Combining 2D and 3D Virtual Reality for Improved Learning

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ABSTRACT

Maintenance training for modern weapons systems requires learning procedures that integrate diagnostic skills with remove and replace skills. Modern weapons systems such as M270A1 MLRS, M1A2 tank or the M2A3 Bradley Fighting Vehicle are complex systems, employing multiple computers, sensors, and displays, linked by networks of digital buses. These weapons systems make use of this digital equipment to provide extensive on-board diagnostics. Maintainers also use Electronic Technical Manuals and advanced Test, Maintenance, and Diagnostic Equipment (TMDE) to troubleshoot these weapon systems. But there is still the need at a certain point in the diagnostic process to find and disconnect cables and check for damaged connectors on the equipment or the cables using basic tools like multimeters, break-out boxes, etc.

Army maintenance training is adopting computer-based virtual maintenance training as adjunct to more expensive constructive and live hands-on training. The virtual maintenance training is used as a prerequisite for constructive and live hands-on training. Key to the success of computer-based virtual maintenance training is appropriate use of 2D and 3D virtual environments, and how the vehicle, the Line Replaceable Units (LRUs), the displays, and the TMDE are presented to the learner. This paper describes lessons learned in the use of 2D and 3D virtual environments for maintenance training on the M1A2, M1A2 SEP, and M270A1 MLRS, and on-going development of these approaches with the Web-based Interactive Motor Pool.

Biographical Sketches

Larry R. McMaster is a Sr. Computer Engineer at RTI International. He was project manager for the Interactive Motor Pool (IMP) and was an engineer on the M270A1, M1A2 SEP, and M2A3 Bradley diagnostic trainer projects.

George Cooper is a Sr. Computer Engineer at RTI International. He was the project engineer on the M1A2 and the M1A2 SEP program.

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Donna Field is a Computer Engineer at RTI International. She was co-project manager on IMP. She managed other projects and performed as software engineer, interface designer/developer on SEP, MTS M1A2, and numerous others.

Robin Baumgart is a Sr. Research Engineer at RTI International. She was the Project Engineer for the original M1A2 project, MLRS project, and is the Project Manager for the M1A2 SEP project.

Geoffrey Frank is a Principal Scientist at RTI International. He has a PhD from the University of North Carolina at Chapel Hill. He was project engineer for the University of Mounted Warfare Design, the Apache Longbow Maintenance Trainer Design, and the Bradley Maintenance Trainer Study. He led efforts to design and install ALEs at Ft. Leavenworth, KS, and Ft. Sill, OK.

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INTRODUCTION

Maintenance training for modern weapons systems requires learning procedures, which integrate diagnostic skills with remove and replace skills. Modern weapons systems such as M270A1 MLRS, M1A2 SEP tank or the M2A3 Bradley Fighting Vehicle are complex systems, employing multiple computers, sensors, and displays linked by networks of digital buses. These highly complex weapons systems make use of this digital equipment to provide extensive on-board diagnostics. Maintainers also use Interactive Electronic Technical Manuals (IETM) and advanced Test, Maintenance, and Diagnostic Equipment (TMDE) to troubleshoot these weapon systems. However, even though the built-in tests and the numerous automated in-systems checks provide invaluable information, there is still the need at certain points in the diagnostic process to find components, disconnect cables, examine the equipment for damaged connectors, and/or do electronic troubleshooting using basic tools like multimeters, break-out boxes, etc.

This paper describes how the Army is using computer-based virtual maintenance training as an adjunct to more expensive constructive and live hands-on training. The virtual maintenance training is used as a prerequisite for constructive and live hands-on training. Key to the success of computer-based virtual maintenance training is appropriate use of 2D and 3D virtual environments, and how the vehicle, the Line Replaceable Units (LRUs), the displays, and the TMDE are presented to the learner.

