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Analysis of System Training Impact for Major Defense Acquisition Programs (MDAPs): Training Systems Acquisition

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Executive Summary

Background

The acquisition of training and training systems in support of major Defense programs has been found to be an increasingly important aspect of the Department of Defense (DoD) acquisition process. When considered over the full acquisition life cycle of the Major Defense Acquisition Programs (MDAPs), training and training systems can increase operational effectiveness and provide significant cost efficiencies. This report addresses key topics that were raised in the *Strategic Plan for the Next Generation of Training for the Department of Defense,* prepared by the Office of the Deputy Assistant Secretary of Defense (Personnel and Readiness) and signed by the Deputy Secretary of Defense on 23 September 2010. This research effort expands on the Phase I research, which addressed how systems training considerations are essential for reaching future training goals in an effective and timely manner. Although evidence has existed for many years regarding the importance of training in acquisition, we highlight five well-known programs to document the need for training planning through the system life cycle. These specific cases were identified in the Phase I MDAP report (see Table ES-1). Here, we discuss the value of considering training early and often, as well as what may happen when such consideration is absent.

Table ES-1. Case studies analyzed.

Weapon System	Rationale for Case Study
Patriot Air and Missile Defense System	Thirty-year Major Defense Acquisition—system upgrades without sufficiently upgrading operator training.
Future Combat Systems	Major Defense Acquisition Program requiring training as a Key Performance Parameter—an example of early consideration of embedded training.
Mine-Resistant Ambush Protection	Rapid Acquisition—operator training was provided after fielding.
Husky Mounted Detection System	Rapid Acquisition—operator training and training devices needed before fielding.
P-8A Poseidon	Commercial-off-the-Shelf Aircraft Platform Acquisition—training for multiuse mission.

The study objective was to identify and analyze the specific benefits of early and effective incorporation of training details into acquisition programs, particularly those with significant human-systems interface requirements. The study results complement the latest DoD acquisition and training policies.

Findings

A number of acquisition and readiness issues are related to a full scope of systems training across the lifetime of any given program. Our analysis suggests that considering training system acquisitions as an integral part of every Major Defense Acquisition Program (MDAP) development should result in more effective and efficient operations and lower system life-cycle costs. Details follow.

Patriot Air and Missile Defense System

The Patriot Program, with more than 20 years of history, provides a strong case for upgrading training in the complex programs on a continuing basis through the system life cycle. Evidence from multiple sources shows that as the significant technical upgrades were performed over the years, the training tools and learning content were not enhanced to optimize the effectiveness of the evolutionary improvements to the system. As a general rule, systems upgrades should be accompanied with corresponding changes to the training content at all levels.

Future Combat Systems

Two aspects of the Army FCS program stand out positively. The FCS program included training as a Key Performance Parameter (KPP), and as a family of net-centric weapons systems it provided netted infrastructure to host embedded training across the many programs and aspects of the system of systems. The Army recognized embedded training as an integral and essential capability for the entire family of systems. The FCS is considered to be a good model of training development for future MDAPs for three reasons: (1) training was stressed from the outset—training was included as a KPP; (2) embedded training was integrated into the FCS operational hardware and software; and (3) material developers worked with training developers to monitor the maturity of technologies and incorporate those technologies into the implementation of training.

Mine-Resistant Ambush Protection

The MRAP program was a rapid acquisition and therefore not subject to the deliberate acquisition planning process evidenced in our other case studies. However, with the rapid production and deployment of the vehicles in 2007–2008, the operators began to experience vehicle rollovers early on—some 60 MRAP mishaps were reported between November 2007 and June 2008, with over one-half of those attributed to rollovers. Lack of training was identified in the narratives for the most serious incidents 60% of the time. The need to improve training for these new types of vehicles was recognized early by the Joint MRAP program office. A series of driver trainers/simulators was developed as expeditiously as possible, but the lesson learned once again is to develop training in concert with systems development—even in rapid acquisitions.

Husky Mounted Detection System

The HMDS is another rapid-development program with some of the same training lessons learned as those found in the MRAP program. It took 2 years for robust HMDS training to be developed, with training development beginning a full year after deployment, and it took 3 years for the HMDS training to reach full effectiveness.

P-8A Poseidon

The Navy P-8A Poseidon is a multi-mission aircraft replacing the single-mission design of the P-3C. The Poseidon is a modified Boeing 737, which has had a mature life cycle in commercial use dating back to the 1960s. The P-8A training simulators are not networked to other platforms to facilitate training for battle group, fleet, or joint task force operations. The change in maintenance concept by the manufacturer resulted in an increased load on Navy training, with analysis underway to define the best courses of action for maintenance training.

Recommendations

The case studies in this report document the benefits of including training in acquisition programs and reinforce the value of determining comprehensive training needs over a program life cycle. Training simulators and learning content for the system operators and maintenance personnel should be developed before initial introduction of the hardware system. Detailed recommendations from this research are listed below:

- Move training assessment to the left (earlier) in the acquisition cycle.
    - Revise Defense and service acquisition policies to require earlier assessments of training.
- Training assessments should be early and continual.
- System upgrades require training upgrades; improvements in systems hardware and software must be accompanied by corresponding training enhancements at all organizational levels.
- All MDAPs (including rapid acquisitions) should address training as an integral part of the acquisition program.
- Impacts to training concepts and systems and devices should be part of the weapon systems development decisions.

- Integrate embedded training with MDAP weapons systems as feasible. Net-centric systems of the future provide special opportunities to build in embedded training.
- Monitor technical maturity to incorporate parallel critical training technologies.
- Provide training with the fielded system as a package to realize the full capability of new systems.
    - Training plans should be developed well before successive program milestones leading to the initial fielding of the hardware system, and similarly updated and packaged with every fielded system modification.
- Require MDAPs to provide network connectivity and logical interoperability for the suite of simulators and training tools so training scenarios are fully supported and integrated with the live, virtual, and constructive training environments.
- Synchronize scheduling of simulators, training tools, and packages to be available to train for first deployment to ensure full system capabilities are available for operations.

Contents

1. Introduction and Background

A. Background

The acquisition of training and training systems in support of major programs has been found to be an increasingly important aspect of the Department of Defense (DoD) acquisition process. Over the full acquisition life cycle of major programs, the training systems considerations can increase operational effectiveness and provide significant cost efficiencies. The premise of this study is that a more thorough understanding of systems training considerations early in the acquisition process will produce significant operational effectiveness benefits over the system life cycle. An understanding of the full spectrum of training and training support may influence major program decisions. Determining the benefits and costs of modern simulators and simulations requires considering the full range of options for individual, classroom, and unit training—beginning in the concept-development stage and extending through the life of a major system.

This research addresses key topics that were raised in the *Strategic Plan for the Next Generation of Training for the Department of Defense*, prepared by the Office of the Deputy Assistant Secretary of Defense (Personnel and Readiness) and signed by the Deputy Secretary of Defense on 23 September 2010. This next-generation training strategy provides guidance and outlines issues for the future of Defense training. The research effort outlined in this document expands on the Phase I research to address how systems training considerations are essential for reaching future training goals in an effective and timely manner. This builds on *Analysis of Systems Training Impact for Major Defense Acquisition Programs (MDAPs), Phase I* (completed in July 2011) was to collect and process several decades of major systems data to illuminate the role of training in optimizing total systems performance for acquisition programs (Wisher, et al. 2011).

The Phase I report reviewed more than 4,000 technical documents and 500 Government Accountability Office (GAO) reports for inclusion in a database for future study. This research examined an extensive list of reports and studies relating to systems acquisition for MDAPs and made the information available for future reference by creating an automated database of common variables. Two central research questions were addressed:

- Do the warfighters (operators, maintainers, and leaders) and the acquisition community benefit from early consideration of systems training in major acquisitions?
- Does early system training contribute to initial readiness and full use of a system's capability upon initial delivery?

The DoD spends billions of dollars each year developing and procuring major weapon systems, and these expenditures have produced the most technologically advanced weapon systems in the world. But the process through which systems are determined and acquired has often proven to be costly and inefficient, as reports by the DoD Inspector General and the GAO (documented in Phase I) have repeatedly recounted.

The Phase I study findings documented results of a gap analysis that searched for differences between an "existing status" and a "potential status" for what might be the desired status. Four types of gaps were identified:

- *Knowledge gap*—a best training practice has not been fully validated or proven for application for a given training system.
- *Awareness gap*—a best training practice is proven, established, and relevant, but has not been applied for the training system of interest.
- *Implementation gap*—a valid best training practice has been identified and attempted, but did not work properly in the case of a given training system.
- *Commitment gap*—a valid best training practice is recognized but not applied due to policy, cost, schedule or other factors.

The Phase I analysis reported 26 instances of gaps, validating the need for a more critical treatment of training in major acquisitions. The gap and trend analysis of these data provide a starting point, namely that much was known about training but not applied in the acquisition of a particular system and this was a persistent and continuous hindrance to overall systems performance. The second phase of the study examines a series of selected systems more closely for detailed training assessment through a case-study methodology.

The present (Phase II) research builds on the Phase I report findings, database, and methodology and on the Institute for Defense Analyses (IDA) staff experience with DoD-wide training and large acquisition program issues. In this study, five specific cases identified in Phase I were selected for detailed analysis (see Table 1-1).

Table 1-1. Case studies analyzed.

Weapon System	Rationale for Case Study
Patriot Air and Missile Defense System	Thirty-year Major Defense Acquisition—system upgrades without sufficiently upgrading operator training.
Future Combat Systems	MDAP requiring training as a Key Performance Parameter—an example of early consideration of embedded training.
Mine-Resistant Ambush Protection	Rapid Acquisition—operator training was provided after fielding.
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P-8A Poseidon	Commercial-off-the-Shelf Aircraft Platform Acquisition—training for multiuse mission.

B. Objectives

The study objective is to identify and analyze the specific benefits of early and effective incorporation of training details into acquisition programs, particularly those with significant human-systems interface requirements. The intent was to provide evidence from acquisition programs to substantiate our study premise regarding more detailed training assessments and planning earlier in the acquisition process. The research provides an empirical base for the DoD training and acquisition communities to understand and justify the need to plan for efficient and effective operator, maintainer, and leadership training early and continually in the acquisition process to improve the resulting capabilities and utility of future complex weapon systems. The study results complement the latest DoD acquisition and training policies.

C. Organization of Report

Chapters 2–6 correspond to the five case studies. Each case study was written by an author (or authors) with relevant expertise. Chapter 7 discusses the general implications to be drawn from the case studies that apply to MDAP acquisition processes in general. Appendix A provides brief resumes of the case study authors. Appendix B gives a definition of nine Technology Readiness Levels as they apply to the Future Combat Systems (FCS). Appendix C lists the figures and tables found in the report, Appendix D lists the references, and Appendix E lists the acronyms.

2. Patriot Air and Missile Defense System

—*Robert A. Wisher*

A. Patriot Background

The Patriot system began because of the need to replace an aging and limited air defense system in the 1970s, the Nike-Hercules, and augment another, the Hawk, with one that can defend against higher altitude threats and do so at ever-increasing ranges. The Patriot case study focuses on gaps between the upgrades to the technical capabilities of a system and the upgrades to the training necessary for effective operation. It highlights the consequences of pursuing substantial increases to a system's capabilities while delivering only marginal increases to an operator's capabilities through training, relying instead on automated procedures to offset the shortcoming.

The Air Land Battle doctrine, published in 1982 as *Operations* (FM 100-5), represented the U.S. Army warfighting formula (US Army 1982). It called for an extended battlefield and a close interaction between air and ground capabilities. Air Defense became one of five critical tasks of the central battle, and with it came the need to counter emerging threats and changing operating environments, from defeating air-breathing threats to defeating tactical ballistic missiles. This shift in warfighting formulation required upgrades to the technical capabilities of many weapon systems, including the Patriot Air and Missile Defense System, and should have ben complemented by upgraded training technologies to match.

The Patriot is a surface-to-air missile system having the primary mission to function as the Army's anti-ballistic-missile system. This case study traces how the program's well-intended but single-minded objective to extend system capabilities led to later problems with overall optimal system performance. Principal factors for this were human-performance and operator-training issues that accumulated but were not resolved along the way. The Patriot system evolved with technical enhancements over a period of more than two decades, but operators lacked the rigorous training to deal with this different role—a role as supervisor of automated functions and services subordinate to the operator. In parallel with the technical enhancements, the manner in which operators controlled the system also evolved, migrating from a manual-engagement mode to one in which operators became supervisors of a set of automated-control systems. The operators, who remain the ultimate decision-makers, needed to deal with new technical features and information sources manifested through higher levels of automation. As this case study illustrates, the lack of proper job task analysis, the lack of job task re-analysis during or after significant upgrades, and reliance on training devices that focused on narrow training scenarios and rote training methods had serious aftereffects. Policies on personnel assignment that impeded the development of needed expertise were another factor. A high rate of fratricides during Operation Iraqi Freedom led to boards of inquiry and demands for improvements to operator training. This chapter also considers that the consequences of improper job task analysis and limited training may be repeated with an even more capable system, the THAAD (Terminal High Altitude Air Defense, formerly Theater High Altitude Air Defense). This case study also offers a general recommendation on policies to upgrade training when technical capabilities are being upgraded.

This study first introduces the Patriot system and the defined role of operators. The study then covers the organizational structure supporting its operation, a depiction of upgrades to the system, training practices, early-warning signs regarding inadequate training, field performance, and calls to upgrade the training years later.

B. Patriot System Overview

The Patriot (Figure 2-1) is a mobile air and missile defense system that counters missile and aircraft threats. It offers commanders the capability to defend deployed forces and critical assets from missile and aircraft attack and to defeat enemy surveillance assets, including unmanned aerial vehicles, in a variety of weather conditions and countermeasure environments. This was not the mission originally envisioned. In 1964, the Secretary of Defense directed that the Army Air Defense System for the 1970s assume the name Surface-to-Air Missile, Development (SAM-D). With the successful engagement of a drone in 1975, SAM-D was renamed the Patriot Air Defense Missile System. Patriot is actually an acronym for Phased Array Tracked Radar Intercept of Target. Full-scale development of the system began in 1976, with deployment in 1984. The Patriot is employed in the field through a battalion echelon organizational structure, which includes a headquarters battery; a maintenance company; and four to six line batteries, each firing battery consisting of three or four platoons. The basic building block of a Patriot unit, the firing battery includes eight missile launchers, radar and communications equipment, and the engagement control station (ECS). From an operator’s training perspective, the ECS is one of the most critical components, and the only manned station in a Patriot fire unit. It is tasked with monitoring readiness, threat-ordering, and giving priorities to radar, among other responsibilities.

The ECS includes the weapons-control computer; the data-link terminal; and work stations for the three operators, a Tactical Control Officer and a Tactical Control Assistant, both trained on Patriot tactics, who together control the air battle for their battery, along with one communications operator. The system is operated through a user interface (screen, keyboard, isometric stick, and switch indicators) in concert with the

Patriot user interface software. The Tactical Control Officer is responsible for all identification judgments and for launching missiles at the tracks that are to be engaged by Patriot. The Tactical Control Assistant aids the Tactical Control Officer by supplying information about incoming tracks. The ECS communicates to the launching stations, other Patriot batteries, and the higher command headquarters.

Source: Raytheon photo gallery:
http://www.raytheon.com/businesses/rids/businesses/patriot/patriot_amdp/index.html.

Figure 2-1. Patriot firing.

The ECS is capable of operating in either an autonomous mode, that is, as a stand-alone facility using its own radar and making its own firing decisions, or in centralized mode, that is, in combination with the ECSs of up to five other batteries to form a battalion under the command of the Information and Coordination Central (ICC). The ICC is similar to the ECS in general appearance and features but monitors a wider sector of operations and directs the activity of subordinate ECSs via voice and digital data links when the battalion is operating in centralized mode. The other components of a fire unit are the radar set, the antenna mast group, the power plant, and the launchers. Additional personnel are employed to handle repair, refuel, and reload tasks.

1. System Upgrades

As with other weapon systems, the Patriot needed additional capabilities to keep pace with changing threat environments and, for example, the demands of joint-warfighting doctrine, such as precision engagement. The program sponsors of the Patriot also desired to take advantage of technological innovation and information superiority to enhance overall performance. In particular, the need to defend against tactical ballistic missiles strained the initial capabilities, requiring a series of Patriot Advanced Capability packages, implemented through a series of stand-alone fielding configurations. Each configuration consists of a grouping of materiel-change packages and a software upgrade called a post-deployment build.

