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Technical Report 843

HARDMAN II Analysis Applied to the Forward Area Air Defense (FAAD) Pedestal-Mounted Stinger (PMS)

John E. Stewart, II and Uldi Shvern
U.S. Army Research Institute

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The Manned Systems Group of the U.S. Army Research Institute is responsible for developing analytical methods that support the Army's MANPRINT (Manpower and Personnel Integration) initiative. This report addresses the trial application of one of these methods, an automated derivative of HARDMAN (Hardware vs. Manpower) analysis called HARDMAN II, to the Army's Pedestal Mounted Stinger (PMS), a component of the Forward Area Air Defense (FAAD) system. The HARDMAN II analysis team had two objectives: to pilot test the analytical technique in a situation where critical input data are severely limited, and to demonstrate to proponents in the systems acquisition process the usefulness of HARDMAN II in generating workload-driven maintenance manpower estimates for a new weapon system. Both objectives were accomplished.

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FAAD MANPRINT Support

FOREWORD

The Manned Systems Group (MSG) of the Army Research Institute for the Behavioral and Social Sciences (ARI) is responsible for developing analytical methods to support the Army's MANPRINT (Manpower and Personnel Integration) initiative. A part of this process is the trial application of new and revised methods to ongoing Army development programs. In this way, MANPRINT analytical tools are tested and demonstrated to potential users while providing useful results to the system proponent. In conjunction with the U.S. Army Air Defense Artillery School, ARI-MSG conducted a front-end analysis (FEA) on the Pedestal-Mounted Stinger (PMS) component of the Forward Area Air Defense (FAAD) system. The objective of the analysis was to derive manpower and personnel estimates for maintenance support of the new system before fielding. An automated derivative of HARDMAN (Hardware vs. Manpower) analysis called HARDMAN II, or formerly MIST (Man-Integrated Systems Technology), was employed.

Findings were presented at the 32nd Annual Meeting of the Human Factors Society in Anaheim, California, in October 1988. The Directorate of Combat Developments and the Air Defense Board at Fort Bliss, Texas, were periodically briefed on the results and progress of the PMS HARDMAN II project. The analysis permitted the Army to revise its maintenance manpower requirements to conform more realistically with expected system performance.

This report illustrates how HARDMAN II can provide combat and training developers with timely guidance on the manpower and personnel requirements for a system. It also demonstrates the role of ARI in developing new FEA methods that, in the future, will play an important part in the decision-making process.

EDGAR M. JOHNSON
Technical Director

HARDMAN II ANALYSIS APPLIED TO THE FORWARD AREA AIR DEFENSE (FAAD) PEDESTAL-MOUNTED STINGER (PMS)

EXECUTIVE SUMMARY

Requirement:

To demonstrate the effectiveness of HARDMAN II (Hardware vs. Manpower) analysis for estimating the maintenance burden on Army weapon systems such as Forward Area Air Defense (FAAD) Pedestal-Mounted Stinger (PMS) so as to provide timely and useful input to key actors in the systems acquisition process.

Procedure:

HARDMAN II, an automated manpower, personnel, and training estimation system, was applied to a generic mobile Stinger-missile-based air defense system similar to the proposed PMS. Estimates of maintenance military occupational specialties required, their workloads, and personnel "pipeline" estimates needed to support the system were derived.

Findings:

Although major maintenance at organization level was adequate to maintain the new system, a shortfall of manpower was evident for systems maintenance. Sensitivity analysis probed the relationship between systems reliability, workload demands, and manpower requirements.

Utilization of Findings:

These findings and periodic updates have been presented to the Chief, Logistics Branch, Directorate of Combat Development at Fort Bliss, Texas, with the most recent briefing being 5 August 1987, and to the Undersecretary of the Army for Research and Development, 21 April 1987. The results helped decision makers to determine the manpower needed to maintain PMS and pointed out potential problems and pitfalls.

HARDMAN II ANALYSIS APPLIED TO THE FORWARD AREA AIR DEFENSE (FAAD) PEDESTAL-MOUNTED STINGER (PMS)

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HARDMAN II ANALYSIS APPLIED TO THE FORWARD AREA AIR DEFENSE (FAAD) PEDESTAL-MOUNTED STINGER (PMS)

INTRODUCTION

Background

The Pedestal-Mounted Stinger (PMS) is a self-propelled, lightweight, highly mobile air-transportable platform with primary armament of launch-ready Stinger missiles and a complementary weapon (gun) which provides missile dead space coverage and ground defense. As a quick-reacting, all-weather system with an integrated fire control component, PMS is primarily designed to be deployed in the brigade rear, division, and corps areas to provide air defense coverage of all critical assets. PMS will allow air defense engagement of low altitude, high performance, ground attack aircraft, armed attack and stand off helicopters as well as self-defense fire against dismounted infantry and lightly armored vehicles. PMS provides stationary, remote, and shoot-on-the-move air and self-defense coverage during convoy deployment. It provides for a 360 degree search capability, an integrated Identification Friend or Foe (IFF) feature, and a fire control component. The PMS carrier is the High Mobility Multi-purpose Wheeled Vehicle (HMMWV).

Two prototypes, similar in configuration, were undergoing testing at the time of the present project: Avenger (Boeing-GE) and Crossbow (LTV). The former system was selected as PMS in August 1987.