ADVANCED LEARNING ENVIRONMENTS FOR MAINTENANCE TRAINING

The key concept behind our maintenance training is learning by doing, using a combination of live, constructive, and virtual maintenance trainers [Frank00]. Our approach to achieving cost-effective maintenance training is to offload training in expensive live equipment and constructive mockups onto low-cost VR desktop trainers, as illustrated by the Training Triangle (***Figure 1***). The training triangle shows the progression through the four steps of Familiarize, Acquire, Practice, and Validate in the vertical direction, and indicates the desired amount of training time as the horizontal direction. Experience, as confirmed by experiments with experienced and inexperienced National Guard soldiers [Helms1997], has shown that specific technologies are cost effective for each of these four steps.

This paper focuses on the role of Virtual Reality (VR) Diagnostic Trainers (DT) using a combination of 2D and 3D virtual reality to provide the virtual stage of training before the soldiers work on the Hands-On Trainers (HOT) or the live vehicles.

VR DTs are a key part of an Advanced Learning Environment (ALE) since they provide a cost-effective component of a complete learning experience. The DTs decrease the requirement for Hands-on Trainers and actual vehicles for institutional training, providing sizeable savings in classroom implementation and life-cycle costs for the Government. The DT lowers tactical vehicle usage for training and thus reduces the number of vehicles that must be diverted from tactical units. An additional benefit from lower training usage on the tactical vehicles is a reduction in the wear and tear at training institutions. The Instructor is able to effectively train classes with a higher Student to Instructor ratio. This is becoming more important as there is an increasing shortage of qualified Instructors in the classroom.

The VR DTs provide a safe, self-paced learning environment for soldiers. The VR DT provides the capability to interject training scenarios, which cannot be replicated on either a HOT or tactical vehicle. Another important issue that the VR DT can directly address is that of safety. The student can make mistakes on the VR DT that would be detrimental to either his health or cause costly equipment damage. Students can learn how to correctly use the TMs and perform instructor also likes the ability to provide immediate remediation when the student has committed an error or a safety violation at either the student station or the IOS.

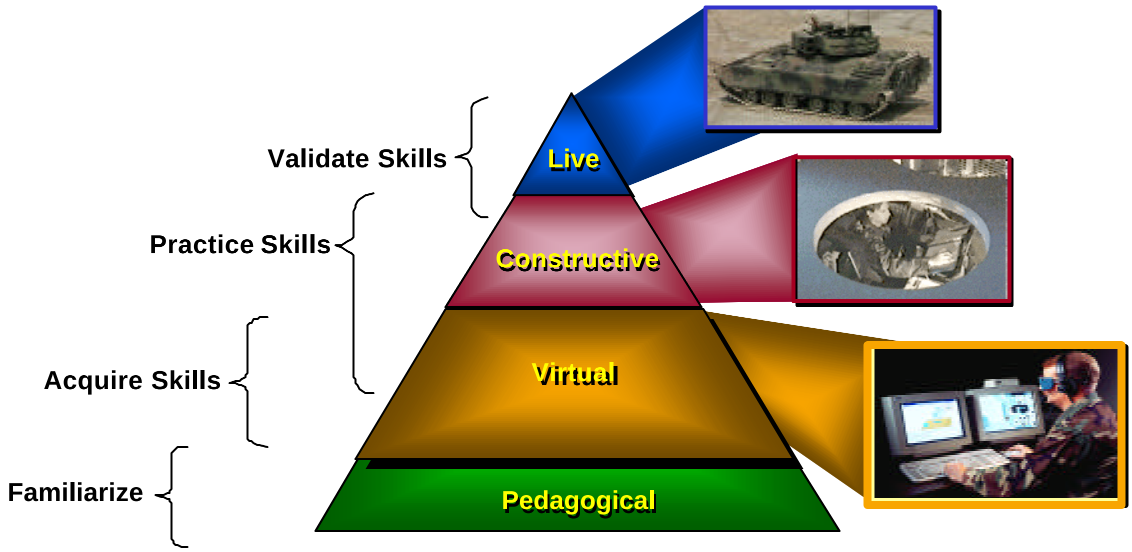

Figure 1: The Training Triangle depicts how to use appropriate live, virtual, and constructive training for different stages of learning.

the same steps on the DTs as they will on the actual vehicle. The student has access to all of the test equipment required to diagnose the faulty LRU. He is able to acquire the knowledge of how to use that equipment in the VR DT. Often his equipment is limited or unavailable for training on the Hands-on Trainer or actual tank. Safety violations, while always flagged for remediation by an instructor, are not dangerous on the DTs, and can teach the student in a secure environment actions that could result in significant injury or damage to either a HOT or a tactical vehicle.