The Patriot system had significant upgrades over the past 30 years. Specific details of operational tests and limited user tests are omitted unless there was an immediate impact on training, which will be covered in a later section on MANPRINT (Manpower and Personnel Integration) assessments. MANPRINT is a management and technical program concerned with the integration of human considerations into systems acquisition.

Full-scale development of the Patriot began in 1976 with the MIM-104 Patriot. The baseline system combined several new technologies at the time, notably the phased-array radar and the track-via-missile guidance system. During the 1980s, the Patriot was upgraded in minor ways, primarily software upgrades. Its modular nature has made upgrades to its hardware and software a relatively straightforward engineering effort, one that was almost continuous in nature over the years. Nearly every major subcomponent has been upgraded, with the most common upgrades to the software and the missile itself. Figure 2-2 is the prime contractor's (Raytheon) chart of these advances to the Patriot's capability over a 10-year period, followed by a brief description.

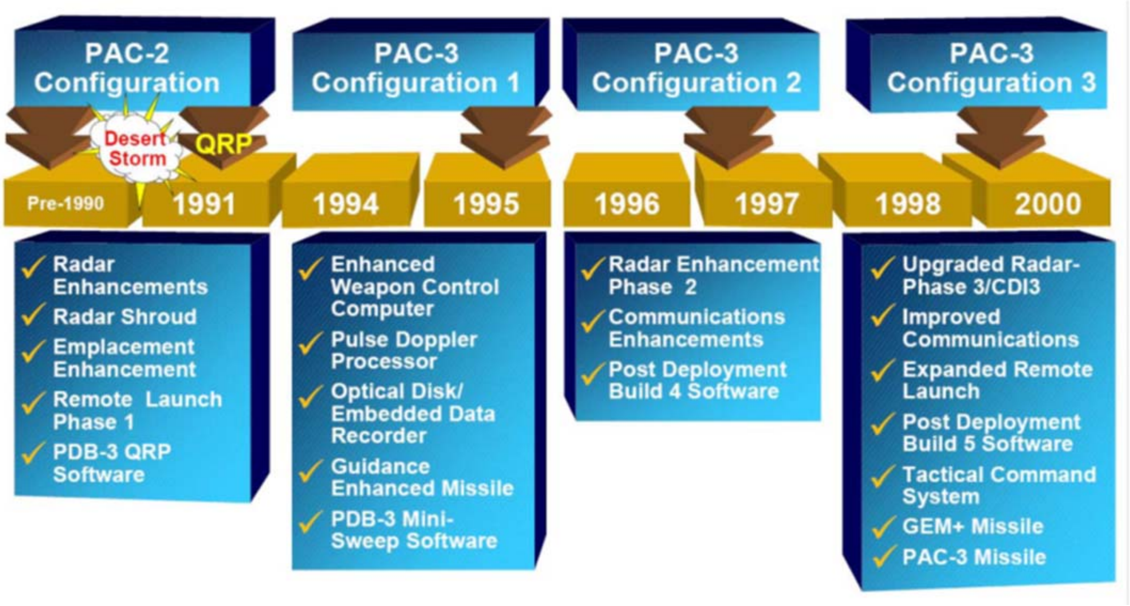

Figure 2-2. Upgrades to the Patriot, 1990 to 2000.

There have been five major variants of the Patriot system from its inception to the present time:

- Variant 1—The MIM-104A, considered the standard missile, was optimized for engagements against aircraft, with limited capability against ballistic missiles, with an operational range of 70 km.
- Variant 2—Patriot Advanced Capability, PAC-1 was the 1988 upgrade. The MIM-104B was a slight variation, with the added capability to seek and destroy electronic countermeasure emitters and with an operational range of 70 km.
- Variant 3—Patriot Advanced Capability, PAC-2. This was the Patriot's first major missile upgrade, with the MIM-104C missile. The upgrade sought a capability to reliably destroy inbound ballistic missiles. PAC-2 was deployed to units in 1990. The operational range was extended to 160 km.
- Variant 4—PAC-2/Guidance Enhanced Missile. Here, the missiles were enhanced significantly with respect to software and warhead detonation. Four versions of the Guidance Enhanced Missile were introduced in the 1990s and early 2000s.
- Variant 5—Patriot Advanced Capability, PAC-3. This is considered a major system improvement over the PAC-2, with a new hit-to-kill interceptor missile, along with improved communications, radar, and ground support systems. Full-scale production began in late 2002.

2. Recent Patriot Activity

The Army conducted one major developmental Patriot flight-test mission and a Post-Deployment Build-7 Developmental Test and Evaluation in FY11. The Army conducted three major developmental Patriot flight-test missions in early FY12. The Medium Extended Air Defense System (MEADS) was intended to be a more deployable, mobile, and capable air- and missile-defense system than Patriot. The DoD has decided not to field MEADS, although it will continue program development through the developmental phase of the program.

C. Patriot Training Systems Development

Job training for a Patriot fire-control enhanced operator, who can serve in the ECS as the Tactical Control Assistant, requires 10 weeks of Basic Combat Training and 20 weeks of Advanced Individual Training with on-the-job instruction. Part of this time is spent in the classroom and in the field under simulated combat conditions, concentrating on ready-for-action drills and how to conduct fundamental commands given by their tactical control officer. Training continues after assignment to an operational unit, with training aids and devices such as the troop proficiency trainer (TPT), an early example of embedded training. Also in the ECS is an Air Defense Artillery Officer who serves as the Tactical Control Operator. The officer must have completed the Air Defense Artillery Officer Basic Course and have knowledge of the Patriot tactics, techniques, and procedures. In some cases a senior noncommissioned officer can also serve as Tactical Control Officer.

Training in the unit is conducted primarily by the battery trainer, who checks that all training meets the Army Training and Evaluation Program and gunnery standards. Battery trainers receive instruction from battalion trainers, who ensure the crews follow the same tactics, techniques, and procedures as directed by the battalion commander. In recent years, a Patriot Master Gunner course was developed (Villa 2006). The certification of units is conducted under the guidance of the Air Defense Artillery Patriot Brigade Gunnery Program. The program, which is based on a series of 12 gunnery tables, is designed to develop and then test the proficiency of the individual, crew, and battery in a sequential, performance-oriented training environment. Following successful completion of the basic gunnery tables (I through IV) individuals receive a basic certification as a qualified crew member. This is achieved through hands-on training, individual instruction, and successful completion of practical and written exercises. The intermediate (V through VII) and advanced gunnery tables (IX through XII) are the responsibility of the parent brigade.

1. The Operator Task

In the context of the current case study, one original task is highlighted, namely the *Perform Air Battle Engagement Task* (Army Task 44-1-9002).[1] The standard for the original task is to deny hostile aircraft successful engagement of high-value assets while providing friendly forces maximum protection. It is assumed that the Patriot system is operational, with the crew ready to participate in an air battle exercises and that the battery is at designated Alert State. There are 10 performance steps, such as *The commander or leader assures no friendly casualties*. Beneath the performance steps are a total of 109 sub-steps, as derived from the task analysis in the Systems Approach to Training model. The analysis indicated that overall task of air battle engagement requires the operator to perform a great variety of discrete actions, including monitoring, detecting, recognizing, identifying, assigning, establishing, operating, evaluating, applying, verifying, confirming, informing, rotating, allowing, ordering, configuring, implementing, directing, ensuring, enforcing, reporting, and updating for the overall task of air battle engagement.

Throughout the performance of the task, many checks are made of the information fed through the operator workstation while communicating with higher headquarters and others in the ECS. A target engagement can be carried out in manual, semi-automatic, or automatic mode. When the decision to engage has been made as ordered by the Air

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[1] The task has since been further refined into a set of smaller tasks, such as *Perform Friendly Protect at the ECS*, which roughly correspond to performance steps in the original task.

Defense Artillery Fire Coordination Officer, the launch station(s) is selected and data are transmitted to the designated missile(s).

The job task analysis surrounding the crew activities has not kept up with the hardware and software system upgrades. Some performance sub-steps in the original task, such as *confirm training in identification friend or foe procedures*, do not necessarily address underlying expectations, such as does the operator have adequate knowledge (the operator's knowledge may not be adequate due to marginal training performance or skill decay). Research on skill decay, for example, shows a time course of knowledge and skill decay for step-by-step procedural tasks, such as the air battle engagement task, that is governed by the characteristics of the specific task, such as number of steps and internal cues (Hagman and Rose 1983). Based on the task description for the original Patriot air battle engagement, the performance of operators will diminish quickly after a period of nonuse as predicted by the Hagman-Rose skill retention model. This translates to a small percentage of operators in a unit being able to successfully perform the task during a retention interval, or a time of nonuse. Furthermore, what might be successfully retained are limited capabilities that are being practiced and may not decay but which do not necessarily improve with practice unless the training adds novelty and challenge to the scenarios.

2. Patriot Training Aids and Devices

Patriot training takes advantage of simulations, simulators, and various training aids. Some are embedded into the actual system, others are housed in classroom facilities, and new versions are available as tabletop trainers. A brief description is provided here.

a. Troop Proficiency Trainer

The TPT is the embedded training simulator that was provided with the original deployment of the Patriot system. A software program used to train ICC and ECS operators, the TPT is also used to evaluate and maintain proficiency levels of current operators. TPT can be programmed for battalion/battery exercise training. It has a scenario authoring capability, but no automated training features, such as feedback, performance feedback, or performance monitoring. The TPT lacks a demonstration mode, in which a training officer, for example, could explain target-management techniques. Similarly, it does not have a capability to freeze, playback, or fast-forward scenarios, further limiting its instructional potential.

b. Patriot Tactical Operations Simulator/Trainer—1976 to 1989

The Tactical Operations Simulator/Trainer was a full-task simulator for the Patriot system. It was designed to simulate the two-person ECS environment. It originally accommodated only a single person and was not designed to accommodate a proficiency assessment capability, although the overall capabilities were enhanced during its life cycle. It was renamed the Reconfigurable Tactical Operations Simulator in 1989.

c. Patriot Conduct of Fire Trainer (PCOFT)—1983 to 2006

The PCOFT was a classroom trainer that used mock-up workstations and computer-generated scenarios to simulate the battlefield. The PCOFT runs Patriot tactical software for console reproductions of the ECS and ICC.

d. Reconfigurable Tactical Operations Simulator, 1989 to present; as a Training device, 2007-present

This training aid has been in use since the late 1970s to support major exercises and experimentation in air defense. The hardware is commercial off the shelf, and the Army owns the software. It is an example of a medium- to high-fidelity trainer, which supports many but not all air battle operations tasks, and is thus referred to as a part-task trainer. It can be reconfigured to support other air defense systems, such as THAAD and MEADS. It can be used as an analytical, exercise, and training tool. The Reconfigurable Tactical Operations Simulator supports the development of air defense scenarios, scripting of timed events, collection and processing of air defense events supporting analysis of scenario results.

e. Reconfigurable Table Top Trainer

This device replaces the original PCOFT for institutional training. Workstations are in use at the institutional training site at Fort Sill, OK, after a recent relocation from Fort Bliss, TX, as part of the base realignment and closure process.

3. Patriot Operator Training Research

In an assessment of performance of enlisted Patriot operators to link performance to the outcomes of simulated air battles, a RAND study examined how differences in personnel quality, as measured by the Armed Forces Qualification Test, and training backgrounds, as indicated by job history and training assignments, affect the execution of Tactical Control Assistant functions and the outcomes of battles (Orvis, Childress and Polich 1992). From late 1988 to mid-1999, virtually all the Army’s enlisted Patriot operators (Military Occupational Specialty 24T at the time) were tested on a Patriot Conduct of Fire Trainer, a device that simulates fully interactive battalion operations. Four simulated air battles were developed for the assessment, along with a written test measuring knowledge of tactical operating procedures. A key finding demonstrated that a one Mental Category change in Armed Forces Qualification Test scores equaled or surpassed the effect of a year of operator experience or of frequent training. Soldiers learned several key tactical skills shortly after Advanced Individual Training, including the ability to decide whether and when to engage aircraft based on the nature and severity of threat. The study provides evidence linking training in units with success during air battles.

Human factor elements of the system were investigated during Patriot's second operational test (Carter and Lockhart 1982). Questionnaires addressing specific test issues were developed, checklists were completed, and interviews conducted with the 85 service members who participated in the operational test. One objective of the interviews was to determine whether problems existed with the troop proficiency trainer programs. For the items related to the four TPT software programs, all were rated poor to fair by the ICC personnel. A summary of open-ended comments from the ICC and ECS personnel indicated the problems:

> The TPT tapes were not programmed correctly. Many errors and problems were identified. They included the signaling of wrong targets as being hooked, alert messages remaining on the screen, and slow presentation of pop-up targets…Crewmen stated that the tapes could not be utilized for training console operators and as an evaluative or diagnostic tool. They also reported that the firing doctrine had not been correctly incorporated into the TPT tapes. The service members were not provided with guidelines regarding the use and function of the tapes and taught how to use them for training. (Carter and Lockhart 1982, p. 9)

The military services were interested in the construct of embedded training, offered by the early TPT, which is training provided by capabilities built into or added onto operational systems. In an early tri-service review of the components of embedded training, Warm et al. (1988) observed that a number of the embedded-training components studied relied on pre-defined scenarios to provide practice and training opportunities. Generally, a limited number of pre-defined scenarios are available for presentation through the embedded training component. Interview data suggested that the small number of scenarios available in some cases, notably the Patriot TPT, restricted the quality and amount of training that could be provided. In the case of the Patriot TPT, this leads to a situation where, after a number of exposures to each scenario, trainees "learn the scenarios"—that is, learn where and when in an exercise to expect particular targets to appear. In such a situation, the training value of the scenarios is quickly lost, since the trainee is responding to a known situation rather than responding to a new and emerging situation. One observation is that when pre-defined scenarios are to be used to implement embedded training, a larger number and variety of scenarios than is provided in the systems studied may be necessary to ensure effective sustainment training.

There is a small body of research on the performance of Patriot operators executing the air battle engagement task. One study reported a considerable range in the accuracy of both Tactical Control Officers and Tactical Control Assistants for tracks with conflicting information (Adelman, Tolcott and Bresnick 1993). Conflict occurs when some information or “cues” indicate that the aircraft is friendly and that other information indicates that it is hostile. In a follow-on academic study of 28 Patriot Tactical Control Officer/Tactical Control Assistant teams, scenarios were programmed into the Patriot simulator, which varied the number of tracks on the display and degree of conflicting information (Adelman, Christian, et al. 1997). The experiment examined the effect of communication training on team performance. The communication training did not improve team performance; rather, it was the number of hours the team had previously worked together that influenced team performance. But this effect held for only the tasks for which the Patriot team routinely trains. Important for the current case study, the effect did not transfer to the infrequent and more cognitively stressing tasks where there is conflicting information about unknown aircraft.

Other research with Patriot operators found significant order effects for difficult identification tasks. An order effect occurs when different identification judgments or different engagement decisions are made depending on the sequence in which the same information or cues are presented to the operator. In particular, order effects were found for tasks with conflicting information about an incoming aircraft (Adelman, Bresnick, et al. 1996). This body of research, sponsored in part by the U.S. Army Research Institute, was conducted after Operation Desert Storm but before Operation Iraqi Freedom.

D. Patriot Training Systems Issues

Stemming from the high fratricide rate during Operation Iraqi Freedom, the Patriot Vigilance project, which was called at the request of the Fort Bliss Commander, examined performance and training issues. During Operation Iraqi Freedom, 18% of engagements resulted in fratricide. Of particular interest in the project were the vigilance of operators and their situational awareness related to the control of automated command systems. Personnel from the Army Research Laboratory were invited to lend their expertise in human systems, human performance, and training to understand the nature of human errors that contributed to the fratricide rate. As part of a critical incident assessment, the staff studied findings from the fratricide boards of inquiry, observed Patriot training and operations, and interviewed key personnel in the Air Defense community. A supporting technical report covered the human performance issues surrounding automated systems and the human checks and balances needed to ensure smooth and accurate operations (Hawley, Mares and Giammanco 2005).

In a review of the Patriot Vigilance project, and a reexamination of more than two decades of MANPRINT assessments and analysis for the Patriot, Dr. John Hawley, a research psychologist and human factors expert with the ARL Human Research and Engineering Directorate, offered observations and lessons from the developmental experience. In 2007, Dr. Hawley issued a report titled *Looking Back on 20 Years of MANPRINT on Patriot: Observations and Lessons* (Hawley 2007), the key points of which are summarized below as they relate to the current MDAP project. The ARL report was intended not as a critique of specific decisions but rather as a reflection on institutional learning and practice improvement.