MANPRINT Considerations

MANPRINT (Manpower and Personnel Integration) refers to the whole process of optimizing the relationship between hardware and human performance, with the latter being treated as an integral part of total system performance. There are two critical aspects of MANPRINT. The first links the design of the system to its expected field performance in the hands of the likely military operators and maintainers; the second is its timing. Design and evaluation techniques based on the six MANPRINT domains (manpower, personnel, training, human factors engineering, health hazards, and system safety) should be employed as early as possible in the acquisition cycle, beginning with the Mission Area Analysis (MAA) phase when threats and deficiencies have been identified, but before a materiel solution has been decided upon.

Development of MANPRINT methods. The Manned Systems Group of the U.S. Army Research Institute (ARI) has as its mission the development of applied analytical methodologies which support the goals of MANPRINT. Currently under development is a family of integrated MANPRINT tools intended for use by key decision makers in the systems acquisition process. Although differing from one another in many respects, the objective of each of these tools is to provide timely answers for MANPRINT-related questions at all phases of the life cycle of a system, such as crew size, operator or maintainer workload, and the availability of key personnel. The testing of such methods in actual development programs is an important step in the development of MANPRINT methods.

Front-end analysis. One of the most important MANPRINT tools currently in use is a family of methodologies called front-end analysis (FEA). FEA techniques are relatively new, and literature and guidance are somewhat limited (see McManus, 1979, for a general discussion of the approaches and problems that underlie early comparability methodologies). In general, FEA consists of comparisons, using a variety of methodologies, between proposed (future), similar (fielded) predecessor systems, and system concepts. Its intent is to discover and identify components of the system that are termed "high drivers" in that they impose inordinate demands on the manpower, personnel and training (MPT) resources. These demands can entail increased training time and costs, the creation of a new Military Occupational Specialty (MOS), or threats to the health and safety of operators and maintainers. One FEA method is HARDMAN (Hardware versus Manpower) analysis. Its usefulness lies in its ability to identify manpower and personnel high drivers implicit in a new system concept, and to aid in their elimination or containment before the system concept matures. If these problem areas and related tradeoffs are considered early, Army combat and training developers can estimate the extent to which supportability of the system may be compromised, before a prototype has been built. In this way alternative solutions and trade-offs can be weighed so as to find the optimal solution in terms of effectiveness, efficiency, and costs.

HARDMAN II

The current project concerned itself totally with the PMS, with emphasis on manpower-personnel estimates for the maintenance burden at organization and intermediate levels. HARDMAN in its automated derivative HARDMAN II, formerly MIST (Man-Integrated Systems Technolology; see Herlihy, et al. 1986) was the methodology of choice. HARDMAN and MIST are two MPT analysis tools that are drawing increasing attention as Army systems become more complex. The specific research concern in this effort was to apply these techniques in a situation where time and data constraints presented a special challenge to the analyst.

The HARDMAN comparability methodology consists of several interrelated steps. The first involves the collection, generation, and formatting of data, while the remainder deal with data analysis and evaluation. Those pertinent to the present effort are summarized below.

Establish a consolidated database (CDB). Two major functions are accomplished. First, the Baseline Comparison System (BCS) and the proposed system are developed and the design differences between them evaluated. Second, all data required to support this and later HARDMAN analyses are identified, collected, and formatted. These usually include operational and support specifications for the proposed weapons system; systems engineering and manpower, personnel and training data.

Determine manpower requirements. In the Manpower Requirements Analysis phase of the process, systematic descriptions of the general operator and maintainer tasks are developed for the BCS. Included in these task networks are empirically-based estimates of repair time, equipment reliability and number of personnel by skill level required to perform each task. Given a mission scenario, these task networks can be used to derive the workload for preventive and corrective maintenance as well as for operational manning. In addition, the BCS task descriptions can be modified to reflect the impact of the design differences and then used to determine workload estimates for the proposed system.

Determine personnel requirements. Personnel Requirements Analysis determines the total personnel demands of both the BCS and the proposed system. This consists of direct personnel needed to operate and maintain the system, as well as the "pipeline" personnel who must be retained and developed in the organization in order to meet the unit manpower requirements. This latter category of personnel is determined by constructing career paths which describe training paths, attrition rates and advancement probabilities for the MOS required by the BCS. These BCS career paths are then modified to accomodate changes in the proposed system.

HARDMAN has been applied to over 20 major systems. There are several drawbacks, however, that have prevented its wider application; the most serious of these is its labor-intensive nature. There are numerous worksheets to complete and many calculations to be made. Of course, programmable calculators and desk top computers can relieve some of the burden, but they offer no solution to the real problem, that is, the interdependence of the different portions of HARDMAN and the resulting data flow between them. Thus manpower requirements necessitate the use of the results of workload analysis; similarly, personnel and training requirements analysis must draw on the results of the manpower requirements analysis. There is no quick and easy way within HARDMAN to transfer results from one worksheet to another; however, by using an automated database the interfacing problems between different portions of the analysis can be solved; changes in one worksheet are automatically "cross-walked" to the others. This is the rationale behind HARDMAN II.

HARDMAN II is an automated system for performing manpower, personnel, and training analyses. It accepts all the necessary data, automatically makes it available to all worksheets that require it, performs all required calculations, and formats the results in a series of reports that detail the MPT requirements of the system being analyzed.