The VR DTs allow students to proceed at their own pace. In the VR DTs, an instructor can assign up to five lessons to a given student and/or class. Advanced students can train on lessons of increased difficulty and not be held back by slower students.

Instructors utilize the feedback from the simulations to evaluate each student's strong and weak areas by reviewing the student report after each lesson. While safety violations always invoke instructor remediation, the capability of allowing the instructor to set the error remediation level by student is a feature well received. The

MAINTENANCE FUNCTIONS TO BE TRAINED

Advanced Individual Training for Maintainers

In the US Army, advanced individual Training is typically where the soldier gets their first Military Occupational Specialty (MOS) training. For maintainers, the training on a specific vehicle will include at least five topics:

- Familiarization with the vehicle and its subsystems
- Training on basic operations of the vehicle that the maintainers must know to do their job, such as starting the engine and accessing the vehicle diagnostic software through the soldier machine interface
- General diagnostic functions, such as executing the Built-In Test (BIT) and Fault Isolation and Test (FIT)
- Special diagnostic functions for subsystems such as power management, hydraulics, fire control, or communications
- Special maintenance functions for subsystems such as purging displays, boresighting, loading and installing tactical

software, and removal and replacement procedures that are specific to certain LRUs such as electro-optical sights.

Increasing Emphasis on Diagnostic Training

The rapid increase in the complexity of electronics in these systems has shifted the emphasis of maintenance functions (and training times) from mechanical, power, hydraulic, and pneumatic components to electronics. For example, most of the changes made in going from the M1A2 to the M1A2 SEP were in improved electronics. Similarly, most of the changes in going from the M2A2 Bradley to the M2A3 Bradley were in the electronics, fire control, and Command, Control, and Communications functions [RTI-UDLP00].

The increased level of integration of digital electronics has shifted the focus of maintenance functions from the extensive use of test equipment focused on cable wiring checkout to the use of the on-board diagnostic software to isolate the faulty component and/or point to the appropriate troubleshooting procedure(s) to follow in the Technical Manuals.

ARCHITECTURE FOR VIRTUAL REALITY DIAGNOSTIC TRAINERS

The Virtual Reality Diagnostic Trainers provide several key functions for maintenance training:

- A Lesson Management System [RTI00]. Provides the ability to manage day-to-day functions of class management, student records, and student reporting.
- Multiple modes of operation. The current VR DTs have the ability to operate in three modes: Institutional, Freeplay, and Standalone.
- Familiarization with vehicle system and cable locations. The student can navigate through the system and get a sense of the relative location of key items.
- Basic vehicle operation skills, such as starting the engine or powering up the turret. The student can acquire and practice these basic skills without access to the actual vehicle and without the risks and costs of actual vehicle operation.
- Troubleshooting and diagnostic skills. The VR DTs simulate built-in and external (e.g., hosted on a SPORT) diagnostic functions. The Instructor can assign lessons for each major system with malfunction conditions. Using the Technical Manuals and/or the Soldier Portable On-Site Repair Tool (SPORT), the student will perform the necessary steps to troubleshoot the fault. Student actions will be monitored, dangerous actions flagged, and student reports created.
- ALE Training aids provided to the Instructor. The Instructor can project the VR environment onto a screen and demonstrate system operations and procedures to support the classroom lecture. The students can also