MANPRINT is an Army program initiated in the 1980s to apply a “systems approach” to weapon system acquisition by providing a framework that calls for early consideration of key system planning activities and development requirements (Booher 1990). MANPRINT was developed in part as a consequence of documented problems found in weapon system acquisitions due to a failure to properly integrate manpower, personnel, and training into the weapon system. MANPRINT is a comprehensive management and technical effort designed to ensure integration of all relevant information from seven MANPRINT domains. Three domains are relevant to the current case study:

- Personnel—The human aptitudes, skills, and capabilities required to operate, maintain, and support a system in peacetime and war.
- Training—The instruction and resources required to provide [Army] personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support [Army] systems.
- Human Factors Engineering—The comprehensive integration of human capabilities and limitations into system definition, design, and evaluation to promote effective soldier-machine integration for optimal total system performance.

1. Twenty Years of MANPRINT on Patriot: Synopsis

Patriot evolved over a two-decade period, during which it incorporated new features and added characteristics appropriate for future systems. The system became increasingly complex and demanded substantial knowledge to comprehend the system’s operation. A logic model was developed for the Operation Iraqi Freedom incidents with the intention to understand how the fratricide incidents that occurred proved to be almost inevitable. The three key factors/blocks in the logic model, basically a causal network, are described briefly below:

- Undisciplined Automation—This is the consequence of designers automating certain functions and then users implementing the now automated functions without regard for consequences on overall human performance. For the Patriot system, there was insufficient attention paid to whether operators could adequately perform residual functions, what the impact was on the reliability of decisions, and how operators should be trained.
- Automation Bias by Operators—A series of operational tests revealed that the Patriot system’s automated engagement logic was subject to misclassification

problems, which in turn were not fully addressed during system software upgrades. A recognition of this shortcoming was not included in operator training, and operators assumed a “fascination with and blind faith in the technology” as cited in the fratricide Boards of Inquiry reports. There was an over reliance on the outputs of automated functions with a resulting decision bias.

- Lack of Comprehension of the Tactical Situation—Patriot system operators were trained to successfully complete routine drills, rather than to actively construct a parallel mental model of an unfolding tactical situation and possess a deeper understanding of the operational picture. This lack of situational awareness becomes apparent when scenarios that differ substantially from those trained are confronted, leading the operator with little choice but to depend wholly on automation for any decisions. The Army Board of Inquiry stated, “the system is too lethal to be placed in the hands of crews trained to such a limited standard.”

Another factor was the practice of assigning relatively inexperienced personnel to the ECS and ICC. This practice accentuated the problem of automation bias. The ARL report is careful to point out that this problem stemmed not from the ability levels of the operators, but rather from a composite effect of decisions made by developers, engineers, trainers, and others that led to a gradual but unchecked shift from manual control to a mode of supervisory control. This change was not reflected in training practices or personnel assignment practices.

Observations offered in the ARL report suggest a number of factors concerning why the MANPRINT domains (in particular personnel, training, and human factors engineering) were not adequately addressed during the growth of the Patriot as a system. Patriot grew from a system slightly improved from its predecessor, the 1960s era Hawk missile system, to a complex weapon capable of anti-ballistic-missile defense. A review of MANPRINT documents and test reports indicates that the methods of MANPRINT assessment also did not progress with advances in technology, instead viewing potential weaknesses through a framework of manual control. However, many of the problems with human performance started to show up in earlier test results, and potential showstoppers were disregarded or overlooked. Such problems were often deemed “isolated training issues” that could be shunted for correction to institutional or unit training. But the emerging supervisory control capacity of the system required a new front-end analysis, job restructuring, and training that addressed situational analysis, problem-solving, and decision-making. In addition, Patriot system operator expertise was not sufficiently developed.

The ARL report recognized that the MANPRINT community was not solely responsible for failing to call attention to the serious consequences of control and training issues. The entire Patriot team, from the materiel and combat developers, to the U.S. Army Training and Doctrine Command (TRADOC) Systems Manager (now called

TRADOC Capability Manager), the test and evaluation community, and the prime contractor did not address the recognized problem. The bottom line is that the organizational inclination is for the larger community to render human performance and training issues as “inconvenient, troublesome problems with no clean (i.e., technology-oriented) solution” (Hawley 2007, p. 10).

The human-performance conditions and operational context that impacted the fratricides led to two actionable items: (1) reexamine the roles of operators, the command and control structure, and the concepts of automation to realize the human supervisory control task and (2) examine the real level of expertise needed to operate the Patriot system in contemporary operating environments.

2. Defense Science Board Report

The Defense Science Board created a task force to examine the lessons from the Patriot systems performance in Operation Iraqi Freedom and assess whether these lessons could be incorporated into future development of the Patriot or follow-on systems. The Board convened between August 2003 and June 2004, issuing a final report, which is classified, later that year. In the unclassified summary report (DSB 2005), the Board declared that the operating protocol was largely automatic, and the operators were trained to trust the information generated by the system’s software. The proposed solution was “more operator involvement and control in the functioning of the Patriot battery, which will necessitate changes in software, displays, and training” (DSB 2005, p. 2).

3. International Training of Patriot Operators

Patriot is in service in Egypt, Germany, Greece, Israel, Japan, Kuwait, the Netherlands, Saudi Arabia, and Taiwan. The training for Patriot operators preparing for operational assignments is done differently by some national defense forces. In Israel, for example, Patriot operators participate in 4 months of initial training, rather than 10 weeks, and are then allowed to observe in the ECS under supervision, rather than serve immediately as an operator (Hawley, Mares and Giammanco 2006). They remain in this supervised position for up to 1 year, depending on their individual skill progression. Upon successful skill progression, they receive 2 months of higher level training and are then considered qualified to serve as a tactical control assistant. From this pool, the top students are selected for officer training, where in addition to officer basic training, they undergo a 4-month air defense officer course and then serve as a low-level Tactical Control Officer. After an additional year of experience in a unit enhanced with substantial simulation-based training, qualified soldiers participate in 2 more months of air defense tactics training and are then qualified to serve as high-level Tactical Control Officers. Altogether, more than 30 months of training combined with unit experience is required for the needed level of expertise to serve as a Tactical Control Officer, undergoing rigorous, performance-based certification. There is a similar story with the training in other nations (i.e., Germany and Denmark). The salient point is that these militaries require much more training and job preparation to become Patriot operators than do U.S. forces.

4. Terminal High Altitude Air Defense

The THAAD is a separate air defense missile system that complements the lower-tier Patriot system and the Navy's upper-tier Aegis ballistic missile defense system. It is designed to destroy short-range and medium-range theater ballistic missile threats. Although originally an Army program, the program office for the THAAD is part of the Ballistic Missile Defense Systems under the Missile Defense Agency. The first THAAD firing battery was activated in 2008 and received all hardware and components for full operation in early 2012. The interceptor missile has a range of about 124 miles. Of concern to the present case study is the potential for the lessons from Patriot not being applied to the relatively early deployment of the THAAD. As suggested by the Defense Science Board (2005), the lessons from the Patriot are useful to be incorporated into other air defense systems.

E. Patriot Summary and Case Study Implications

The implications of this case study address upgrading training for a system as its technical capabilities are undergoing an upgrade. The training that may have been acceptable for an early operational capability is not necessarily adequate as the mission addresses new threats and the system takes advantage of technological advances. In the case of the Patriot missile defense system, upgrades over a period of more than 20 years were not countered with enhancements to operator training. Just as advances in electronics, sensors, and propulsion pave the way for a more capable missile defense, so too do advances in training technology, the learning sciences, and the engineering of instruction pave the way for a better trained operational force.

This case study has demonstrated the impact of early program issues with systems training, the lack of training development with technology upgrades, an acceptance of the status quo, and an aftermath of consequences. The early training issues began surfacing even with the baseline system. Research on the operator's task reflected its complex nature. The initial job task analysis resulted in an almost unwieldy task of air battle engagement broken into more than 100 subtasks and steps. Further, the training analysis did not appear to keep up with the system upgrades. The training of routine drills with limited scenarios was criticized in the Board of Inquiry report after the Operation Iraqi Freedom fratricides; the report called for training that would improve high-level judgment. Unit evaluations supported the view of overall preparedness based on satisfactory performance of routine battle drills. Also, evidence was published that training routines for Patriot operators did not generalize, or transfer, to more complex, stressing scenarios with conflicting information.

The larger implications are drawn from the lessons offered in the Hawley (2007) report. The first is that if a flawed system concept (i.e., training approach) is not corrected early and carried into development, it becomes more difficult to modify and achieve the needed level of performance, in this case human performance. It was not the case that the automation of certain system functions could override the impact of limited training. A deeper understanding of the operator-system relationship was needed, especially as the nature of this relationship changed with system upgrades.

The second lesson is that training issues really matter. The training lacked substantial rigor, surprise elements, and guided practice. There were early attempts at developing such training approaches, such as the experimental Intelligent Conduct of Fire Trainer developed in the late 1980s by Bolt, Beranek & Newman Inc. that overlaid student performance and expert solutions in a real-time simulation, with feedback from an articulate expert in the form of computer text (Youngblut 1995). Advanced development of such intelligent tutoring systems that afforded more rigorous training was possible, but not pursued. The third lesson from this report is that testing must be more comprehensive and rigorous. In the case of testing a post-deployment build, limited user test for the Patriot in the 2006 time frame, the impact of soldier performance was a secondary issue, more of a supportability issue. Human performance was measured on the basis of utility judgments by users, which are subjective and of limited value in addressing performance issues. They may be useful in a formative evaluation, but not as indicators of the ultimate outcome of operator-system performance. Test players are not adequately trained for analysts to clearly understand the issues emerging from test data. Was it a system or operator problem?

The program manager should work closely with the training community to develop options for individual and collective training for operators, maintainers, and support personnel that are based on training effectiveness evaluations to maintain skill proficiencies and reduce individual and collective training costs. The program manager is responsible for developing training system plans to maximize the use of new learning techniques, simulation technology, embedded training and distributed learning (DoD Instruction 1322.26), and instrumentation systems that provide “anytime, anyplace” training and reduce the demand on the training establishment.

Another source of guidance comes from TRADOC Pamphlet 525-8-2, *The Army Learning Concept for 2015*, which describes the transformation of the soldier training process (TRADOC 2011). Instead of traditional lecture-based classroom training, soldiers will be engaged in collaborative learning exercises; receive tailored, blended training; and have anytime, anywhere access to instructional material. Tedious classroom presentations will be replaced by engaging, scenario-based exercises that instructors will author as needed to represent the most current knowledge from theater. The ultimate goal of these and other recommendations is to provide soldiers with relevant, personalized training in a technology-enabled format that maximizes training benefits. Whether this concept is carried into the early plans and development for future weapon systems remains to be seen.

Finally, how well an operator initially learns the tasks is of great importance to overall system performance. Many studies indicate that the single most important factor affecting skill retention is the degree of original learning (Arthur, et al. 1998). If the Patriot operator is trained well from the start, it will have a lasting impact on the operational effectiveness of the Patriot system.

F. Recommendations

- System upgrades require training upgrades; improvements in systems hardware and software must be accompanied by corresponding training enhancements at all levels.
- As hardware and software are upgraded in the system, consider similar technical upgrades in training systems.
- Move training assessment to the left (earlier) in the acquisition cycle.
- Employ training lessons learned over the years in Patriot to the THAAD program.

3. Embedded Training in the Future Combat Systems

—*John E. Morrison*

A. FCS Background

The concept for the FCS program arose from a series of studies conducted in the 1990s under the Army After Next (AAN) initiative and culminated in the Army's Transformation Campaign Plan, which was described by then Army Chief of Staff General Eric Shinseki (2000). AAN studies revealed a gap in U.S. ground force capabilities based on lessons learned from post-Cold War operations and performed analyses of then-current Army assets. Despite their unparalleled lethality, survivability, and staying power, U.S. heavy forces lacked strategic responsiveness and deployability and had an unacceptably large logistical footprint. In contrast, the Army's light forces were responsive and deployable but were deficient in terms of lethality and survivability and lacked staying power. To fill this capability gap, Army planners proposed to transform the Army into a lethal yet strategically responsive fighting force. This transformation process entailed reorganizing the combat force into smaller and more standardized units equipped with the light, highly mobile, and lethal combat weapon systems that would be wirelessly linked to enable network-centric operations. These proposed weapon systems were designed and developed under the collective umbrella of the FCS program.

As depicted in Figure 3-1, the FCS was conceived as a family of weapon systems, comprising eight types of manned vehicles: Mounted Combat System, Infantry Carrier, Non Line-of-Sight Mortar, Non Line-of-Sight Cannon, Reconnaissance and Surveillance, Command and Control, Medical, and Recovery and Maintenance.[2] Although these FCS vehicle types differed in functions and capabilities, they shared a common chassis and engine to reduce the logistical burden of maintaining the combat force. Furthermore, all FCS vehicles were originally designed to be limited in size and weight to allow them to be transported by the Air Force's large fleet of C-130 aircraft. Perhaps the most innovative aspect of the FCS was that it connected the disparate vehicles and systems to a common network. This network was designed to allow the family of FCS vehicles and systems to act as a coherent whole and to conduct network-centric military operations.

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[2] The FCS Program also included unmanned systems, but they were not considered relevant to the embedded training capability and are not considered here.

One of the key services provided by the FCS network was the embedded capability to train anywhere and anytime in live, virtual, and constructive simulation environments.

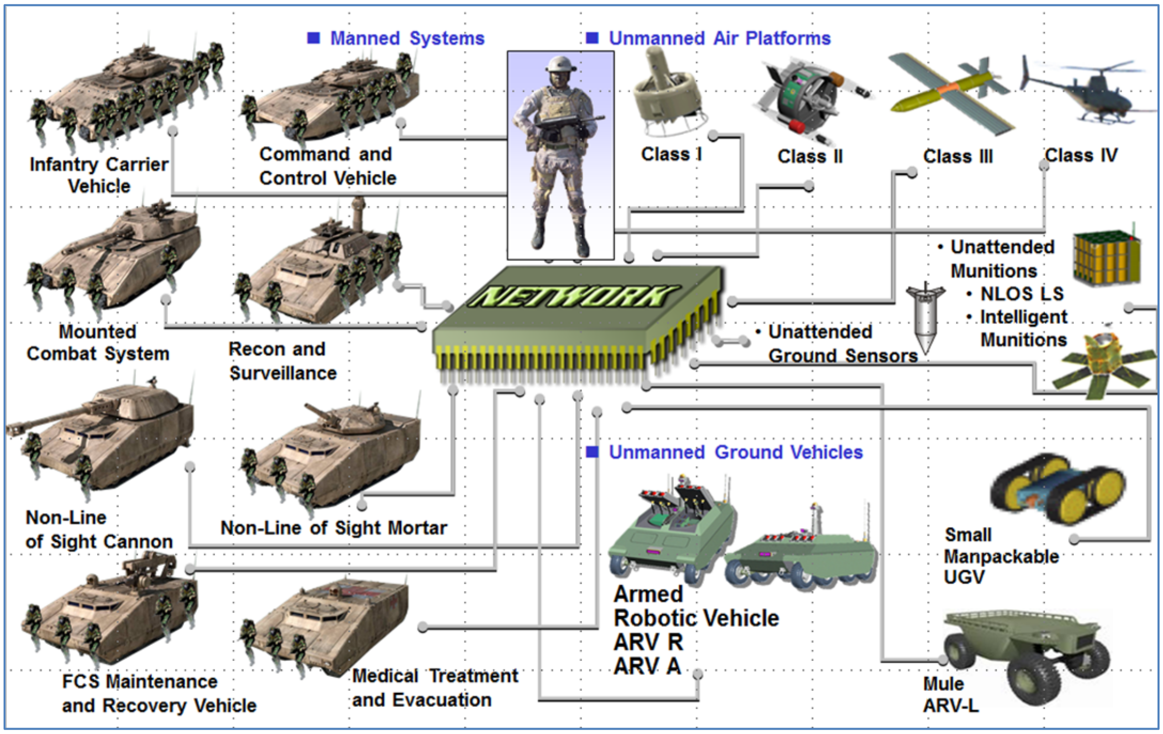

Figure 3-1. FCS conceptual diagram as of September 2004.

B. FCS System Overview

Many of the core warfighting concepts and technologies in the FCS program were first raised in the AAN program in the 1990s, including the capability to provide embedded training. As described in a 1996 Defense Advanced Research Projects Agency (DARPA) paper, the AAN would require new ground combat platforms that embed training capabilities into onboard command, control, communications, computers, and intelligence systems (Gully et al. 1996). These embedded training capabilities would include tactical engagement simulation (TES) for live simulation and after action review systems for enhancing performance feedback from training exercises and combat operations.