Project Overview

Predecessors. The predecessor system for the PMS is the Towed Vulcan Air Defense Weapons System. The Lightweight Air Defense System (LADS) was proposed to replace Towed Vulcan. Two candidate systems for LADS (Setter and Avenger) were somewhat similar to the two PMS candidates (Crossbow and Avenger), though the doctrine and tactics surrounding the LADS system in the light AD battalion were Vulcan-based and hence quite dissimilar to those supporting Stinger. Thus, it is apparent that although the LADS and PMS have some components in common, the conditions under which they would be utilized would not be the same. For example, the PMS would be attached to Headquarters and Headquarters Battery (HHB) in a FAAD heavy battalion, and would be used to defend the rear areas, whereas LADS would have been assigned to a light battalion. As would be expected, these different roles for the hardware would impact usage rates and maintainer workload.

Manpower-personnel impacts and constraints. The FAAD system under Army of Excellence requires zero force growth. The combat and materiel developers need MPT estimates as to MOSs, skills and tasks that will be required to maintain the new system. Likewise the materiel developer will need similar estimates as part of the Integrated Logistic Support (ILS) deliverables. One of the methodologies that can support both MANPRINT and ILS concerns in the MPT area is HARDMAN comparability analysis. The application of this FEA technique comprised the focal point of the present study.

METHODOLOGY

Database

In HARDMAN the first analytical step is to assemble a Consolidated Data Base (CDB). Essential inputs into HARDMAN II require contractors' proposals for adequate description of the candidate weapons systems, down to the level of subsystems and assemblies. Likewise, requirements documents, such as the Required Operational Capabilities (ROC) and Operational and Organizational (O&O) Plan, set forth usage rates and operational scenarios for the proposed system. Databases that feed into HARDMAN II are the Navy 3M, (Materiel Maintenance Management) the Army's MARC (Manpower Requirements Criteria) and SDC, (Sample Data Collection) as well as contractors' RAM (Reliability, Availability, and Maintainability) estimates.

It soon became apparent that the preferred data inputs were unavailable. The contractors' proposals were not releasable for scrutiny, so direct comparisons between the three proposed systems were not possible. The PMS O&O Plan and ROC provided some guidance as to usage rates and operational requirements.

Thus it was possible to configure a prototype BCS using LADS. Although the BCS was generically similar in many ways to both PMS candidates, it was difficult to determine how close it came to the actual specifications of either system.

Input data. The LADS HARDMAN data involved such measures as workload, Mean Time to Repair, (MTTR), Mean Time Between Failures (MTBF), MOSs who would be performing the maintenance tasks and their paygrades, as well as predecessor and BCS tasks. Promotion, attrition and Transients, Trainees, Holdees and Students (TTHS) rates also comprised inputs.

Output. HARDMAN II outputs in this analysis were manpower requirements in terms of the number of MOSs and their paygrades needed to maintain the system at organization level, (and to a lesser extent, intermediate) and personnel requirements in terms of the number of each MOS that would have to be recruited in order to support the former requirements. Normally training outputs such as number of instructors required, costs per instructor and per graduate are generated.

Sensitivity Analysis

Cherry, Promisel, and Miles (1984) point to the centrality of sensitivity analysis as a decision making aid during early phases of the acquisition process. At the core of sensitivity analysis in such an application is the assumption that manpower, personnel and training considerations constitute an integral part of total system performance. Sensitivity analyses were planned as an adjunct to HARDMAN II, in the sense that two key MPT issues were perceived as crucial to the performance of the PMS as a total system. These were the performance of the Electronic Aids to Maintenance (EAM) systems, specifically the Built-in Test (BIT) fault diagnostic system, and the degree to which the 16X MOS operator-maintainer could be expected to perform his dual role.

The analysis allocates maintenance manhours based on initial HARDMAN II findings between the 16X and the 24X MOSs, for different estimated repair times at different levels of BIT performance. In this way the joint effects of BIT and task allocation on manpower requirements are estimated.

Applied in this fashion, sensitivity analysis can be a powerful diagnostic and prognostic tool for estimating the impact of BIT performance degradation on manpower requirements. It can provide a sense of the critical levels of BIT at which additional manpower is needed to compensate for system degradation. This is very important in the instance of the present analysis because of the stated ROC requirement that BIT isolate 81% of all system faults. The performance record of BIT systems does not warrant this expectation. Sensitivity analysis can provide a picture of what maintenance manpower requirements would be at much lesser (and realistic) levels of BIT performance.

SME questionnaire. As an ancillary part of the sensitivity analysis, a 20-item questionnaire (see Appendix) was administered to 15 subject matter experts (SMEs), ten of whom were currently SHORAD instructors at Fort Bliss; the remainder, currently consultants with a contractor, were retired Warrant Officers and Senior NCOs who had mostly Nike-Hercules experience. The question items were concerned with times for maintenance actions, expectations of BIT and 16X performance, and the amount of training time necessary for the 16X to perform adequately his role as operator-maintainer. The sample was nonrandom; all of those available at the time were surveyed.