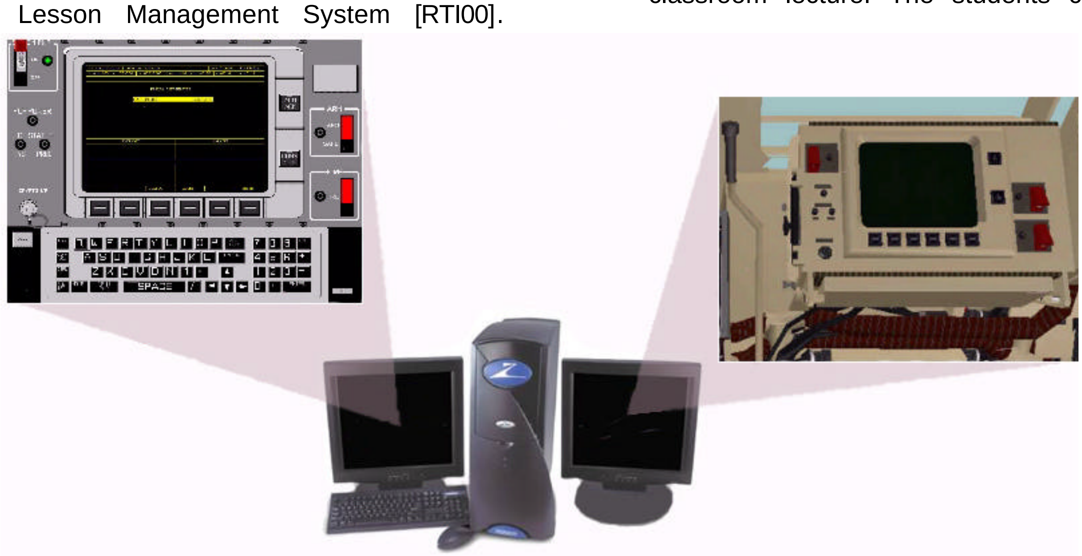

Figure 2: The VR DTs use two screens: one is a high-resolution 2D touch-screen for displays and interactions and a second for the 3D view of the vehicle

perform the steps along with the Instructor to augment the learning experience.

Figure 2 depicts the VR DTs use of two screens: one for the 3D virtual environment, and one for a high-resolution 2D display for interactive control panels. This combination has proven to be very effective for training. The 3D environment allows the student to navigate in and around the virtual vehicle, understanding the relative location of LRUs and cables. The high-resolution 2D display provides the mechanism for interacting with the Soldier Machine Interface (SMI) where the on-board diagnostics reside and for interacting with bezel buttons or touch screens.

In ***Figure 3***, the 2D display also provides a mechanism for showing high-resolution displays required for close-up work such as probing cable jacks and connectors, or reading meters on test and diagnostic equipment.

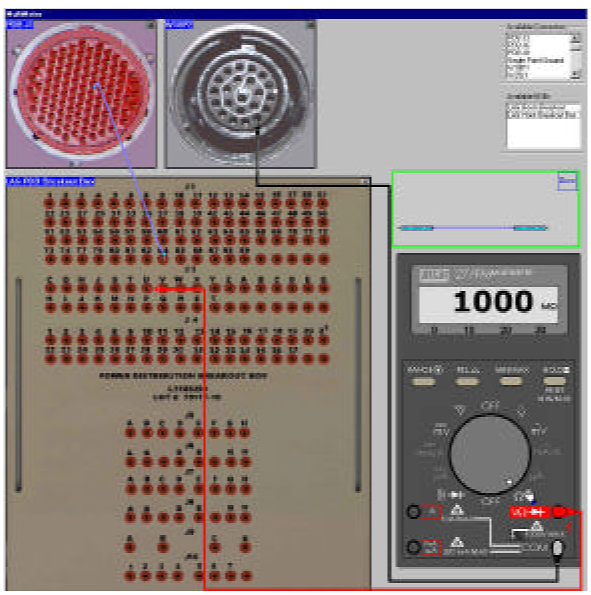

Figure 3: VR maintenance simulators also provide interactive simulation of test and diagnostic equipment such as a multimeter.

EXAMPLES OF DESKTOP VIRTUAL MAINTENANCE TRAINERS

M270A1 Multiple Launch Rocket System

The M270A1 VR DT [RTI00] is designed to train student mechanics at the Unit level to diagnose, troubleshoot, and repair the M270A1 MLRS vehicle, including in particular the launcher/ loader module (LLM) and the computers and hydraulics that control it. The MLRS VR DT simulation supports 145 training exercises for both faulted and normal operations.