The emphasis on embedded training was carried through to conceptual phase of FCS program. In May 2000, DARPA awarded contracts to four industry teams to study technologies, missions, and tasks required to conduct combat operations anticipated for the FCS. According to the original solicitation in January 2000, the team proposals must include the following:

> A training system/capability for the soldier as well as maintenance. The system training concepts are encouraged to be imbedded, minimizing additional equipment and manpower requirements. In addition, the cost of

> training should be addressed as well as the advantages/disadvantages of virtual vs. actual operation of the equipment during training operations. (DARPA 2000, para 4.5.i)

In April 2003, TRADOC released the FCS Operational Requirements Document (ORD). The FCS ORD identified seven Key Performance Parameters (KPPs), which are measurable performance objectives that FCS must attain to enable its mission and operational goals. Training was called out as a separate KPP[3] for FCS, which was unprecedented for an MDAP weapon system at that time. The FCS Training KKP was defined as follows:

> The FCS FoS [family of systems] must have an embedded individual and collective training capability that supports live, virtual, and constructive training environments. (Department of the Army 2003)

In the FCS ORD, critical technologies were identified for each FCS KPP. Two critical technologies were deemed necessary to meet the Training KPP objective:

- Computer Generated Forces (CGF), which provides the virtual and constructive simulation training environment for embedded training.
- Tactical Engagement Simulation System (TESS), which enables valid simulations of enemy and friendly weapons effects required for live training.

Note that the FCS embedded training system is not an appended embedded training system or add-on feature of the weapon system. Indeed, one of the first principles for design of the FCS embedded training system is that it be developed in parallel with and fully integrated into the operational system design (Shiflett 2009). As shown in Figure 3-2, the FCS embedded training system was integrated with four of the five architectural layers of the FCS network: transport (telecommunications), services (middleware that provides interoperability within and across platforms), applications (software packages for 10 battle command functions), and sensors/platforms (distributed and networked array of multi-spectral sensors). This level of integration ensures that no additional systems or capabilities are required to immerse soldiers in realistic embedded training scenario.

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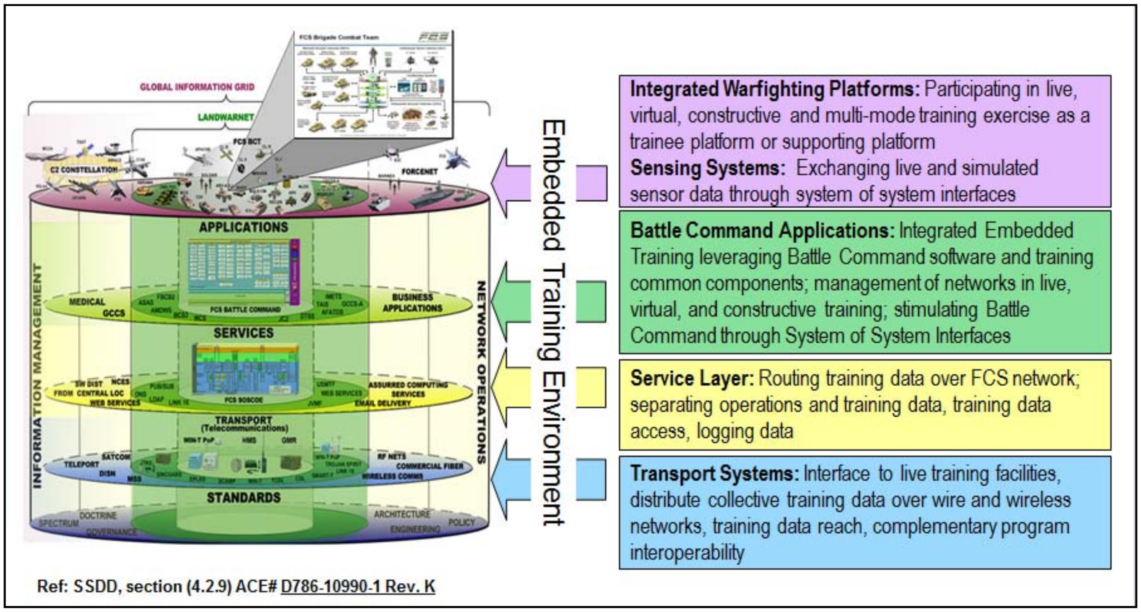
[3] The other six KPPs were Joint Interoperability, Networked Battle Command, Networked Lethality, Transportability, Sustainability/Reliability, and Survivability.



Integrated Warfighting Platforms: Participating in live, virtual, constructive and multi-mode training exercise as a trainee platform or supporting platform
Sensing Systems: Exchanging live and simulated sensor data through system of system interfaces

Battle Command Applications: Integrated Embedded Training leveraging Battle Command software and training common components; management of networks in live, virtual, and constructive training; stimulating Battle Command through System of System Interfaces

Service Layer: Routing training data over FCS network; separating operations and training data, training data access, logging data

Transport Systems: Interface to live training facilities, distribute collective training data over wire and wireless networks, training data reach, complementary program interoperability

Ref: SSDD, section (4.2.9) ACE# D786-10990-1 Rev. K

From Shiflett (2009).

Figure 3-2. Diagram showing integration of embedded training functionality into operational system architecture.

C. FCS Technology Development

FCS technologies, including its embedded training system, were developed over a 10-year period (from 2000 to 2009). Figure 3-3 is a time line of significant events that relate to the FCS system as a whole and to the embedded training system in particular. Phase 1 (Concept Development) of FCS began in 2000 with the DARPA solicitation and lasted approximately 2 years. In March 2002, the Army chose the team of Boeing and Science Applications International Corporation to serve as lead systems integrator overseeing key aspects of the FCS development process. At Milestone A in May 2002, the FCS Program moved to Phase 2 (Technology Development). One year later (May 2003) at Milestone B, the Defense Acquisition Board approved FCS to move to Phase 3 (System Development and Demonstration). In August 2004, the lead systems integrator awarded 21 companies contracts to develop FCS vehicles, platforms, and hardware/software (Tiboni 2004). The product-development phase lasted for about 5 years and had been planned to lead to a Go/No Go Milestone C decision of whether the program should enter into the production phase. However, in June 2009, Secretary of Defense Robert Gates issued an acquisition decision memorandum canceling the FCS program. In explaining his decision, Secretary Gates said that there were “significant unanswered questions concerning the FCS vehicle design strategy…we must have more confidence in the program strategy, requirements, and maturity of the technologies before proceeding further” (Gates 2009). However, as discussed below, the unanswered questions that led to cancellation of the FCS program did not pertain to its training system or related technologies.

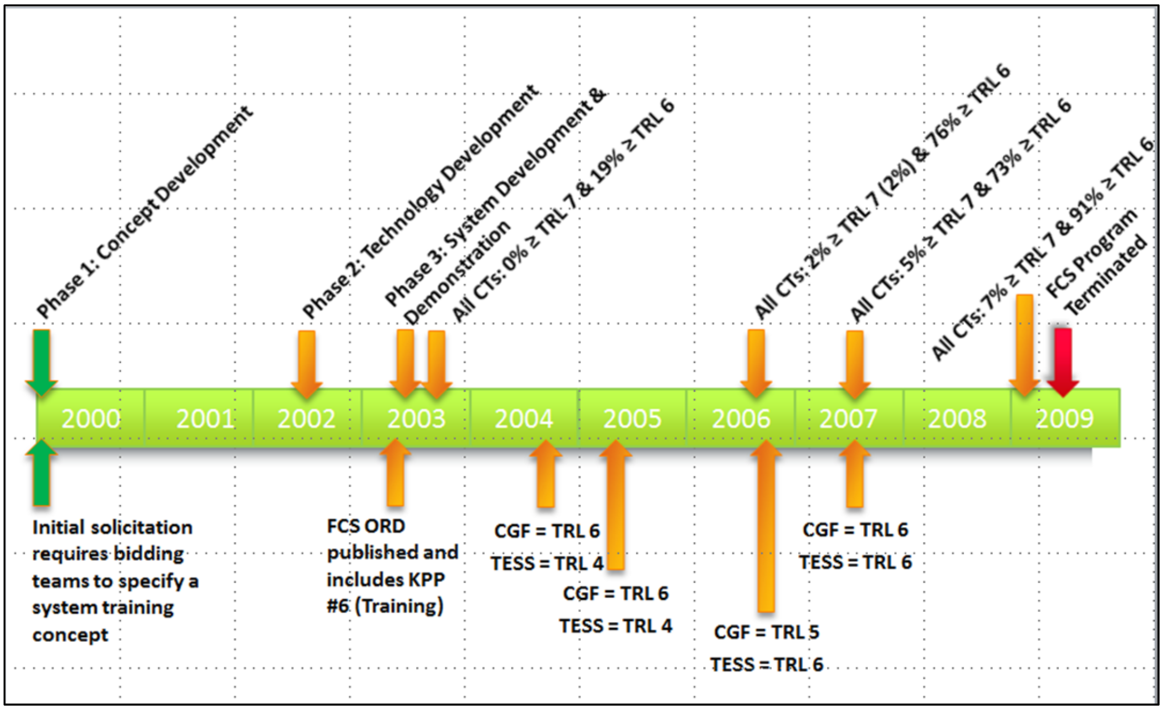


Figure 3-3. Technology-development events relating to the FCS as a whole (above the time line) and to the embedded training system in particular (below the time line).

Concerns about maturity of FCS technologies were expressed throughout the program design and development. As early as the initiation of the System Development and Demonstration (SDD) phase in 2003, it was noted that many of the proposed FCS technologies were insufficiently mature to start vehicle system development (GAO 2003). Maturity of FCS critical technologies was tracked using the Technology Readiness Level (TRL) construct pioneered by the National Aeronautics and Space Administration and frequently used in DoD acquisition programs incorporating new technologies. Appendix B describes Technology Readiness Levels 1 through 9 as the GAO has applied the three levels to the FCS program. The GAO has consistently maintained that it is an industry best practice and DoD policy preference to mature technologies to at least TRL 7 before the start of product development—that is, before the start of SDD phase, which occurred in May 2003. TRL 7 requires that the technology be in prototype form and possess the form, fit, and function of the finished product as demonstrated in a realistic environment. For the FCS program, the Army had a substantially more lenient maturity goal: All critical technologies for FCS had to be at TRL 6 before going into the production phase that had been scheduled for May 2009.

Table 3-1 tracks the actual maturation of the critical technologies from the start of the FCS SDD phase in 2003 until just before program cancelation in January 2009. The interpretation of progress made over that time differs depending on the maturation goal adopted. According to the GAO goal, the FCS program was not ready to enter the SDD phase in 2003 and had made little progress since then, showing only 7% of technologies fully mature in 2009. By the Army goal, nearly all critical technologies (91%) had matured to TRL 6 by January 2009, and the remaining four critical technologies at TRL 5 were scheduled for TRL 6 demonstrations before the system-of-systems preliminary design review (Milestone C) that was scheduled for May 2009. However, unlike the previous three assessments, not all critical technologies listed in the January 2009 assessment had been validated by an independent review team. Previous independent review teams downgraded initial assessments provided by the LST, and questions remained about maturity of three critical technologies in particular: (1) the Joint Tactical Radio System ground mobile radio, (2) Mobile Ad-hoc Networking Protocols, and (3) Wideband Networking Waveforms. So even using the more lenient standard, there was some concern that all FCS technologies would not be sufficiently mature to enter the production phase of development.

Table 3-1. Technical Readiness Levels for FCS critical technologies.

Technical Readiness Level	Program Start 2003		August 2006		July 2007		January 2009	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
TRL ≥ 7	0	(0)	1	(2)	2	(5)	3	(7)
TRL ≥ 6	10	(19)	35	(76)	32	(73)	40	(91)
TRL ≤ 5	42	(81)	11	(24)	12	(27)	4	(9)
Total critical technologies	52		46		44		44	

Note: Data from GAO (2009).

Table 3-2 focuses on the two critical technologies associated with the embedded training system. This table indicates that the CGF critical technology was relatively mature soon after the start of SDD. The independent review team justified the TRL 6 assessment of computer generated forces as follows:

> OneSAF CGF [computer generated forces] has been in continuous use for at least a decade. It is being upgraded/expanded to provide a greater variety of the conflict interactions, but urban dismounts being tested in FCS-C2, stabilization and peacekeeping are not yet included. (Delaney et al. 2004)

Table 3-2. Technological Readiness Levels for embedded training critical technologies.

Critical Technologies	September 2004[a]	April 2005[b]	August 2006[c]	July 2007[d]
Computer Generated Forces	6	6	6	6
Tactical Engagement Simulation System	4	4	5	6

[a] Data from *Independent Review of Technology Maturity Assessment for Future Combat Systems* (Delaney, et al. 2004)

[b] Data from GAO (2006).

[c] Data from GAO (2007).

[d] Data from GAO (2008).

In contrast to CGF technology, the TESS started at TRL 4 but achieved TRL 6 by the July 2007 assessment. The initial problem was that the TESS architecture had not been developed in any detail and it was not clear how it would interface with other FCS systems (e.g., the Joint Tactical Radio System) and external live-simulation architecture (e.g., the Common Training Instrumental Architecture used at Army Combat Training Centers). Most of these issues were resolved with development and demonstration of the OneTESS architecture that successfully integrated OneSAF and live training simulation architectures. Thus, while some of the FCS critical technologies lagged in development, the technologies related to embedded training (CGF and TESS) were relatively mature well before the planned start of production in 2009.

D. FCS Training System Issues

Even though the FCS program was canceled, the embedded training system is worthy of study if for no other reason than it was the training system in the most ambitious Army modernization program in history. An argument can also be made that future net-centric-capable systems will provide enhanced opportunities to maximize the potential of embedded training systems. Furthermore, as discussed below, there are three specific aspects of the embedded training system within the FCS that argue for including it as a case study as well.

1. Embedded Training as Integral Capability

The embedded training system was considered an essential capability for the entire FCS family of systems. The perceived capability gaps in deployability and responsiveness gave rise to the requirement to train anytime and anywhere for a variety of potential missions. Given these requirements, it would be difficult to imagine, much less design, an FCS family of systems without an embedded training capability.

2. Embedded Training as Key Performance Parameter

One of the unique aspects of the FCS program was that it elevated training to the level of a system KPP. This ensured that training remained a high-visibility concern throughout the history of FCS program. And as the current Joint Capabilities Integration Development System manual notes, having training as a system KPP provides a hedge against the historic problem of trading away training resources to supplement the increased cost of the parent system (DAU 2012).

Another perhaps less obvious implication of raising training to KPP status is that it requires the system developer to monitor critical training technologies. For the FCS, that amounted to increased concern about the maturity of CGF and TESS technology. In fact, that led to the early identification and eventual resolution of problems of integrating TESS with systems within the FCS platforms and with architectures of live training instrumentation systems at major combat training centers. Had this technology not been monitored, the TESS issue could have languished from lack of attention and not been addressed appropriately.

3. Embedded Training as Technology Spin Out

When the FCS program was canceled, some of the FCS technologies were transitioned to the Brigade Combat Team Modernization (BCTM) program. Not included in this transition was the Manned Ground Vehicle (MGV), which was the primary platform for the embedded training system. As a result of the MGV cancellation, many of the features of the embedded training system were lost. However, some aspects of the FCS embedded training were incorporated into the BCTM Embedded Training Software (BETS). Perhaps the most important aspect transitioned from the FCS program was the design principle that BETS be integrated into the operational BCTM Network and Mission Command Software. The final version of the BETS was demonstrated and delivered to the BCTM program in May 2011 (Shiflett 2011). That the FCS embedded training system was successfully spun off to the BCTM program attests to the maturity and viability of its design principles.

E. FCS Summary and Case Study Implications

The FCS program embedded training system is considered a good model of training development for MDAPs. Discussed below are positive aspects of the FCS embedded training systems design and development that apply to MDAPs in general and not just to the FCS in particular.

1. Stress Training from Outset

Even in the earliest conceptual discussions of the proto-FCS system in the AAN studies, embedded training was considered an essential capability of the proposed weapon system. As the FCS moved into the initial conceptual phase, studies and analyses were required to assume that embedded training was a fundamental system capability. Then as the FCS program moved to the Technology Development (TD) phase, training was defined as a KPP. This stress on training enabled the topic to emerge and be maintained as a principal consideration throughout the design development of the weapon system.