RESULTS AND DISCUSSION

Manpower Estimates

High drivers. A high driver is any component (such as hardware, tasks, training courses, etc.) that imposes extremely high demands on existing MPT resources. The present study identified four high drivers among the systems comprising the PMS. These were, in order of their severity: the forward-looking infrared system (FLIR), the fire control computer, the HMMWV, and the laser rangefinder. The FLIR stood apart from the other components in having the highest maintenance ratio (approximately .5 to 1).

Organization level maintenance. Table 1 lists manpower requirements at this level. The manpower requirements for the PMS assumed a 9 hour day. To maintain the PMS alone, a total of 3 63B (light wheeled vehicle-generator mechanic) and 13 24X (a notional MOS for systems maintenance) would be required. Currently, the motor maintenance area seems adequate for the total of 109 vehicles listed in the Table of Organizations and Equipment (TOE) for the FAAD Headquarters and Headquarters Battery, (HHB) with a total of 10 63Bs. However, the same cannot be said for systems maintenance, which calls for only 4 24X MOS systems mechanics.

Table 1

Manpower Requirements: Maintenance Workload per Battalion

MOS	Paygrade	Manhours (7 days)	Manpower Requirements
24X			
	E-3	172	3
	E-4	247	4
	E-5	242	4
	E-6	137	2
63B			
	E-3	42	1
	E-4	44	1
	E-5	76	1

Thus, for the PMS only, about 9 additional 24X systems mechanics would be required to handle the maintenance burden for the fire control system, FLIR, and other electronic components.

Intermediate level maintenance. At this level of maintenance it was determined that 6 MOS 27X system repairers were needed, plus one MOS 63W wheeled vehicle repairer.

Personnel Estimates

The following figures represent annual accessions per battalion, that is, the number of accessions needed per year to support the manpower needs in a battalion. These were: 24X, 6 per year; 27X, 4; 63B, 3; and 63W, 1. Personnel Requirements per battalion, that is, how many MOS's will be needed in the "pipeline" to support the system, are: 24X, 31; 27X, 14; 63B, 13; 63W; 5. Table 2 presents these requirements by paygrade.

Table 2

Personnel Requirements per Battalion by Paygrade

Paygrade	Requirements
E-1	8
E-2	7
E-3	10
E-4	16
E-5	10
E-6	7
E-7	3

Keep in mind also that PMS will be fielded five years after the LADS HARDMAN analysis was conducted. Within that time frame, the RAM characteristics of hardware can change considerably.

The RAM estimates used were quite varied in the degree of confidence that one can have in their accuracy. The 3M, SDC, and MARC data are generally more trustworthy than contractors' estimates. This situation will be encountered in all FEA analyses of this type.

Applications of these Findings

From the current results, it appears that the problem area in the organizations supporting the FAAD HHB is systems maintenance, where the manpower requirement in the TOE (44-166L000) of only four 24 series MOS seems inadequate. In fact, it has been proposed that this requirement be revised to 9 spaces, yet this is still not sufficient to support PMS in addition to the other assets of the FAAD headquarters battalion. The 24 series MOS is of relatively low density, so there could be problems in recruiting a sufficient number to maintain the system.

The rationale behind the concept of the operator-maintainer should be evident when one considers these manpower-personnel limitations. The 16S MOS comprises a much larger pool of candidates than the 24 series (approximately 3200 vs. fewer than 400).

Trainability issues. Looking at the mental category distribution of these two MOS (see Table 3), it would appear that, if the Army decided to cross-train the 16S as a maintainer, only 40 percent would fall into the same ranges as the 24s. This may very well preclude the original plan to train all the 16Ss as operator-maintainers, and should give pause to consider alternative training strategies. Perhaps it would be judicious to examine closely the training programs that currently exist for other operator-maintainers, the 13R Firefinder radar operator-maintainer being a good example. For this MOS, all are initially trained as operators, and of these, the most promising candidates are selected for cross-training as radar maintainers.

Table 3

AFQT Mental Category Percentage by MOS and Skill Level

Category	MOS 16S Skill Level 1	MOS 16S Skill Level 2	MOS 24M Skill Level 1	MOS 24M Skill Level 2
I-IIIA	38%	18%	82%	59%
IIIB-IV	62%	82%	18%	41%

What can be inferred from an examination of Table 3 is the fact that the two MOSs in question represent distinct aptitude populations. This finding highlights a major MPT problem which the Training and Doctrine Command must work to overcome if PMS is to be fielded successfully.

Sensitivity Analysis Results

SME Questionnaire Responses. The SMEs who responded to the questionnaire (all but one did) were quite experienced, with the median years' Army experience being 17 years (range 5-31 years). All but two indicated experience with SHORAD, and all indicated a high degree of familiarity with various 24-series systems maintainer MOS, the most familiar being 24M and N (7 mentions each) followed by 24P and Q (2 mentions each). Of the positions held, 10 reported having been series 24 MOS themselves, 2, 16-series, and 2, 224 (Warrant Officer) MOS series. Also represented were the 25, 35, 76, and 222 MOS series (one mention of each). All of these MOS are maintenance related.

Utilization of questionnaire input. Although respondents did not show a high degree of consensus across all question items, there were nevertheless consistent differences in estimated performance and training times for the 16X and 24X MOS. These estimates were incorporated into the sensitivity analysis.