The student logs into the trainer and the trainer supplies him with the appropriate maintenance form describing the malfunction. The student then utilizes the Interactive Electronic Technical Manual to traverse through the troubleshooting tree to find the malfunction. In isolating the malfunction, the student is required to remove and examine cable connections. In some lessons the student uses the multimeter while performing actions either in the 3D or 2D environments. By having the student perform the same techniques on the DT that would be accomplished on a tactical vehicle, those techniques become ingrained and translate directly to mockups and actual vehicles. The MLRS trainer utilizes the three modes of operation previously described to provide the greatest range of training scenarios possible.

Figure 4 shows the VR model of the hydraulics for the LLM. This high-fidelity model allows soldiers to inspect the hydraulic system for faults.

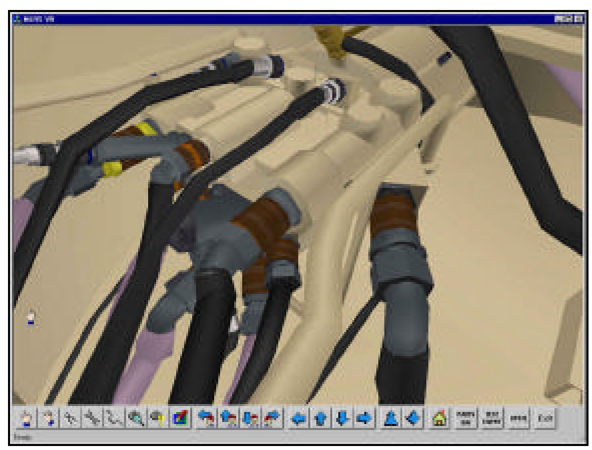

Figure 4: The M270A1 VR DT has detailed 3D VR models of the hydraulics system for the missile launcher loader.

M1A2 System Enhancement Program (SEP)

The M1A2 SEP VR DT is an upgrade to the M1A2 VR DT trainer that is designed to teach the organizational maintenance skills required to maintain the SEP tank. ***Figure 5*** shows the 3D VR model of the SEP commander's station.

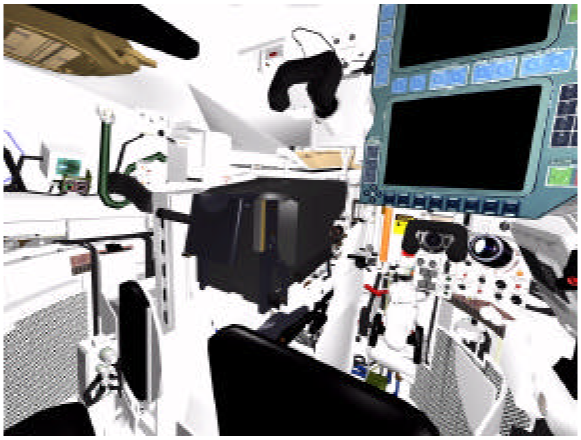

Figure 5: The SEP VR DT provides a detailed model of the Commander's Station, the Gunner's Station, Loader's Station, Subturret floor and the Driver's Compartment.

The M1A2 SEP VR DT offers two modes of training, Institutional and Free Play. In the Institutional mode, the Instructor can provide lessons for the student where he is required to diagnose and repair a fault. The student is required to follow the basic troubleshooting philosophy:

- Verify the problem (identify the symptom)
- Find the appropriate diagnostic procedure
- Isolate the Fault using the procedure
- Verify the repair

In the Free Play mode, the student is provided an opportunity to explore the turret, subturret floor, exterior, and driver's compartment of the SEP tank. Normal operations include the Hydraulic system, Engine system, Thermal Management System, Thermal Imaging System, Fire Control System, Cautions, Warning and Advisory notification and Power Management System. The Instructor can also use this mode to demonstrate normal operational capabilities by displaying the actions on the overhead monitor.