The early incorporation of training into system design and development is consistent with current guidance on the Joint Capability Integration Development System. The Joint Capabilities Integration Development System Manual (dated 19 January 2012) maintains that training requirements should be addressed in parallel with planning and materiel development (DAU 2012). Specifically, this manual asserts that training KPPs are required for all MDAPs. Although formal KPPs are not required for Milestone A (entry into TD phase), the guide requires that an initial/draft training plan be developed during the Materiel Solution Analysis phase prior to Milestone A. The FCS program essentially performed these studies in the pre-TD phase of conceptual development from 2000 to 2003.

2. Integrate Embedded Training with Weapon System

One of the more remarkable aspects of the FCS embedded training system was the degree to which the embedded training system was integrated into the FCS operational hardware and software. Such integration provides different types of benefits. First, integration of training with operational system benefits training by (1) maximizing training fidelity in that it allows individuals and units to train as they fight and (2) enabling the ability of units to train anytime and anywhere the operational systems are available—including during deployments. Second, integration benefits overall system development by reducing needless duplication in software development and by avoiding increases in size, weight, and power requirements associated with appended training systems.

Another important, albeit nonobvious, benefit of the integration of training and operational systems is that it reduces baseline divergence of training systems and operational software (TRADOC 2006). As illustrated in previous cases, such divergence is common if the training system is developed as a separate component from the operational system. In contrast, integrating training and operational system provides an inherent constraint for ensuring that training upgrades are synchronized with system upgrades.

3. Monitor Maturity of Critical Training Technologies

Simply stressing training in materiel development is not enough. Training system developers need to provide due diligence by closely monitoring the maturity of technologies required to implement training effectively. For FCS, the TESS technology was identified as potentially problematic. However, early identification of problems enabled developers to find appropriate solutions. Similarly, newer training systems may be dependent upon other advanced technologies, such as models of text understanding, methods for measuring eye fixations and movements, and brain activity monitoring. If such technologies are deemed “critical” for the training system, then developers must monitor their maturity closely to ensure that the technologies will actually work as intended in the operational environment.

F. Recommendations

- Stress training from outset—All MDAPs (including rapid track acquisitions) should address training as an integral part of the acquisition program.
- Move training assessment to the left (earlier) in the acquisition cycle.
- Integrate embedded training with MDAP weapons systems.
- Monitor technical maturity of critical training technologies.
- Provide training with the fielded system as a package to realize full capability of new systems.

4. Mine Resistant Ambush Protected Vehicle

—Anthony Ciavarelli

A. Mine Resistant Ambush Protected Vehicle Background

1. Mine Resistant Ambush Protected Vehicle Acquisition Historical Summary

A GAO study stated that 75% of all casualties in Iraq and Afghanistan as of July 2008 were attributed to improvised explosive devices (IEDs). To reduce this casualty risk, the DoD initiated the Mine Resistant Ambush Protected Vehicle (MRAP) Rapid Acquisition Program, which sought to develop better armored vehicles (GAO 2009).

The DoD MRAP acquisition program began in 2007 and used a "tailored" rapid acquisition process to rapidly acquire and field protective vehicles. The essential elements of a rapid acquisition process were (1) the use of proven technologies and commercially available products; (2) the establishment of minimal operational requirements; and (3) the use of a concurrent development, test, and evaluation framework. DoD made the acquisition of MRAPs its highest priority and maintained direct control of system integration (Feickert 2008). Figure 4-1 shows an RG 33 MRAP.

Source: http://www.military-today.com/apc/rg33_mrap.jpg.

Figure 4-1. RG 33 MRAP.

The 2008 Defense budget included the MRAP funding in excess of $8 billion for 7,700 vehicles across the services, and after massive production in 2009, the cost rose to $22.7 billion for 14,000 MRAPs. Schedule and cost performance were deemed to be very good overall.

B. MRAP System Overview

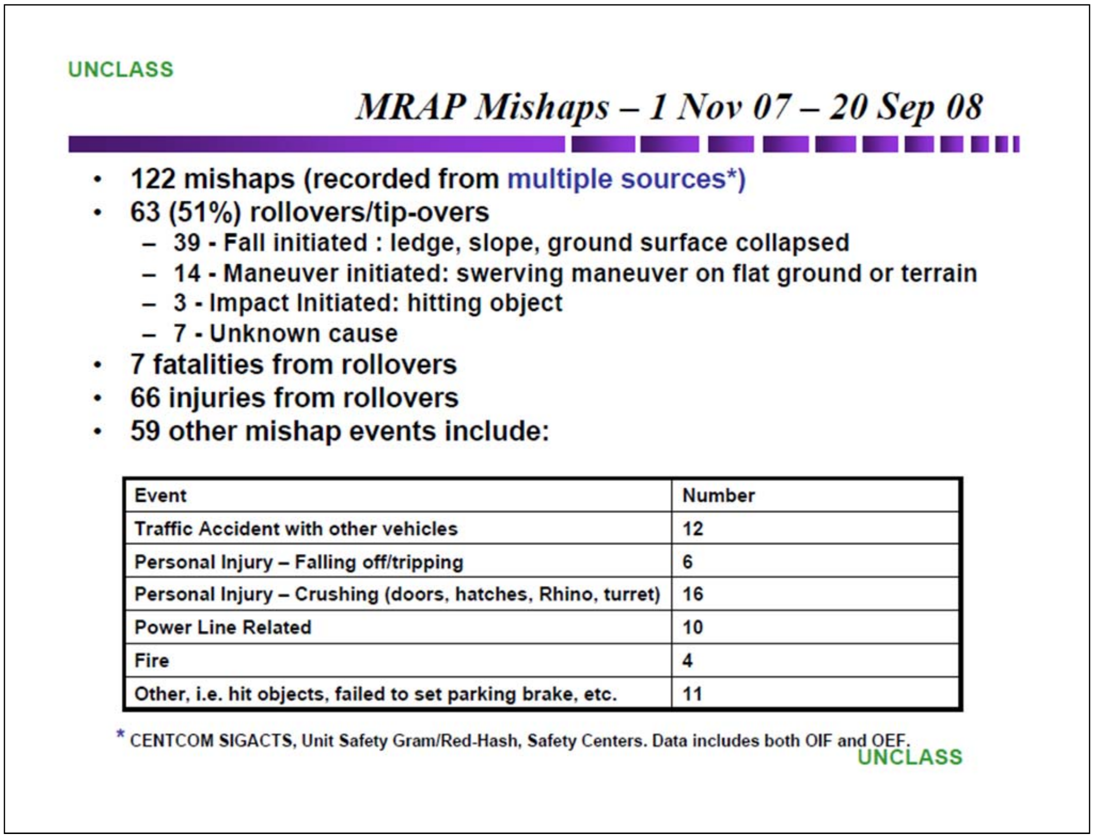
Following rapid production and deployment of MRAP vehicles (2007–2008), it became clear that sustaining a fleet of about 15,000 vehicles "could pose significant challenges" (Feickert 2008, GAO 2008). The exact vehicle type and inventory varied greatly by military service, and they also varied by the type of mission and theater of operations; but all vehicles were designed in a similar fashion—tall and heavy. The vehicle designs gave ample protection, in most cases, but at a price of increased vehicular accidents—primarily vehicle rollovers.

1. Vehicle Safety Issues

There were over 60 MRAP-related mishaps between November and June 2008; over one-half of these were rollovers (USMC 2008). The Marine Corps reported that the cost of MRAP mishaps occurring from 2008 to 2010 was 360 lost work days and $3,462,221 in material losses (HQ USMC 2010). HQ USMC also identified the major cause of most MRAP accidents as follows: "When reported, LACK OF TRAINING is identified in the narrative for class A/B (the most serious) mishaps 60% of the time."

The death of three U.S. Army Special Forces (Green Berets) in Afghanistan on 29 June 2008, which occurred when their RG-31 MRAP rolled into a river, raised awareness of the high risk of rollovers in the MRAP fleet. As a result, DoD began to study alternatives for mitigating rollover mishaps, including vehicle redesign and additional driver training to help reduce rollover risk (Feickert 2008). Figure 4-2 shows the mishap statistics reported in one study that raised awareness of the safety of MRAP operations in Iraq and Afghanistan (Rice 2008).

As shown in Figure 4-2, the majority of MRAP mishaps were rollovers. Nearly 75% of the rollovers occurred outside urban areas—typically when driving on soft road shoulders, riverbanks, and berms, and over poorly constructed bridges. In most cases, drivers were unaware of the hazard, such as poorly constructed bridges and berms. When encountering an imminent rollover, drivers typically over-corrected steering because they were not trained to initiate proper counter-maneuvers. Following a rollover, some personnel perished because they could not exit the vehicle in time to avoid a resulting fire or drowning in the river or canal water.



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MRAP Mishaps – 1 Nov 07 – 20 Sep 08

- **122 mishaps (recorded from multiple sources*)**
- **63 (51%) rollovers/tip-overs**
  - **39 - Fall initiated : ledge, slope, ground surface collapsed**
  - **14 - Maneuver initiated: swerving maneuver on flat ground or terrain**
  - **3 - Impact Initiated: hitting object**
  - **7 - Unknown cause**
- **7 fatalities from rollovers**
- **66 injuries from rollovers**
- **59 other mishap events include:**

Event	Number
Traffic Accident with other vehicles	12
Personal Injury – Falling off/tripping	6
Personal Injury – Crushing (doors, hatches, Rhino, turret)	16
Power Line Related	10
Fire	4
Other, i.e. hit objects, failed to set parking brake, etc.	11

* CENTCOM SIGACTS, Unit Safety Gram/Red-Hash, Safety Centers. Data includes both OIF and OEF.

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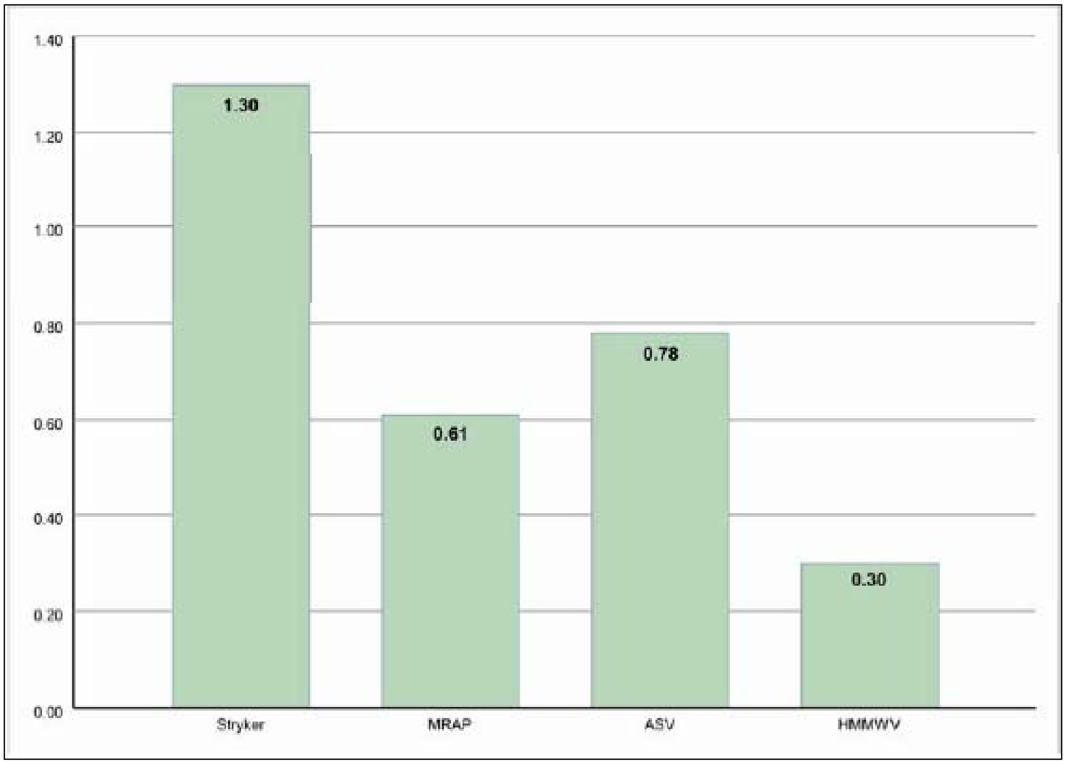
Source: Slide from presentation by Rice (2008)

Figure 4-2. Summary of MRAP mishaps in FY2008.

Figure 4-3, taken from Rice and Rodriguez-Johnson (2009), compares several vehicle types by average monthly rollovers per 1,000 fielded vehicles. The figure shows that the standard high mobility multipurpose wheeled vehicle (HMMWV) (unarmored) vehicle was also subject to rollovers, but such rollovers were mainly due to excess speed and turning too severely and fast, not due to vehicle design. Evidence from anecdotal input (discussed later) did show a marked increase in rollovers for the Armadillo (armor upgraded) HMMWV. Figure 4-3 shows that the MRAP-type vehicles had a greater rollover rate than the standard HMMWV. The Stryker (a large, heavy MRAP-style vehicle) had about four times the standard HMMWV rollover rate, and the "generic" MRAP had about twice the rollover rate of the standard HMMWV.



Source: Graph from Rice and Rodriguez-Johnson (2009).

Figure 4-3. MRAP Mishaps, November 1, 2007—August 31, 2009, by type.

In an AP story, Lardner (2008) described the first fatal MRAP rollover:

> A crew of six Soldiers from the 101st Airborne was traveling over an irrigation canal in a Caiman 9-foot tall, 19 ton MRAP when the driver turned too quickly and the rear tires sank in the dirt shoulder which collapsed under the vehicle. The driver tried to maneuver out of the rut by accelerating and turning quickly but the vehicle flipped over on its side and rolled down an embankment into the canal. It sank into 10 feet of water causing the power to shut down, leaving the crew in darkness. Some crew members were fortunate to find an air pocket and were later rescued. But two crew members died by drowning.

But it was the aforementioned death of three U.S. Army Special Forces (Green Berets) in an RG-31 MRAP that dramatically raised awareness of the high risk of MRAP rollovers (Feickert 2008).

2. U.S. Marine Corps Operator Anecdotal Report

Some key highlights of an anecdotal experience depicting the impact of simulation training for the armored HMMWV (Armadillo version) are presented below. The U.S. Marine (Yates 2012) describing the sequence of events is a graduate of the MOVES

Institute Naval Postgraduate School and served as the simulation officer for the Operator Driving Simulator (ODS).

> As the IED became the primary lethal threat to troops in Iraq we rushed to up-armor our vehicles. The "Armadillo" armor kit that was applied to the 7-ton MTVR [Medium Tactical Vehicle Replacement] truck was a huge improvement in survivability for troops riding in the back. Until the first MRAPs were fielded the MTVRs with the Armadillo kit were the most survivable wheeled vehicles in Iraq from an IED blast. However, the accident rates began to skyrocket when trucks were upgraded with the Armadillo. In April 2006 the first two Armadillo equipped MTVRs arrived at MCAGCC [Marine Corps Air Ground Combat Center] for use by Marines in the Mojave Viper Exercise. Within a week of the first two trucks being delivered the driver of one truck rear-ended the truck in front of him because he was following too closely and the brakes would not stop the vehicle before it collided. The damage to one vehicle was so severe that it had to be returned to the Oshkosh factory for a repair of a crack in the chassis (>$100k). Over the next six weeks at MCAGCC there were an average of two operator error vehicle mishaps with Armadillo equipped MTVRs every week and many involved injury to Marines. Armadillos did not accelerate, brake, or corner like a regular MTVR. Yet, in the hurry to field the more survivable Armadillo package *there was no driver training component developed* for the modified vehicle. Marines never saw or got a chance to drive an Armadillo equipped truck before deploying to Iraq because they were being shipped directly to Iraq as soon as they rolled off the assembly line at Oshkosh...

Following the introduction of hands-on Driver Simulator training, a remarkable improvement was observed:

> In the words of the Operations Officer from the Mojave Viper Support Detachment, "*the impact of the ODS trainer was immediate and dramatic.*" From the day that ODS training began in May 2006 through the end of that calendar year there was not another mishap involving an Armadillo variant MTVR. The accident rate had dropped from two per week to zero.

The evidence from mishap statistics, this Marine's experience, and the experience of others as reported by U.S. Marine Corps safety specialists (Rice 2008, USMC 2008, USMC 2010) pointed to the need for greater attention on providing safety instruction and improved training for MRAP drivers.

