-specific states and transitions, how many of these items requiring tracking are likely to change in the target version?
   b) If the embedded maintenance/diagnostic software has been improved so that one or more simulated faults produce the desired results, determine how much work will be required to alter the simulation models to accurately present symptoms of the same fault

to the improved software. If this is not possible to do, how much additional work -- including changing the course POI and all appropriate training system documentation -- will be required to choose, implement, and document another fault of equal educational value.

## CONCLUSIONS

The A3 BFVS DTs have proven to be a cost-effective way to provide maintenance training to today's Army mechanic. Use of tactical software in maintenance trainers does not guarantee lower costs in keeping training devices current with fielded vehicles. Many of these same or similar issues will need to be addressed in embedded maintenance training.

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