In the Institutional mode, the student is required to troubleshoot a fault within one of the systems. In this mode, each of the student actions is monitored to evaluate that he is performing the correct steps as dictated by the Technical Manuals. This learning activity is critical in teaching students how to correctly locate procedures within the TMs, and to evaluate the results of the diagnostic steps that he has executed. The SEP tank provides on-board Built in Test (BIT) and Fault Isolation Test (FIT), which guide the mechanic to the faulty component or Troubleshooting Procedure (TP) in the TMs. For some malfunctions, the BIT and FIT are unable to isolate the fault, and the mechanic is required to use Manual Troubleshooting Procedures or Symptom Discernment Procedures to diagnose the faulty component. The SEP DT provides the mechanism for the student to learn how to use the onboard diagnostics as well as the alternative troubleshooting methods. The student is able to acquire the skills required to master the troubleshooting philosophy and procedures to correctly diagnose and repair faulty components on the tank. The student's actions are also monitored for actions that could result in serious harm to the mechanic or incur significant damage to the tank. If the student engages in a safety violation, the simulation will halt with an indication that instructor remediation is required. Once instructor remediation is given, the student is allowed to continue.

M2A3/M3A3 Bradley Fighting Vehicle

The A3BFVS VR DT [Waters02] is designed to support training for the M2A3/M3A3 Advanced Skills Indicator (ASI) for organizational mechanics responsible for the maintenance of the M2/M3 Bradley series vehicles. The M2A3/M3A3 ASI course will be taught to selected soldiers assigned to units with the M2A3/M3A3 vehicles. The A3BFVS VR DT has also been installed at Ft. Benning to support Master Gunner training.

A combination of devices has been designed to provide a cost-effective mix of live, virtual, and constructive training for A3BFVS maintenance training [RTI-UDLP00]. The A3BFVS VR DT uses two displays, one for the 3D virtual reality world (on the right in ***Figure 6***), and a high-resolution touch-screen display for 2D displays (on the left in ***Figure 6***). The A3BFVS VR DT uses the actual tactical software to provide a high level of realism [Waters02]. The contents of the Bradley's tactical display are managed by the core tactical software and are directly displayed via the Xwindows format on one of the computer monitors.

Figure 6: The M2A3/M3A3 VR DT uses a combination 3D and 2D displays where the 2D display is driven directly by the tactical software.

The A3BFVS VR DT has recently completed User Validation. This involved ten students and one B9-ASI course involving six students. It has proven to be a very effective training device, familiarizing and training up to eight students at a time.

Interactive Motor Pool

The Interactive Motor Pool (IMP) was developed as a proof of concept that VR training could be delivered over the Web. As shown in ***Figure 7,*** the IMP supported Preventive Maintenance Checks and Services (PMCS), organizational maintenance, and Preventive Maintenance Inspections (PMI) for the M1A2 SEP and the M270A1 MLRS.

Figure 7: The Interactive Motor Pool provides Web-based training in PMCS, basic operations, and maintenance inspections for M1A2 SEP and MLRS vehicles.

The major problems to overcome in Web delivered VR training courses are:

- Size of the VR environment
- End users computing platform
- Type of skills to be trained

The overall size of the VR training course is a primary concern, since the entire course content must be provided over the Web. This involves connection speed, size of the VR models used, and behavioral aspects of the VR environment. Once the size and behavior aspects have been determined and a Web viable solution developed, the end user's computer must be considered. Some items to be considered involve:

- Operating System
- Browser
- Plug in Software
- Processor Speed
- Graphics Capability

One last item for consideration is determining the skills that are to be trained.

Familiarization and basic operation skills can be taught using web-delivered, technical manual-based simulations. These simulations require standard computer and peripherals, and therefore do not require that a unit obtain and support additional training devices that are not commonly available at home station locations. These simulations support acquisition of knowledge about the vehicle, its component systems, and its capabilities. For example, these simulations can be used to teach procedural skills for vehicle operation, such as:

- Starting and stopping the engine
- Running on-board vehicle diagnostics
- Driver/operator PMCS
- Maintenance Leader PMI

Figure 8 shows a screenshot for the IMP simulation that uses virtual reality to bring alive and provide context for the technical manual figures. It also uses simulation to help students