C. MRAP Training Systems Development

1. Perceived Training Need

The need to improve training for these new types of vehicles was recognized by the Joint MRAP program office shortly after the first vehicles were fielded. The U.S. Marine Corps awarded a logistics and training support contract in November 2007 to support “MRAP University” located at the U.S. Army’s Red River Army Depot, Texarkana, Texas. The university provided a schoolhouse course that included 10 hours of classroom instruction and limited “hands-on” driving instruction, which may have offered little opportunity to practice under operational driving conditions. Course materials were designed for both operators and maintainers (Weirauch 2011).

The U.S. Marine Corps fielded the first vehicle trainer, the Common Driver Trainer. The U.S. Marine Corps driving simulators are produced by FAAC (Aerotech Training and Simulation Division). The reconfigurable simulators are placed at active and reserve U.S. Marine Corps training centers and bases located in the United States.

The U.S. Army began a new procurement for driving simulators in 2011 when it awarded a $36 million contract to Raydon Corporation to build 11 MRAP virtual trainers. The Army also initiated a “MRAP familiarization” course at the U.S. Army McGregor Range. This course is a 1-day event that covers “general maintenance and basic operation of the vehicle.”

2. MRAP Simulation Training

a. Common Driver Trainer

The Common Driver Trainer is an MRAP vehicle trainer that includes high-resolution visual and motion simulations representing the MRAP vehicle operational environment. It is built on a full-motion base that rotates in all axes (six degrees of freedom). The system displays a variety of virtual world scenes that simulate on- and off-road terrains and obstacles. It has a control room for the training operator/instructor and observer.

The Common Driver Trainer can conduct scenario-based training under varying environmental conditions (day-night, sandstorm, IED contact/explosive threats). The training includes scenarios designed to teach avoiding and controlling the vehicle in a rollover situation. The Common Driver Trainer provides driver training for a variety of vehicles, including M1A2 Abrams, Stryker, and MRAP varieties, using reconfigurable vehicle cab and software routines. The Common Driver Trainer was fielded in November 2007 and is now used by the U.S. Marine Corps and the U.S. Army.

b. Operator Driving Simulator

The ODS was developed to accommodate a wide variety of trucks—from HMMWVs to larger heavy tank haulers. The simulator uses a “generic” vehicle cab that can be reconfigured using dashboard kits and modular software changes.

There are various versions of the simulator, including fixed-site facility or self-contained mobile trailers. Some of the key features of ODS are as follows:

- ODS can be fielded in several configurations (fixed sites and trailer options).
- Motion cuing systems include six-degree-of-freedom full-motion seats
- Visual environments are scalable and range from 180 to 225 degrees.
- FAAC ODS has a six-level training curriculum, varying in degree of difficulty.
- FAAC ODS has a trainee-performance tracking system that monitors and scores trainee progress on over 50 parameters.
- The Instructor Operator Station provides display information regarding trainee performance status and provides input to the instructor for any required remedial training.

An expanded version of ODS was developed to provide two-crew training for missions related to route clearance. This version includes controls and display kits that enable the operator to operate external cameras and sensors. Also included is a surface-scraping simulation of terrain deformation and soil disturbance.

c. Egress Simulator

The MRAP Egress Trainer (MRET) is designed to improve the ability of the vehicle crew to quickly and safely egress from a rollover event. This simulator was constructed in response to lessons learned from rollover mishaps indicating that inability to escape the vehicle after rollover was a key factor in lethality of these mishaps.

The MRET simulates rollovers under “dry conditions” and trains the drivers and crew to a safe egress, considering external environment and vehicle load. Training is accomplished by teaching correct crew procedures and hazard avoidance, using a combination of classroom training and scenario-based simulations. Some of the key features of the MRET include the following:

- MRAP cab is interchangeable.
- Cab is on a frame that allows 360-degree rotation.
- Crews are trained to egress using specific crew-coordination procedures.
- Scenario training includes simulated blocked doors and damaged vehicle egress.

D. MRAP Training System Issues

1. MRAP Acquisition Issues

Some of the key issues regarding MRAP procurement and initial deployment are as follows:

- Accelerated deployment schedule was required to meet an urgent need for protection from IED threat, overriding the systems training needs.
- Rapid Acquisition did not give early attention to incorporating sustainment in the form of logistical and training support functions.
- MRAPs designed for survivability against mines and IEDs were prone to rollovers and also were difficult to egress safely following a rollover mishap, necessitating early systems training and simulators.
- Accident rate (mainly rollovers) was too high.
- Most MRAP drivers did not attend a driving school—most had to learn on the job (when deployed)—and standard "truck driver training" did not adequately address key operational hazards encountered in Iraq and Afghanistan.
- Drivers had little or no opportunity to practice driving.

Following an analysis of numerous rollover mishaps, the U.S. Marine Corps safety personnel and commanders agreed that MRAP drivers should follow these specific procedures to help ensure safe operations of the vehicles (USMC 2008):

- Brief route familiarization, including road and terrain hazards before the mission.
- Conduct a pre-mission inspection of vehicle tire pressure, steering, and brakes.
- Know your vehicle driving performance limitations.
- Be especially cautious when roadway clearances are narrow, traveling at or near canals and rivers, and unimproved roads.
- Avoid hard turns and sudden maneuvers.
- Adjust speed to conditions, and do not overcorrect steering.
- Recognize and avoid rollover hazards and conditions.
- Maneuver cautiously to avoid rollover or collision hazard.

2. Learning Objectives

Based on analysis of mishap data and U.S. Marine Corps guidelines above, here is a list of some appropriate top-level training objectives that could have been enunciated and used as a point of departure for MRAP training system development:

- Given description of on-road or off-road conditions the student will be able to identify hazards and rollover risk. (Knowledge – concept – classification)
- The student will be able to describe procedures for driving up and down a grade in mountainous terrain. (Knowledge procedure – task steps)
- The student will be able to describe procedures for driving on wet and muddy roadways, off road, on soft road shoulders, near riverbanks, and on bridge crossings. (Knowledge procedure – task steps)
- Given various photographic or video examples of road conditions, the student will be able to define the hazard level depicted. (Knowledge concept – definition of concept attributes)
- When approaching a hazardous road or off-road condition, the student will be able to maneuver the vehicle to avoid the hazard or drive to lessen the risk of rollover. (Skill – pattern recognition – complex perceptual motor skill)
- The student will be able to avoid or recover from an impending rollover event. (Skill – complex perceptual motor skill)
- Following a rollover event, the crew will be able to coordinate egress task activity and follow correct procedures for safe egress. (Skill – individual complex perceptual motor and crew communication)

E. MRAP Summary and Case Study Implications

This chapter summarizes a case study regarding the acquisition of MRAP vehicles and the impact of delayed training system development for the MRAP program.

Most of the casualties in Iraq and Afghanistan were due to injuries sustained from IEDS. To address the IED threat, the DoD initiated a program of rapid acquisition of MRAP vehicles. The focus was on vehicle designs that protected military personnel against the IED threat. The MRAP rapid acquisition program was very successful in quickly fielding numerous vehicles, within program cost and schedule. And there was little question that the MRAP designs provided much better protection against IEDs. But the MRAP vehicles were much taller and heavier than those previously fielded vehicles and therefore were very vulnerable to rollover mishaps that resulted in extensive material damage and numerous fatalities. The mishap rate (mainly rollovers) was too high. MRAPs had three times the rollover mishap rate of conventional (unarmored) HMMWVs. The MRAPs designed for survivability against mines and IEDs were not only prone to rollovers but also were difficult to egress safely following a rollover mishap.

Safety publications and GAO and congressional reports indicated that the root cause of many of these mishaps was traced to inadequate training—soldiers and Marines were not adequately trained to drive the new vehicles and were not prepared to encounter the hazardous driving conditions found in Iraq and Afghanistan.

From 2007 to 2008, which represented one of the most significant vehicle fielding time periods, there were 122 MRAP mishaps, and over half of these vehicle mishaps were rollovers. The vehicle designs—relatively higher and heavier than other vehicles—contributed to the mishap rate. For example, the Caiman MRAP stands 9 feet tall and weighs 19 tons. Other factors were the poorly constructed roads, low bearing weight river berms, and bridges found in the operational theaters.

Following such a rash of mishaps, military leaders expressed concern about the adequacy of training for drivers. The U.S. Marine Corps and the U.S. Army supported augmenting training with additional schoolhouse training to address the issues of vehicle design and common road hazards. Consideration also was given to the use of training simulators that could model selected MRAP vehicle driving characteristics and could train to scenarios with realistic terrain conditions.

Training development started after the vehicles were deployed, and it followed operational lessons learned by addressing both augmented driver training and the need for rollover training. Two major simulator developments took place: the ODS and the Common Driver Trainer. Both simulators used reconfigurable truck cabins and modular software, and both simulators trained to scenarios that included hazardous terrain conditions.

It did appear, however, that the training was developed more or less ad hoc and without significant formal DoD sponsored front-end analysis and without an extensively documented training requirements analysis. And while the simulators are equipped with some form of trainee performance monitoring, it is not clear from the literature whether or not the training is "performance or competency" based.

The MRAP case study report included a brief overview of training evaluation methods, both objective evaluation (training-transfer experimental methods) and subjective (training-attribute instructional-quality checklists). The evaluation section of the report was included as a point of departure for possible follow-on study efforts that would cover measurement methods and metrics for evaluating the status of training at different phases of system acquisition and for assessing the quality and training effectiveness following implementation and operations. Indeed, it is suggested that training evaluation continue during entire life cycle of the weapon system.

The overall conclusion of the MRAP case study report is that an argument can be made for improving weapon system acquisition by establishing, funding, and enforcing a disciplined methodology for timely and systematic training development and timely delivery of training, whether or not that acquisition is on a rapid or normal time scale.

It is therefore recommended that follow-on efforts consider addressing the issue of identifying, defining, or redefining the development framework, processes, and methods for training development and continual training system evaluation.

F. Recommendations

- All MDAPs (including rapid acquisitions) should address training as an integral part of the acquisition program.
- Move training assessment to the left (earlier) in the acquisition cycle.
- Any MRAP follow-on efforts should include a comprehensive training systems plan as an integral part of the program.
- Refer to Section 4.D.2. for a list of system-specific learning objectives for future systems development.
- Provide training with the fielded system as a package to realize full potential/capability of new systems.

5. Husky Mounted Detection System

—*Rebecca Grier and Jennifer Brooks*

A. Husky Mounted Detection System Background

1. System Description

The Husky Mounted Detection System (HMDS), developed for the Joint Improvised Explosive Device Defeat Organization, is being used by route-clearance patrols to detect mines and IEDs in support of Operation Enduring Freedom. The HMDS was executed as a rapid acquisition program in response to the large number of casualties that occurred in Operation Enduring Freedom. The HMDS was first deployed in 2008. A new version (First Generation, Second Edition) was deployed in October 2011. A total of 180 systems have been deployed to date, with a third edition now in development. Each combined system (HMDS and Husky) costs approximately $500,000.

B. HMDS System Overview

The HMDS (Figure 5-1) consists of a 4-panel, 51-channel ground-penetrating radar (GPR) mounted at the front of a Husky vehicle and a touch-screen graphical user interface (GUI) mounted inside the cab of the Husky. During route-clearance missions in theater, the single occupant (soldier operator) drives the Husky, stops upon audio alert of a suspected target, examines the GPR data using the GUI mounted in the cab of the Husky, and determines whether to mark the suspected target for further interrogation. If an alert is further investigated it slows the rate of advance of the route-clearance patrol. If an alert is ignored the Husky or another vehicle in the patrol could be hit by a mine or IED. The Husky and the HMDS are considered separate systems. All operators of HMDS must be trained on driving the Husky before receiving training on HMDS. This case study will discuss only HMDS training, not the Husky training.

Figure 5-1. HMDS in field.

C. HMDS Training Systems Development

To provide deployed military personnel a desperately needed capability as quickly as possible, the HMDS was developed using rapid acquisition. Unlike in traditional acquisition, in rapid acquisition the role of the life-cycle logistician is not well defined. One consequence of this for HMDS was that no training plan was developed before the first systems were deployed in 2008, although training has evolved since then. The time line of this evolution is represented in Figure 5-2.

The HMDS training initially only occurred in theater and was conducted by the original equipment manufacturer. Although the training was scheduled to last 1 week, soldiers were often pulled away from HMDS training to complete other operational tasks or training. In some cases, the soldiers were receiving no training on HMDS before operating it. If soldiers received the entire week of training, they began with a day of classroom training, followed by 4 days in the actual system. Over the course of training (both classroom and in vehicle), soldiers spent approximately 4 hours on troubleshooting, and 24 hours on threat detection and identification; the remaining time was spent on system constraints, GUI operation, and vehicle operations. Although the majority of soldiers are certified Husky operators before training, the GPR panels, which are mounted to the Husky for IED detection operations, significantly change the performance of the vehicle. As a result, some training is devoted to learning to drive the Husky with the GPR panels.

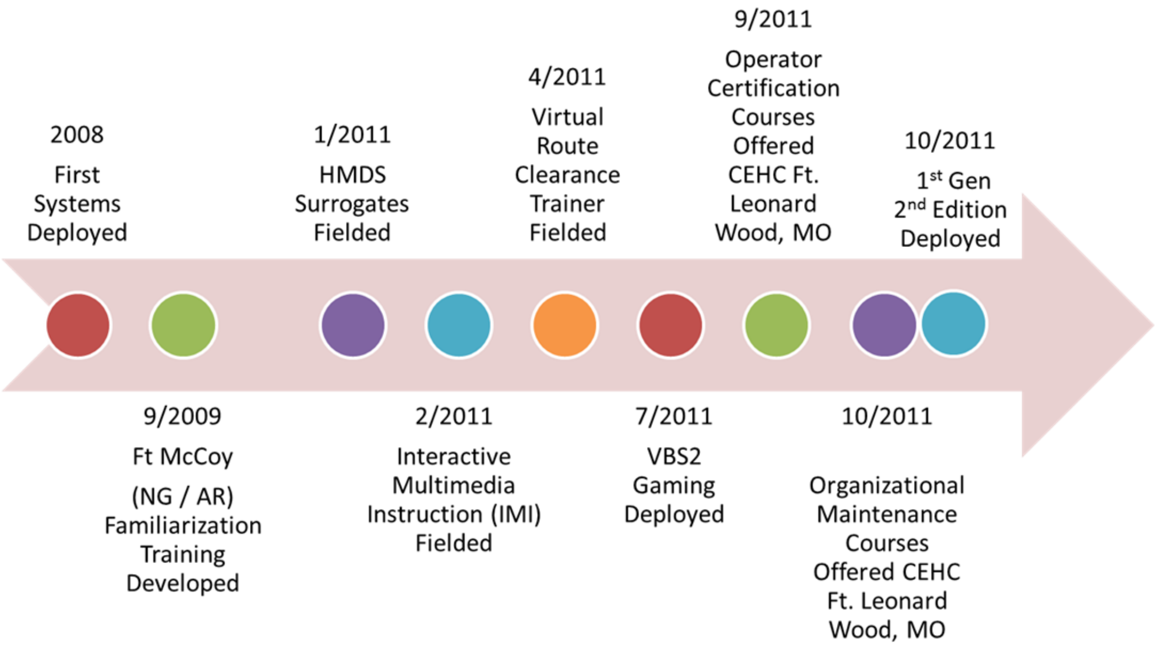


Figure 5-2. Training development time line.

The student-teacher ratio for this training was 4:2, but instruction while operating the HMDS in an actual Husky is one on one. Since the Husky cab only seats one person, for instruction to occur, the soldier sits in the cab of the Husky with the overhead doors open, and the instructor is outside the cab leaning into the vehicle. Instruction covers the following: (1) driving the Husky with the mounted GPR panels, (2) detection and identification of threats, (3) maintenance troubleshooting, (4) use of GUI, and (5) how system constraints affect operation in different environments (e.g., speed, terrain, etc.). When the system was originally deployed, the soldiers who were not in the Husky waited for their turns. On average, soldiers would receive 8 hours of instruction in the Husky during the 4 days of in-vehicle instruction.

The training enhancements that have occurred since 2008 have made training available before deployment and improved the quality and cost effectiveness of the training. The majority of operators are now receiving training before deployment. The first major enhancement to the training was the development of familiarization training for the National Guard and Army reserves. This training was first delivered at Ft. McCoy in 2009 (a year after the HMDS was initially deployed). This training did not replace the in-theater training, but the familiarization training increased the likelihood that operators had some training before operating the system. In some cases, one soldier received the training and then another soldier was selected to be the in-theater operator.