At this point it seems that the biggest problem to be anticipated in the maintenance area is the excessive workload of the 24X. This could be reduced by allocating some of these tasks to the 16X. This option would be most effective if the 16X were to do all of the BIT diagnosis plus some of the repairs, and if BIT were able to successfully isolate at least 65% of the faults. Below 65% the operator-maintainer option does not seem worthwile.

Sensitivity analysis is a rationale for examining trade-offs in the MPT area, where several variables seem to be driving MPT requirements. Based on SME estimates and knowledge, it appears that the number of 24X personnel is dependent on several factors:

the success of BIT, the trainability of the 16X operator-maintainer to perform diagnosis with the BIT system, and the percentage of the 24X's workload that can be taken over by the former MOS. Table 4 summarizes the number of 24Xs required at varying levels of BIT effectiveness.

Table 4

Sensitivity Analysis for Operator-Maintainer: Worst-Case Scenario

		16X Task Loading				
	Diagnosis Repairs	None None	50% None	100% None	100% 50%	100% 100%
BIT Isolation	MOS	Number of Soldiers in Each MOS Required				
81%	24X	12.6	11.7	10.8	6.4	2.0
	16X	0.0	1.3	2.7	7.7	12.8
65%	24X	13.2	12.6	12.0	7.9	4.1
	16X	0.0	1.1	2.2	6.7	11.3
50%	24X	13.7	13.2	12.8	9.8	6.9
	16X	0.0	0.8	1.7	5.1	8.5
30%	24X	14.4	14.2	13.9	12.1	10.3
	16X	0.0	0.5	1.0	3.1	5.1

Note that in the worst possible scenario (30% BIT successful fault isolation rate) approximately 15 24Xs would be needed if the 16X were to assume none of the maintainer workload; if the 16X were to perform all of the repairs under the same conditions, approximately 10 or 11 24Xs would be required for the PMS. Given the best scenario (81% success rate), 11 24Xs would be required if the 16X were able to perform 100% of the diagnoses without doing any repairs. If he also were to perform all the repairs, then only 2 24Xs would be required.

Although the workload of the 24X can be reduced, the conditions that are most likely to occur will lead to small reductions in workload while the conditions that would permit a significant decrease in the 24X workload are least likely to occur. It is most likely that BIT will diagnose no more than 50% of system failures. It is also doubtful that the 16X will perform any maintenance duties beyond BIT diagnosis. In this set of circumstances not more than one 24X position can be eliminated. Significant savings in 24X workload can be achieved only if the 16X can perform most or all of the repairs; however, this may not be achievable.

It should be noted that 81% fault isolation does not mean that BIT will successfully isolate all faults down to one LRU (which can be anything from a black box to a circuit card to a chip). The ROC requires that 72% of faults be isolated to one LRU, the remaining 9% to a prioritized list of five LRUs referred to as an ambiguity group). For the 19% remaining, the detected faults will not be successfully isolated. The critical break-even point of this analysis is 65% BIT isolation. Below this point, manpower requirements begin to increase beyond the 13 24X spaces originally generated by HARDMAN II.

Revised Sensitivity Estimates

Underlying assumptions. Admittedly, the results of the first set of estimates were pessimistic, much more so than those endorsed by the FAAD Program Manager (PM) Office for PMS, or the MANPRINT Joint Working Group (MJWG). In a sense, the former could be termed the worst case or conservative estimates. Subsequent interviews with SMEs allowed new assumptions to be incorporated into the analysis. These were: Repair time for 16X vs. 24X ratio = 1.4; BIT isolate: repair time ratio= .5; BIT fault isolation time for 16X vs. 24X = 1.4, and manual: BIT fault isolation time = 3.0. In keeping with the track record of EAMS systems it was assumed that false alarms would run at least 10 percent. Both worst-case and most revised estimates reflect these assumptions.

RAM scenarios. For this set of estimates, the arithmetic mean of the worst case estimates and the optimistic MJWG estimates for the three systems maintenance high drivers (FLIR, fire control computer, and laser rangefinder) was computed, incorporating the foregoing assumptions. The revised estimates were somewhat more moderate than those originally generated from HARDMAN II, even though more rigorous assumptions were made concerning repair times and false alarm rates. The scenario set forth by the latter estimates may be more realistic in light of the fact that in the time between the LADS HARDMAN and PMS First Unit Equipped (FUE), there may well be improvements in the RAM characteristics of the electronic systems, especially high-risk items which were found to be high drivers in the former analysis. Table 5 presents the 24X manpower requirements for the revised "realistic" scenario.

Table 5

Sensitivity Analysis for Operator-Maintainer: Most Likely (Realistic) Scenario

		16X Task Loading				
	Diagnosis	None	50%	100%	100%	100%
	Repairs	None	None	None	50%	100%
BIT Isolation	MOS	Number of Soldiers in Each MOS Required				
81%	24X	9.3	8.6	7.9	4.7	1.5
	16X	0.0	1.0	2.0	5.7	9.4
65%	24X	9.7	9.2	8.8	5.8	3.0
	16X	0.0	0.8	1.6	4.9	8.2
50%	24X	10.0	9.6	9.3	7.2	5.3
	16X	0.0	0.6	1.2	3.7	6.2
30%	24X	10.6	10.4	10.1	8.8	7.5
	16X	0.0	0.4	0.7	2.2	3.7

Even in the "realistic" scenario, the number of 24Xs can be kept to 7 or less only if BIT can detect and diagnose at least 50% of the failures and if the 16X can perform a large portion of the repairs. Having the 16X's maintenance duties limited to BIT diagnosis, even in the very unlikely scenario of 81% of the failures being detected or diagnosed, will save only one or two 24X positions. Hence sensitivity analysis, which provides the recommended operator-maintainer task allocation scheme, has shown the most feasible allocation of maintenance duties to the 16X to be of minor benefit. It also suggests strongly that the most helpful allocation (training him as a true operator-maintainer) is not feasible.