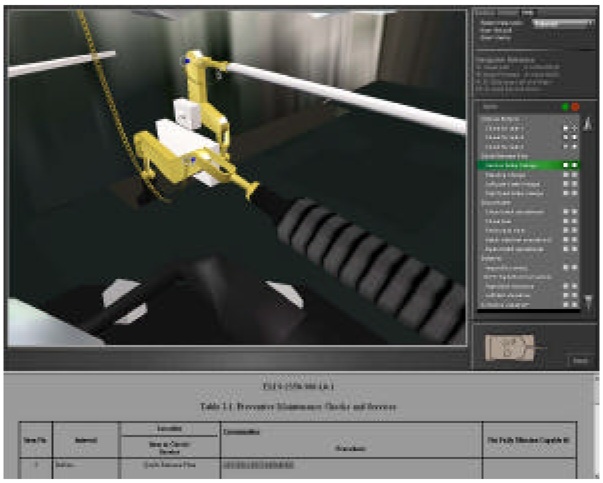

Figure 8: Using the Web-delivered Interactive Motor Pool courseware for Visual Inspection.

acquire, practice, and validate operational skills.

The IMP was able to draw upon the classroom courses developed for the M1A2 SEP and M270A1 MLRS. The procedures chosen to train were not those trained in the VR DT but were visual inspections to determine vehicle capabilities.

LESSONS LEARNED

The main lesson learned in the development of these types of trainers is the need for a viable training plan. Determining the training goals at the earliest stage of trainer development allows the trainer to be efficiently designed. This plan should reflect the strengths and weaknesses of live, virtual, and constructive training methods.

The training plan should consider soldier safety as a primary goal. Virtual training should be used as a "gate" to ensure that soldiers are well versed in basic safety procedures before they start training on the mockups and live equipment. A key element of the training plan is selecting which faults will be trained using which methods. Fault injection in actual vehicles is limited by the need to keep the actual vehicles in running condition and to avoid damaging the equipment. However, faults that require sophisticated motor skills need to be trained using the mockups or live equipment. Good data collection is important for a realistic virtual trainer. Dials, meters, and displays must be readable. Appropriate actions by the equipment in faulted and normal modes must be documented and then simulated.

Additional factors, which should be considered, are trainer dependant and include:

- Level of Interactivity
  - What level of interactivity is needed to satisfy the teaching point?
  - What objects need to be interactive?
- Graphics (2D versus 3D)
  - What objects need further refinement in the 2D screens?
  - What is the interactivity between 2D and 3D screens?
- Level of Detail
  - What is the appropriate level of detail?
  - How many levels are required?

The instructors need to be part of the Integrated Product Team. There needs to be ample time in the development schedule to allow the instructors to provide continuing review of the graphics, realism of the simulation, and usability of the simulation for training. Once the instructors have a vested interest in the training device, they become advocates. This is critical for the training devices to be used, rather than sitting on the shelf.

CONCLUSIONS

The use of Virtual Reality Trainers, both desktop and Web-delivered, is a cogent and highly cost effective method of providing training. It allows the student to train at their own pace and allows them to make the inevitable mistake without injury or property damage.

The student in today's military has been exposed to computer simulations as early as primary school. They adapt to the virtual environment quickly and tend to be enthusiastic about training. This type of training has been well received in the schoolhouse because it improves both the level of training and provides a lower cost per student trained.

The lower cost per student trained aspect is very apparent when purchasing new hardware for additional classrooms. During the time period that this paper was written, the authors were in the process of obtaining equipment for a second lot of MLRS DTs. Both the first and second lot of DTs consist of one Instructor Station and six Student Stations (7 equivalent computers and 13 21" monitors). The total cost of the second lot (identical in function) is less than the cost of two (2) Student Stations (computers only). While costs are certainly a driving factor, the computing capability must also be considered. We have been able to provide the Government with a DT with equivalent computing power and substantially increased graphics power. A Lot 1 DT's graphics card could render approximately 15 million triangles per second, while Lot 2 DT's graphics card does approximately 54 million triangles per second for 1/3 the cost.

While the declining cost of desktop computers has impacted the cost of classroom based trainers, the current laptop machines are approaching the computing power delivered in the MLRS Lot 1 DT at a substantial cost savings. This will allow development of future trainers to be Web-delivered and received by a wider audience.

ACKNOWLEDGEMENTS

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