The next development in the training of HMDS did not occur until January 2011, with the fielding of surrogate systems. Before this development, millions of dollars were spent replacing panels damaged during training, when the operators would run the panel into the ground because they were unfamiliar with how the Husky handled with panels for the HMDS mounted. Each of the four GPR panels in the HMDS costs $40,000. The surrogate systems fielded in January 2011 cost only $15,000 each, and an individual surrogate system panel costs $1000. Currently, 26 surrogate systems are fielded, but the plan is to field a total of 55 systems.

The detection capability of the surrogate panels is done with software, since there is not any actual detection capability in them. Also in the surrogate system, there is software that enables an instructor to introduce up to 10 various targets to the operator. Specifically, when the operator gets to a predetermined point, the system provides an alarm and presents an image similar to what the operator would see on an actual system. The operator then makes a determination of “target” or “no target.” The instructor has three methods available for selecting targets: radio-frequency identification tag, GPS-based, and “tick wheel” or distance-based. All three methods are available for use in each vehicle.

The third development in HMDS training, interactive multimedia instruction, was fielded in February 2011. Interactive multimedia instruction is delivered via CD and enables the operator to review system start-up procedures, preventive maintenance checks and services, as well as GPR scans of threats that have been encountered by other operators. This training can be completed anytime, anywhere and provides soldiers who are waiting for their turn in the vehicle a chance to interact with HMDS. It also increases exposure to a wider diversity of GPR scans (false alarms and threats) during training.

In April 2011, the next development in training, the virtual route clearance trainer, was fielded. The virtual trainer exists in four tractor trailers, each with multiple stations inside. Some or all of the 26 positions in a route-clearance patrol, including the HMDS operator, can participate in simulation-based training that mirrors real-world variables such as terrain, weather, IEDs (including smoke, fire, and explosions), and friend and foe vehicles. Three more virtual route-clearance trainers are in development. In addition, the latest version of Virtual Battle Space (VBS2), a gaming system used by the military to expand vehicle training, included HMDS as one of the vehicle systems the gamer can select. The version of VBS2 with HMDS was deployed in July 2011.

Finally, in fall 2011, a full operator-certification course and the first maintainer-certification course were offered at Counter Explosives Hazard Center, Ft. Leonard Wood, MO. Operator training is still provided in theater as described above. The operator certification course now offered at Ft. Leonard Wood is similar to the training described above as well, but the student-teacher ratio is 8:3.

D. HMDS Training System Issues

The training that was provided upon initial deployment was not a mature training concept. It took 1 year from initial deployment for any improvements in the training. It took a further 2 years for an operator certification course to be offered in the United States. This delay in training resulted in an HMDS that was not as capable as it could be in the hands of a well-trained crew, and the life-cycle costs increased due to damage to expensive components in early operational training.

1. Impact on Performance

Initially, the only training occurred when soldiers arrived in theater. This training was limited by the constraints of the vehicle, as well as the operational environment. Training was further interrupted by other demands pulling soldiers away from training. Therefore, soldiers were often operating the system with minimal training. Some soldiers who did not receive a complete training cycle believed that the primary benefit of the system was to take a hit by a mine or IED and not to detect threats (stated by one soldier during an operational test of HMDS).

Even if the soldiers did believe that the primary goal of HMDS was to detect threats, due to lack of training areas or simulators, they had limited exposure to the variety of threats and false alarms that could be encountered. As a result, their ability to determine the nature of a threat was impaired. Interactive multimedia instruction increases soldiers' exposure to different GPR scans, which improves their ability to distinguish between threats and false alarms.

2. Life-Cycle Costs

The lack of mature training not only affected soldier performance, it also affected the life-cycle cost of HMDS. The student-teacher ratio was reduced from 4:2 to 8:3, which lowered the cost of the training. In addition, there are now several options (including the VBS2, the virtual trainer, and the interactive multimedia instruction) for increasing operator exposure to HMDS features.

As noted above, soldiers who did not receive proper instruction on the system operated the system as if it were to take the brunt of a mine or IED. Each Husky-HMDS costs $500,000. Training soldiers to understand the most effective way of using the system saves the cost of replacement systems.

The GPR panels are an expensive and delicate subsystem of HMDS. When soldiers were learning to drive the Husky with the installed panels, many panels were damaged (e.g., some soldiers ran the panels into the ground while driving through a ditch). According to NIITEK, the manufacturer, millions of dollars were being spent every few months to replace damaged panels. Surrogate systems have been fielded that can be used to instruct on driving with the panels. Besides costing less than the GPR panels, these surrogate panels are much studier. As a result, they are replaced with less frequency than the fully functioning panels.

E. HMDS Summary and Case Study Implications

It took 2 years for proper HMDS training to be developed. Because training development did not begin until 1 year after deployment, it took 3 years for HMDS to reach its full effectiveness. Not only is this a disservice to our military personnel, it is an inefficient use of program funds. All acquisition programs must recognize that full system effectiveness will not be reached until a training plan is in place to achieve the full system operational capabilities.

F. Recommendations

- All MDAPs (including rapid acquisitions) should address training as an integral part of the acquisition program.
- Move training assessment to the left (earlier) in the acquisition cycle.
- “Right size” student-to-trainer ratio.
- Allow for training to be completed without interruptions.
- Provide training with the fielded system as a package to realize full potential/capability of new systems.

6. P-8A Poseidon

—*Charles G. Sanders*

A. Poseidon Background

The P-8A Poseidon (Figure 6-1) is a long-range anti-submarine warfare; anti-surface warfare; intelligence, surveillance, and reconnaissance aircraft capable of broad-area, maritime and littoral operations. The P-8A will be a multi-mission aircraft, unlike the single-mission design of the P-3C. This broader mission responsibility adds to the complexity of crew training and is discussed in more detail later in this chapter. The U.S. Navy plans to purchase 117 P-8As (a modified Boeing 737) to replace its fleet of P-3C aircraft. The first test aircraft began formal flight testing in late 2009. Initial operational capability is slated for 2013.

Source: http://www.boeing.com/defense-space/military/p8a/docs/P-8A_overview.pdf.

Figure 6-1. P-8A Poseidon.

The P-8A will conduct rotational deployments, consistent with the Fleet Response Plan, consisting of three 6-month phases (Basic, Intermediate, and Deployed). In November 2005, the Navy announced that the P-8A preliminary design review (PDR), conducted from October 31 through November 4, was the best major weapons system PDR it had ever reviewed; however, there was no mention of training or simulators in the document. A successful critical design review was completed in July 2007. Dates for the Operational Test and Evaluation, a significant stage in the acquisition process where system training is evaluated, were TBD as of May 2012.

B. Poseidon System Overview

To determine the current developmental status of the P-8A, a number of reports were reviewed and are summarized below.

1. Technology Development Strategy (January 2012)

The P-8A Poseidon program employs an evolutionary acquisition approach, with Increment 1 planned to achieve Milestone C, with full rate production and initial operating capability planned for FY13. Increment 2 is currently being managed as an Engineering Change Proposal, with planned introduction in FY16. This Technology Development Strategy applies to the third increment. As a follow-on Increment of the P-8A program, this effort is designed to be a modification to the weapon system that is expected to be operationally fielded by FY13.

The Increment 3 modification will provide both new and improved capability to the warfighter. The P-8A Increment 3 program intends to maximize the use of mature technologies, including non-developmental items, government-off-the-shelf technologies, and commercial-off-the-shelf technologies to reduce cost, schedule, and program risk.

The program will build on an open-application framework to provide an integration layer between the baseline aircraft architecture and capability subsystems. This approach is designed to take advantage of open-source development standards to produce application consistency with increased portability while maximizing competitive acquisition approaches and best-of-breed solutions.

P-8A Increment 3 is not a new start program; it is budgeted as a Project Unit (3218) within the P-8A Poseidon Project Element (0605500N). The P-8A baseline and defined Increments are described as Navy-only programs with joint potential in the future.

The evolutionary acquisition strategy was established and approved at Milestone B for the P-8A program in 2004. The delivery schedule for Increment 3 is based on the delivery of the baseline program in FY13 and Increment 2 delivery in FY16.

Following the Milestone A decision, the program entered the Technology Development phase, followed by Engineering and Manufacturing Development entry at Milestone B. The strategy for production and deployment of Increment 3 is based on retrofit of the fielded P-8A weapon system. This is expected to begin in FY19, following the completion of Integrated Test.

The details of program-sustainment strategy are included in the Life Cycle Sustainment Plan, which will be updated to include Increment 3 capabilities as required. This indicates that plans for training of P-8A crew are not finalized. Plans for the P-8A major contracts described in this document do not include the training-development contract.

2. Defense Acquisition Executive Summary (February 2012)

The Program Manager's estimate for full rate production has changed from April 2013 to June 2013. This change is the result of a 2-month delayed start of Live Fire Test and Evaluation due to test asset availability. The program is currently fully funded.

The Defense Acquisition Executive Summary reported delays in integrated test execution, and the T&E rating remains Yellow against the contracted plan. Due to inefficiencies in test execution, the program has not yet achieved execution of the integrated test program per the plan. The Initial Operational Test and Evaluation start date was moved from April 2012 to June 2012 based on demonstrated test execution performance. Although early P-8A flight-test instrumentation and flight-test maintenance immaturity slowed initial progress, flight-test efficiencies have improved.

3. Program Assessment Report (February 2012)

The Training Systems and Government Services Division of Boeing continues the process of planning to optimize the overall schedule by making changes affecting a combination of Contract Line Item Number 0503 and LRIP-Phase 2. The Training Systems and Government Services Division is also evaluating workaround plans to improve the Part Task Trainer-Phase delivery. There were no known training issues noted in this report.

C. Poseidon Training Systems Development

The Navy Training Systems Plan (NTSP) dated June 2010 was reviewed by CNO staff for approval. Based on the NTSP dated June 2010, the P-8A training program will consist of initial and follow-on training for operator and maintenance personnel. Enlisted Air crewman Operator training will be provided by Center for Naval Aviation Technical Training Detachment (CNATT DET) Kaneohe Bay, which currently provides this training for the P-3A. CNATT Unit (CNATTU) Jacksonville will provide enlisted maintenance training for the P-8A. P-3A maintenance training is currently provided by CNATTU Whidbey Island and CNATTU Jacksonville.

Navy will utilize a combination of full-motion simulators, weapons tactical trainers, and aircrew part task trainers for P-8A crew training. There will also be a deployable mission readiness trainer and maintenance trainers. This mix is consistent with other programs as an appropriate means to balance capability and cost.

The NTSP states that the goal is to satisfy 90% of all P-8A aircrew training and Training and Readiness requirements in simulators or in a classroom environment. This is a significant increase over past programs, which historically rely on live training venues for meeting the Training and Readiness matrix requirements. Initially, Boeing will provide Interim Contractor Support for the aircraft training system.

The instructor cadre will consist of contractors and naval personnel, with Navy personnel providing training on tactics, operational employment, and check ride/certification events.

Initial training, primarily in support of developmental testing and evaluation, is in progress.

The plan is to transition squadrons from P-3C to P-8A during inter-deployment readiness cycle. Follow-on training for pilots and Naval Flight Officers will be provided by VP-30, the training squadron for the P-3 community. Air crewman Operator training will be provided by CNATT DET Kaneohe Bay. Maintenance training will be provided by CNATTU Jacksonville.

D. Poseidon Training Systems Issues

Five findings discovered during analysis of the P8A as a case study are discussed below with associated concerns and any follow-up actions.

1. Training Simulators are Not Networked

a. Finding

The NTSP indicates that all major training elements of DoD Directive 1430.13, Training Simulators and Devices, will be addressed. It also states that training plans will maximize new learning technologies, simulation technology, embedded training, and instrumentation systems to provide anywhere, anytime training.

b. Concern

There is no mention of networking P-8A training systems with other platforms to facilitate battle group or joint training. This should be at least an implicit requirement, since there is also no mention of battle group, fleet, or joint task force training that addresses how the P-8A will be incorporated into the fleet or the impact that the P-8A will have on fleet training. Without the ability to network P-8A training simulators to other platform simulators, the only way to train as a battle group is during live training on the training range. Informally, we have been informed by PMA-205 that they will be adding the capability to link the simulators.

c. Follow-up

In a phone conversation with PMA-205 (on 26 March 2012), it was found that the Navy has plans for the P-8A simulators to link into the Fleet Synthetic Training Joint events through the NCTE. It was further stated that an NCTE node is installed in Jacksonville, with future plans to install nodes in the other simulator locations. When asked why these plans are not addressed in the NTSP, it was stated that the latest version (dated June 2010) is under revision, with a draft release for review expected in the summer of 2012.

2. Training Packages Lag System Development

a. Finding

The NTSP highlighted one negative aspect of the training concept, in that if four squadrons are transitioned it would require hands-on labs to be conducted on LRIP aircraft. This issue is due to the revision to the transition plan, which is better synchronized with construction of a new building, but delivers training packages about a year later than originally planned.

b. Concern

Because of the requested SDD Training System Alternative Analysis, decisions on use of mission Part Task Trainers, Integrated Avionics Trainers, and Deployable Mission Readiness Trainers is not finalized. This adds risk to the effectiveness of the NTSP.

3. Contractor Determines Maintenance Training Requirements

a. Finding

Due to the change in maintenance concept from Contractor Logistics Support to organic, the number and type of organic maintenance courses have yet to be determined. A Training Situation Analysis is being conducted by Boeing to determine required maintenance training for the P-8A.

b. Concern

It is unclear why the Navy would ask the contractor to analyze the training requirements, instead of having the Navy training community do the analysis. It is the understanding of the study group that the Navy training community should be better qualified to determine the training requirements for the P-8A.

4. New Missions Imply New Training Requirements

a. Finding

With the increase in mission areas for the P-8A over the P-3C, the Training and Readiness matrix will be enlarged.

b. Concern

The NTSP does not address whether or not the crew will have any challenges in satisfying the increased training requirements or how the increase will be handled.

c. Follow-up

When PMA-205 was asked, current intent was stated (phone conversation, 26 March 2012) that the focus is primarily on three mission areas, with first priority placed on the anti-submarine-warfare mission and secondary time/resources dedicated to anti-ship and intelligence, surveillance, and reconnaissance missions. The experience of the study team is that primary focus on anti-submarine warfare is not consistent with the fleet training trend or Combatant Command requirements over the past several years.

5. Manpower Requirements for Logistics Support Increased

a. Finding

At contract award, the Program of Record decision for P-8A organizational level maintenance was established as full Contractor Logistics Support. However, in April 2007, Boeing submitted Contractor Logistics Support manpower requirements, via Contract Data Requirements List A00W-147, which showed a substantial increase in the manpower requirements over its November 2004 Contract Data Requirements List delivery estimate.

b. Concern

This may cause a significant impact on training resources. These increased requirements resulted in a corresponding increase in the total life-cycle cost estimate for the P-8A Program. This prompted the Program Manager to initiate a formal Business Case Analysis to determine the most cost-effective, best value approach, with an acceptable risk for P-8A organizational-level maintenance manpower. A Manpower Working Group was established to perform the Business Case Analysis.

New Additional Qualification Designation codes were developed for Navy pilots and Naval Flight Officers assigned to P-8A squadrons. In addition, new planned Navy Enlisted Classification codes were developed for P-8A maintenance personnel. The manpower requirements are significantly less than what is programmed in the FDYP for the P-3C. The P-8A will have a 9-member crew, in contrast to the 11-member crew for the P-3C. Note that this crew reduction comes in spite of the broader, multi-mission roles of the P-8A, which will require the logically broader training associated with the expanded mission capabilities.

E. Poseidon Summary and Case Study Implications

The P-8A training program will consist of initial and follow-on training for operators and maintainers. Due to the change in maintenance concept from Contractor Logistics Support to all organic, the number and type of organic maintenance courses had not been determined at the time of publishing this NTSP. Boeing completed the Training Situation Analysis in February 2010 and is currently (spring of 2012) in the process of conducting a Fidelity Analysis to further define the best courses of action for maintenance training.

A Training Situation Analysis is one of four major analysis activities of the Navy Training Systems Requirements Analysis, which is how the Navy satisfies Department of Defense Directive 1430.13, *Training Simulators and Devices*. It is intended to be the front-end analysis for training requirements. The other three analysis activities are Training System Alternatives Report, Training Device Requirements Document, and Training System Functional Description.

F. Recommendations

- Add the requirement to provide network connectivity and logical interoperability for the suite of P-8A simulators to ensure battle group, fleet, and joint task force training scenarios are fully supported and integrated with the live, virtual, and constructive training environments.
- Require analysis of the training load associated with the increase in mission areas to verify if the crew will actually have time and resources to satisfy all the mission and training requirements.
- Synchronize scheduling of simulators, training tools, and packages to be available to train for first deployment to ensure full system capabilities are available for operations.
- Expedite any changes to logistics and maintenance plans to include the full complement of maintenance personnel and training to define the best courses of action.
- Move training assessment to the left (earlier) in the acquisition cycle.