Effects of increased travel time. If average travel time between the unit maintenance section and the fire unit is increased by half an hour either because of greater travel distances or slower travel rates, manpower demands will increase by approximately four people for the worst-case scenario and three for the "realistic" scenario (Tables 6 and 7). The increases in manpower requirements are for either the 24X or 16X, depending upon how the diagnosis and repair tasks are allocated.

Table 6

Requirements for 24X and 16X: Travel Distance Doubled to 20 Km (Worst Case)

		16X Task Loading				
	Diagnosis	None	50%	100%	100%	100%
	Repairs	None	None	None	50%	100%
BIT Isolation	MOS	Number of Soldiers in Each MOS Required				
81%	24X	17.0	16.1	15.2	9.0	2.9
	16X	0.0	1.3	2.7	9.5	16.3
65%	24X	17.5	17.0	16.6	10.8	5.6
	16X	0.0	1.1	2.2	8.2	14.3
50%	24X	18.0	17.6	17.3	13.2	9.0
	16X	0.0	0.8	1.7	6.3	10.9
30%	24X	18.7	18.6	18.3	16.0	13.3
	16X	0.0	0.5	1.0	3.8	6.5

Table 7

Requirements for 24X and 16X when Travel Distance is Doubled to 20 Km

		16X Task Loading				
	Diagnosis	None	50%	100%	100%	100%
	Repairs	None	None	None	50%	100%
BIT Isolation	MOS	Number of Soldiers in Each MOS Required				
81%	24X	12.4	11.7	11.0	6.6	2.1
	16X	0.0	1.0	2.0	6.9	11.9
65%	24X	12.8	12.5	12.1	7.9	4.1
	16X	0.0	0.8	1.6	6.0	10.5
50%	24X	13.2	12.8	12.6	9.6	6.8
	16X	0.0	0.6	1.2	4.6	8.0
30%	24X	13.7	13.6	13.4	11.5	9.7
	16X	0.0	0.4	0.7	2.8	4.8

Historical Lessons with EAM

In one of the most comprehensive reviews of the literature on EAMs, Nauta (1985) does not paint a very optimistic picture for the success of BIT as a substitute for adequately-trained operators and operator-maintainers. According to this author, there are some inherent limitations to BIT that seem to defeat much of its purpose as a maintenance aid. He maintains that one of its weaknesses is the fact that BIT cannot discriminate from those failures it was designed to detect and those it was not. In short, while very effective in detecting and isolating faults that are anticipated by its designers, the system cannot handle failures that do not meet design assumptions (estimated to be about 50 % of failures). Another problem he cites is the fact that because BIT detects those failures that are part of the engineering model and not those that deviate from it, its performance is always less than predicted. The design model also does not anticipate what actually occurs, that is, a degradation in system performance over time, primarily because frequent removal and replacement of modules causes damage to interfaces, and these failures are not detected by BIT. Thirdly, he states that although BIT failures may not affect system availability, frequently it is the case where BIT malfunctions are not identifiable as such, resulting in the system being taken down unnecessarily. Under these circumstances we would expect high false removal rates, and indeed, according to Nauta, this has been the Navy's experience, with these running from 30 to 50 percent for line replacable units (LRUs). He further found that for the maintenance personnel using EAMs, most could run the built-in diagnostics successfully but 85 percent did not know what to do when a fault was detected and not isolated to a single LRU.

Furthermore, in an article by Demers (1987) Nauta stated that the foremost lesson learned in the past 15 years that BIT technology has been employed, is that BIT will never reduce maintenance technician skill requirements; on the contrary, he maintained that BIT functions best in the hands of the skilled technician who understands the schematics and theory behind the system.

While Nauta's research dealt primarily with Navy systems, some lessons have been learned from currently-fielded Army ground systems that reinforce any cautionary statements regarding the disparity between what BIT is supposed to do and what one can realistically expect it to do. Marcus and Kaplan (1984) in their report on the M1 tank, found that fault diagnosis time for this vehicle comprised 20% of total downtime. Two likely reasons for this, the authors concluded, were (a) insufficient preparation of maintenance personnel to use properly the EAM equipment; (b) lack of a fundamental knowledge of how the system functioned.

In another reverse engineering study, Arabian, et al. (1984), found that for the Multiple Launch Rocket System (MLRS), actual fault detection and false removal rates fell woefully short of contracted standards. While a 90% fault detection rate had been called for in the ROC, the actual rate was only 15%. By the same token, false removals, set by standard to be only 7%, ran an average of 54%.

Frederickson, et al. (1986), reviewing these and other Army data sets, concluded that there is no factual basis in the current state of the art to conclude that EAMs will allow soldiers to perform maintenance actions with lesser training than their predecessors; on the contrary, they cite experiences from the Army, Navy and Air Force that have shown the need for more highly skilled technicians at organization level than previously required when BIT is used. For the Army's current system, false alarm rates range from 13 to 32%, necessitating skilled technicians to conduct trouble shooting when fault isolation fails. These historical data do not serve to bolster the operator-maintainer concept; indeed, they make a strong case for the retention of the 24X in the HHB for PMS to back up the 16X when attempts at fault isolation inevitably fail. Also, they suggest that in order to be effective, the 16X be trained as a true operator-maintainer, similar to the 25L (AN/TSQ-73 Systems Operator-Maintainer), and not as an operator who only incidentally performs simple maintenance tasks which do not require much knowledge of the system. Sensitivity analyses have shown this alternative to be less practical than training dedicated 24X maintainers.

CONCLUSIONS

Questions that PMS HARDMAN II has not Answered

Further inquiry needs to be made into two issues that relate closely to the maintenance workload for the PMS: The expected effectiveness of BIT (Built in Test Equipment) and the viability of the operator-maintainer concept. Historical evidence argues against placing an inordinate amount of faith in BIT.

For the operator-maintainer concept, there are two issues which must be addressed. These are: (a) Will the current pool of 16S MOS candidates be able to successfully complete the training necessary for an operator-maintainer, or will attrition be so high as to preclude such cross-training? (b) Whether or not the 16S is cross-trainable in sufficient numbers to fulfill the need for the 16X MOS, will he be able to handle the workload of operating the system as well as performing the maintainer tasks? The sensitivity analysis conducted as an adjunct to the HARDMAN II analysis could not really answer these questions directly. Even so, it seems doubtful whether the 16X can supplement enough of the 24X's workload to reduce significantly the requirements for the latter MOS.

Additionally, there needs to be some attention paid to maintenance demands within the HHB Battalion as a whole. Unfortunately, HARDMAN II only looks at the "slice" through a battalion, and ignores the maintenance burden on non PMS vehicles. Assignment of personnel to these units may be driven more by policy (in terms of how many spaces are available) than by workload; therefore, the efficacy of HARDMAN II is somewhat compromised by this limitation in scope. Later versions of HARDMAN II should be able to overcome this problem by generating MPT estimates for heterogeneous organizations composed of different mixes of weapons systems.

Lessons Learned

One added benefit of this attempt to perform FEA in house were the MANPRINT lessons learned, which have given a valuable perspective on organizational and communication problems which constitute potential barriers to the successful execution of HARDMAN II, HARDMAN and other data-intensive FEA methods. Unfortunately, elaboration of the causes and consequences of the problems encountered in the current effort would be beyond the scope of the report. However, some mention must be made of these problems, attempts to resolve them, and the success or failure of these attempts.

The most serious obstacle encountered was the failure to get access to the contractors' proposals, a rather essential requirement for HARDMAN II analysis.

It would appear that the researchers on the present project should certainly have a sufficient need to know the content of the proposals, specifically the Logistics Support Analysis Record (LSAR) and the Historical RAM Data sections. Also it would seem a reasonable supposition that comparative maintenance burden estimates for the three competing systems would be a very important factor to be taken into consideration by the Source Selection Evaluation Board (SSEB) in its recommendation of which candidate to select.

No one outside the SSEB could legally have access to the proposals, which were deemed competition-sensitive, and so the HARDMAN II team was forced to fall back on the secondary data sources used in the present study. This was not a solution to the problem, only a stop-gap measure. In all fairness, this problem was due to situational factors (a fast-track acquisition), and seldom can all the key actors in the MANPRINT process foresee every legal, procedural or logistical problem that may arise. Still, valuable lessons can be learned from experiences like this one.

There may be some potential solutions for future projects where FEA techniques are to be applied. The most important consideration would be a requirement that if it seems necessary to perform a HARDMAN II analysis, members of the Army Research Institute (ARI) who are capable of performing it be allowed to serve as consultants to the SSEB, or at least be privy to documentation on the systems. It was not only the current research team that was not permitted to see the proposals; the same restriction applied to the Logistics Branch of DCD at Fort Bliss, which had contracted out the Logistics Support Analysis (LSA) tasks that were essential in determining the manpower needed to field the PMS. Of necessity these estimates cannot be of the calibre as they would have been had the proposals been released.

In the abstract, MANPRINT does not anticipate impasses such as this one. It is incumbent on those who are involved in the planning and implementation of MANPRINT to see that these pitfalls do not occur in the future. This would require that planners take cognizance of FEA techniques and what kind of data they necessitate, as well as inserting language into requirements documents and the RFP which bind the contractors to comply legally with any requests for RAM and other data when they are essential to the successful completion of analyses which support MANPRINT applications in the acquisition process. In short, there is a need to move from policy statements and other philosophical abstractions about "making MANPRINT happen" to a concrete program plan, complete with measurable objectives that will make it happen. Thus far the emphasis has been on MANPRINT as process, but now it should shift to MANPRINT as outcome.

At the present time, FEA techniques are evolving and will become the core of the MANPRINT process as they become more sophisticated and user-friendly. As HARDMAN II and its sister methods become more commonplace, these problems should disappear as comprehensive automated databases are built, and access to proposals by researchers becomes a rule rather than an exception.