7. Findings and Recommendations

A. Findings

The training systems acquisition study has met the research objective of providing evidence from a range of case study programs to reinforce the need for training systems considerations to be incorporated early in the major Defense programs and on a continuing basis through the life cycle of a given system. The objective of this task is to identify and analyze the specific benefits of early and effective incorporation of training details into acquisition programs, particularly those with significant human systems interface requirements. The research provides an empirical base for the DoD training and acquisition communities to understand and justify the need to plan for efficient and effective operator, maintainer, and leadership training early and continually in the acquisition process to improve the resulting capabilities and utility of future complex weapon systems. The study results complement the latest DoD acquisition and training policies.

The Patriot Program, with more than 20 years of history, provides a strong case for upgrading training in the complex programs on a continuing basis through the system life cycle. The case study includes evidence from multiple sources that as the significant technical upgrades were performed over the years, the training tools and learning content were not enhanced to optimize the effectiveness of the evolutionary improvements to the system. As a general rule, systems upgrades should be accompanied with corresponding changes to the training content at all levels.

The Army FCS program provides a useful case study from a training perspective. Two aspects of the program stand out positively. The FCS program included training as a KPP, and as a family of net-centric weapons systems it provided netted infrastructure to host embedded training across the many programs and aspects of the system of systems. The Army recognized embedded training as an integral and essential capability for the entire family of systems. The FCS is considered to be a good model of training development for future MDAPs for three reasons: (1) training was stressed from the outset—training was included as a KPP; (2) embedded training was integrated into the FCS operational hardware and software; and (3) material developers worked with training developers to monitor the maturity of technologies and incorporate those technologies into the implementation of training.

The MRAP program was a rapid acquisition and therefore not subject to the deliberate acquisition planning process evidenced in our other case studies. However, with the rapid production and deployment of the vehicles in 2007–2008, the operators began to experience vehicle rollovers early on—some 60 MRAP-reported mishaps between November 2007 and June 2008, with over one-half of those attributed to rollovers. Lack of training was identified in the narratives for the most serious incidents 60% of the time. The need to improve training for these new types of vehicles was recognized early by the Joint MRAP program office. A series of driver trainers/simulators was developed as expeditiously as possible, but the lesson learned once again is to develop training in concert with systems development—even in rapid acquisitions.

The HMDS is another rapid-development program with some of the same training lessons learned as those found in the MRAP program. It took 2 years for robust HMDS training to be developed, with training development beginning a full year after deployment, and it took 3 years for the HMDS training to reach full effectiveness.

The Navy P-8A Poseidon program provides a useful case study from several different perspectives. First, it is a multi-mission aircraft replacing the single-mission design of the P-3C. The Poseidon is a modified Boeing 737, which has had a mature life cycle in commercial use dating back to the 1960s. Among the findings in this case study was the indication that the P-8A training simulators are not networked to other platforms to facilitate training for battle group, fleet, or joint task force operations. The change in maintenance concept by the manufacturer resulted in an increased load on Navy training, with analysis underway to define the best courses of action for maintenance training.

A number of acquisition and readiness issues are related to a full scope of systems training across the lifetime of any given program. Evidence has been documented here to expect more effective and efficient operations and lower system life-cycle costs through consideration of training system acquisitions as an integral part of every MDAP development.

B. Recommendations

The case studies in this report reinforce the value of determining comprehensive training needs over a program life cycle. Training simulators and learning content for the system operators and maintenance personnel should be developed before initial introduction of the hardware system. Detailed recommendations from this research are listed below:

- Move training assessment to the left (earlier) in the acquisition cycle.
  - Revise Defense and service acquisition policies to require earlier assessments of training.
- Training assessments should be early and continual.

- System upgrades require training upgrades; improvements in systems hardware and software must be accompanied by corresponding training enhancements at all organizational levels.
- All MDAPs (including rapid acquisitions) should address training as an integral part of the acquisition program.
- Impacts to training concepts and systems and devices should be part of the weapon systems development decisions.
- Integrate embedded training with MDAP weapons systems as feasible. Net-centric systems of the future provide special opportunities to build in embedded training.
- Monitor technical maturity to incorporate parallel critical training technologies.
- Provide training with the fielded system as a package to realize the full capability of new systems.
    - Training plans should be developed well before successive program milestones leading to the initial fielding of the hardware system, and similarly updated and packaged with every fielded system modification.
- Require MDAPs to provide network connectivity and logical interoperability for the suite of simulators and training tools so training scenarios are fully supported and integrated with the live, virtual, and constructive training environments.
- Synchronize scheduling of simulators, training tools, and packages to be available to train for first deployment to ensure full system capabilities are available for operations.

Appendix A.
About the Authors

Jennifer Brooks

Jennifer Brooks is currently a Research Associate III at the Institute for Defense Analyses. Her research includes performance analysis of the Husky Mounted Detection System (HMDS). From 2005 to 2006, she served as the Deputy Director of the Advanced Distributed Learning (ADL) Alexandria Co-Laboratory (Co-Lab), where she assisted the director in facilitating and directing an open, collaborative environment for learning technology research and implementation. Prior to being named deputy director, Jennifer was the lead software engineer in the ADL Co-Lab for 2 years. Jennifer is also Adjunct Faculty at George Mason University, where she has taught Cognitive Psychology and ADL-related courses. In 2004, Jennifer was selected as a National Science Foundation (NSF) Fellow for the Summer Data Policy Institute on the National Center for Education Statistics and NSF databases. Jennifer received a Bachelor of Arts degree in Psychology and a Master of Science degree in Computer Science at the University of North Carolina, Greensboro. She is currently working toward a Ph.D. in Computer Science and Machine Learning at George Washington University.

Anthony Ciavarelli

Dr. Ciavarelli, currently an IDA consultant, recently retired from his appointment as a Research Professor assigned to the MOVES Institute, at the Naval Postgraduate School, Monterey, California, where he taught and conducted research in human factors and training technology. He served as Associate Provost for Instruction at the Naval Postgraduate School from 1999 to 2001, where he was responsible for supervising curriculum updates and faculty academic services. In that position Dr. Ciavarelli spearheaded the school’s entry into Web-based instruction, including the development of a strategic plan and initiation of a faculty-development program for distance-learning support. Dr. Ciavarelli has a broad technical expertise that includes training requirements analysis, system engineering development, and human-machine interface design gained from over 20 years in the Aerospace and Defense Industries. He is an experienced Human Factors Engineer and Research Psychologist. Dr. Ciavarelli is well recognized for his research in military aircrew training and human performance assessment in operational settings. Dr. Ciavarelli was initially assigned to the School of Aviation Safety, at Naval Postgraduate School, where he taught Human Factors and Air Safety for 15 years. His work in aviation safety included a problem definition and training requirements study for the Navy and Marine Corp aviation night vision goggle training, for which he received a commendation letter from U.S. Navy, Office of CNO. His later research entailed the development and validation of online surveys designed to measure organizational climate and safety culture. Dr. Ciavarelli was awarded tenure in 1996 and promoted to full professor in 1999. He is the recipient of the Navy Superior Civil Service Award and two Meritorious Service awards for outstanding achievement in higher education. Dr. Ciavarelli was a study member on the Phase I, "Analysis of System Training Impact for Major Defense Acquisition Programs" report published in August 2011.

Rebecca Grier

Dr. Rebecca Grier is a Human Factors Psychologist with extensive experience working to improve human-computer interaction in military, intelligence, and commercial systems. She has conducted hundreds of human factors tests and evaluations in both the field and the laboratory. Currently, she is a Research Staff Member at the Institute for Defense Analyses (IDA) in the Science and Technology Division. In this role, she conducted a Human Systems Integration (HSI) test of the Husky Mounted Detection System (HMDS). Before joining IDA, Dr. Grier was the acting Technical Warrant Holder for Displays and Controls and the HSI lead for Aegis Modernization at Naval Sea Systems Command (NAVSEA). Previously, she served as the Lead Scientist for the Human Automation Interaction and Interface Design Team at Aptima, Inc. In this role she managed and led the work-centered development of a variety of military and intelligence software applications. Dr. Grier has also worked for NSWC Dahlgren, where she developed a plan to educate NAVSEA engineers about HSI, as well as for SBC Technology Resources Inc. (now AT&T Labs), designing and evaluating tools for customers and employees. Dr. Grier holds a Ph.D. and M.A. in Human Factors/ Experimental Psychology from the University of Cincinnati and a B.S. Honors in Psychology from Loyola University, Chicago.

Frederick E. Hartman

Fred Hartman, a member of the Research Staff at the Institute for Defense Analyses in Alexandria, VA, has specialized in problem-solving through use of modeling and simulations, assessing training systems, and technical applications. Joining IDA in 1996 as a modeling and simulation advisor to the Deputy Under Secretary of Defense (Readiness), he went on to serve from 2000 to 2003 as Technical Director, Joint Simulation System (JSIMS), and simultaneously as Manager, Enterprise Division of the Defense Modeling and Simulation Office (DMSO). In 2003 he was detailed to the office of OSD (Personnel and Readiness) as Director, Training Transformation Joint Assessment and Enabling Capability, and as Deputy Director, Readiness and Training Policy and Programs. In this assignment he was study director for the Training

Capabilities Analysis of Alternatives, a major training systems cost-benefit analysis for modeling and simulation applications in joint training, and for the Training Transformation Block Assessments. Back at IDA he has continued to support the training and modeling and simulation areas with strategic planning and acquisition projects. Fred graduated from the U.S. Military Academy, received a Masters in Operations Research from the Naval Postgraduate School, has served for 6 years as a member of the Army Science Board, led a study panel for the National Academy of Sciences Board on Army Science and Technology, and is a past President and Fellow of the Military Operations Research Society.

John E. Morrison

Dr. Morrison is a Research Staff Member at the Institute for Defense Analyses (IDA). Prior to working at IDA, he was a Research Psychologist at the Fort Knox Field Unit of the Army Research Institute for the Social and Behavioral Sciences (ARI) and Senior Staff Scientist at the Fort Knox office of the Human Resources and Research Organization (HumRRO). While at Fort Knox, Dr. Morrison performed training and human factors research on armored vehicles and ground combat tactics. Since moving to IDA, he participated in two reviews of the FCS program and related technologies. The first was the FCS Tech Review for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, conducted 8–11 April 2002 in Arlington, Virginia. This review was mandated by the Chief of Staff of the Army to conduct an independent evaluation of FCS enabling technologies to support Milestone B decision. The second review occurred in November and December 2003, when IDA had a task with the Office of Program Analysis and Evaluation (now Director of Cost Assessment and Program Evaluation) to support the development of KPPs for FCS. Dr. Morrison was involved primarily with development of KPP 6 (Training). Finally, in October 2009, Dr. Morrison served as the Technical Reporter for a North Atlantic Treaty Organization (NATO) Workshop titled “NATO Human Factors and Medicine Workshop: Human Dimensions in Embedded Virtual Simulation” (HFM-169). Although the FCS program had been canceled, the FCS-embedded training technology was central topic in the workshop. (See Shiflett 2009.)

Charles G. Sanders

Dr. Sanders is a Training and Organizational Development Scientist with extensive experience in training systems and training program development. He served in the U.S. Navy for over 20 years as a nuclear engineer and surface warfare officer. In addition to his sea tours, he was an Operational Test Director for the Navy Operational Test and Evaluation Force and Joint Training Technology and Policy Analyst for the Director of Navy Training on the Navy Staff. While on the Navy Staff, Dr. Sanders was the requirements analyst and resource manager for Joint Simulation System Maritime and joint training constructive simulation system. After retiring from the Navy, he supported the Office of the Deputy Under Secretary of Defense for Readiness for about 12 years. During this time, he provided analysis for the DoD Advanced Distributed Learning Initiative, and was instrumental in the initiation and development of the DoD Training Transformation Program, which included development of the Joint National Training Capability and Joint Knowledge Online. Dr. Sanders earned a Master's of Science in Information Systems Management from Syracuse University and a Ph.D. in Organizational Development from Regent University.

Robert A. Wisher

Dr. Robert Wisher is an Independent Consultant to the Institute for Defense Analyses (IDA). Bob served a distinguished career of 32 years as a research psychologist for the Department of Defense. He received a B.S. degree in mathematics from Purdue University and a Ph.D. in cognitive psychology from the University of California, San Diego. He began his career at the Navy Personnel Research and Development Center in San Diego, engaging in research on the costs and effectiveness of computer-based multimedia training. Bob then held a position as Senior Research Psychologist for 20 years with the U.S. Army Research Institute, Alexandria, Virginia, where he conducted laboratory research in training systems, developed advanced training methods, and conducted training assessments in field settings. Bob completed his federal career as the Director the Advanced Distributed Learning Initiative at the Office of the Secretary of Defense from 2002 to 2009. From July 2009 to June 2011, Bob was a Research Professor at the Naval Postgraduate School in the Modeling Virtual Environments and Simulation Institute, where he completed an edited volume on the future of e-learning and was the technical lead on the Phase I, "Analysis of System Training Impact for Major Defense Acquisition Programs" report published in August 2011.

Appendix B.
Technology Readiness Levels

Table B-1. Technology readiness levels as applied to the Future Combat Systems.

Technology readiness level	Description	Hardware and software	Demonstration environment
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis).	None.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis).	None.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytical studies and demonstration of non-scale individual components (pieces of subsystem).	Lab.

Technology readiness level	Description	Hardware and software	Demonstration environment
4. Component and/or breadboard. Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	Low-fidelity breadboard. Integration of non-scale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory Integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc.). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.	Prototype—Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.

Technology readiness level	Description	Hardware and software	Demonstration environment
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative operational environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight-qualified hardware	Developmental test and evaluation in the actual system application
9. Actual system "flight proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form	Operational test and evaluation in operational mission conditions

Source: "GAO analysis of National Aeronautics and Space Administration data," Table 3 in "Appendix VI: Technology Readiness Levels," in "Defense Acquisitions: Decisions Needed to Shape Army's Combat Systems for the Future," GAO-09-288, March 2009.

Appendix C.
Illustrations

Figures

Tables

Appendix D.
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Appendix E.
Acronyms

AAN	Army After Next
ARL	Army Research Laboratory
BCTM	Brigade Combat Team Modernization
BETS	BCTM Embedded Training Software
CGF	Computer Generated Forces
CNATTU	CNATT Unit
CNATT DET	Center for Naval Technical Training Detachment
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DSB	Defense Science Board
ECS	Engagement control station
FCS	Future Combat Systems
GAO	Government Accountability Office
GPR	Ground-penetrating radar
GUI	Graphical user interface
HMDS	Husky Mounted Detection System
HMMWV	High mobility multipurpose wheeled vehicle
ICC	Information and Coordination Central
IDA	Institute for Defense Analyses
IED	Improvised explosive device
KPP	Key Performance Parameter
LRIP	Low Rate Initial Production
MANPRINT	Manpower and Personnel Integration
MCAGCC	Marine Corps Air Ground Combat Center
MDAP	Major Defense Acquisition Program
MEADS	Medium Extended Air Defense System
MRAP	Mine-Resistant Ambush Protection
MRET	MRAP Egress Trainer
MTVR	Medium Tactical Vehicle Replacement
NTSP	Navy Training Systems Plan
ODS	Operator Driving Simulator
ORD	Operational Requirements Document
PAC	Patriot Advanced Capability
PCOFT	Patriot Conduct of Fire Trainer
SAM-D	Surface-to-Air Missile, Development
SDD	System Development and Demonstration
TESS	Tactical Engagement Simulation System
THAAD	Terminal High Altitude Air Defense
TPT	Troop proficiency trainer
TRADOC	U.S. Army Training and Doctrine Command

TRL	Technology Readiness Level
VBS2	Virtual Battle Space

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14. ABSTRACT

Consistent with DoD interest in adding rigorous analysis early in the life cycle of major acquisition programs, the training concepts and strategies must be completed early in the acquisition process. The objective of this task is to conduct analysis of the systems training Phase I coded data and expand the scope of data collection to include systems training in acquisition programs with significant human integrations requirements. This research will provide an empirical base for the DoD to more fully understand and justify the need to provide for efficient and effective operator, maintainer, and leadership training early in the acquisition process to improve the resulting capabilities and utility of future complex weapon systems. It is anticpated that early consideration of training considerations will both decrease system costs and increase training effectiveness with training strategies, tools, simulators and simulations accommodated as an integral part of major Defense programs.

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