REFERENCES

Arabian, J.M., Hartel, C.R., Kaplan, J.D., Marcus, A. & Promisel, D.M. (1984). *Reverse engineering of the Multiple Launch Rocket System: Human factors, manpower, personnel and training in the weapons acquisition process*. (ARI Research Note 84-102, ADA 142850).

Cherry, W.P., Promisel, D.M. & Miles, J. L. (1984). *Human factors, manpower, personnel and training clauses for the concept exploration and the demonstration and validation requests for proposal*. (ARI Research Product 84-24, ADA 174774).

Demers, W.A. (1987). BIT: Unfulfilled potential. *Military Logistics Forum*, 3, (April), 8-10.

Dynamics Research Corporation (1986). *Application of HARDMAN methodology to the Army's Lightweight Air Defense System (LADS)*. (Final Report, Contract No. DABT60-84-0077). Wilmington, MA.

Frederickson, E. W., Lindquist, J. W. & Lehman, J. A. (1986). *A study of electronic aids to maintenance (EAM) for the Light Helicopter family (LHX)*. (Final Report, Contract No. DAAA 09-85-0035) Horizons Technology Incorporated, Oakton, VA.

Herlihy, D.H., Iceton, J.A., O'Neal, J.,& Guptill, R.V. (1985). *Man Integrated Systems Technology (HARDMAN II) user's guide*. (Contract No. MDA903-81-C-0561), Dynamics Research Corporation, Wilmington, MA.

Marcus, A. and Kaplan, J.D. (1984). *Reverse engineering of the M 1 fault detection and isolation subsystem: Human factors, manpower, personnel, and training in the weapons system acquisition process*. (ARI Research Note [illegible] 1, ADA 142850).

McManus, J.C. (1979) *Equipment comparability techniques used during early system design*. (AFHRL Technical Report 79-24. ADA 071411).

Nauta, F. (1985) *Alleviating fleet maintenance problems through maintenance training and aiding research*. (NTEC Technical Report MDA903-81-C-0166-1, ADA 155919).

APPENDIX

SME MAINTENANCE QUESTIONNAIRE

Responses of 15 SMEs to Questionnaire on Operator-Maintainer

1. Assuming 1.5 hr for the typical maintenance action performed by the 24X, how much of this time is spent performing....

	TIME	PERCENT RESPONDING
A. BIT DIAGNOSIS	1-5 min	33
	6-10 min	27
	12-18 min	13
	30 min	27
B. GET READY-PUT AWAY	10-15 min	60
	30 min	40
C. REPAIR (REMOVE/REPLACE)	10-20 min	40
	21-30 min	13
	45-60 min	40
	60 plus min	7
D. TRAVEL organizational/FIRE UNIT		
	10-20 min	13
	30-40 min	40
	45-60 min	47

2. How long should it take the 24M to do typical maintenance action, assuming BIT?

TIME	PERCENT RESPONDING
30 min or less	40
60-90 min	60

3. Same as (2) but assume no BIT.

TIME	PERCENT RESPONDING
60-90 min	47
120-150 min	33
180 plus min	20

4. How long should it take the 16S to do the same, assuming BIT ?

TIME	PERCENT RESPONDING
30 min or less	20
60-90 min	47
120-150 min	27
180 plus min	7

Appendix (Continued)

5. 16S diagnoses with BIT; No repairs; How much additional training?

TIME	PERCENT RESPONDING
Less than 1 wk	47
1-2 wk	27
3 wk	13
4-6 wk	13

6. 16S takes HALF of 24M workload, performs only diagnosed repairs. How much additional training?

TIME	PERCENT RESPONDING
1-2 wk	27
3 wk	40
4-6 wk	20
over 6 wk	13

7. 16S performs ALL repairs that are diagnosed. How much additional training?

TIME	PERCENT RESPONDING
3 wk	28
4-6 wk	44
over 6 wk	28

8. Estimate probability that average 16S will use BIT effectively.

PROBABILITY	PERCENT RESPONDING
100-90	20
89-79	13
78-68	40
67-57	13
56 or less	13

9. All 16S are trained to isolate faults and repair 50% of those isolated. Estimate probability of success.

PROBABILITY	PERCENT RESPONDING
100-90	13
89-79	33
78-68	13
67-57	27
56 or less	13

Appendix (Continued)

10. Same as (9) but assume 16S repairs ALL isolated faults.

PROBABILITY	PERCENT RESPONDING
100-90	13
89-79	27
78-68	20
67-57	7
56 or less	33

11. Expected successful isolation rate, FUE (First Unit Equipped) plus 3 yr.

	PERCENT RESPONDING
100-90%	20
89-79	53
78-68	20
45 or less	7

12. Expected false alarm rate, FUE plus 3 yr.

	PERCENT RESPONDING
35-25%	20
24-13	20
12 or less	60

13. Expected false removal rate, FUE plus 3 yr.

	PERCENT RESPONDING
35-25%	20
24-13	27
12 or less	53

14. When a malfunction is isolated down to five LRUs, one of which is faulty, do the other four constitute false removals?

	PERCENT RESPONDING
No	27
Yes	53
No Response	20