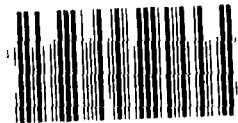


GAO

April 1987

WEAPON SYSTEMS

Shortfalls in Automatic Fault Diagnostics



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United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

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April 24, 1987

The Honorable John O. Marsh, Jr.
Secretary of the Army

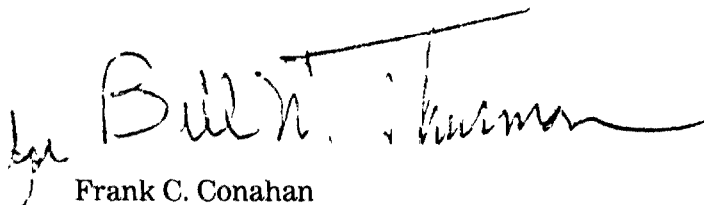
Dear Mr. Secretary:

Automatic fault diagnostics are a necessity in maintaining modern Army weapon systems. This report focuses on problems the Army has with fault diagnostics, how they are being addressed, and improvements needed to prevent their recurrence

This report contains recommendations to you in chapter 5. As you know, 31 U.S.C. 236 requires the head of a federal agency to submit a written statement on actions taken on our recommendations to the House Committee on Government Operations and the Senate Committee on Governmental Affairs not later than 60 days after the date of the report. A written statement must also be submitted to the House and Senate Committees on Appropriations with an agency's first request for appropriations made more than 60 days after the date of the report

We are sending copies of this report to the Chairmen of the above Committees; the Secretary of Defense; the Director, Office of Management and Budget, and the Chairmen, House and Senate Committees on Armed Services.

Sincerely yours,



Frank C. Conahan
Assistant Comptroller General

Executive Summary

Purpose

Modern weapon systems, with their greatly increased complexity, have become heavily dependent on automatic diagnostics to verify system readiness, to detect faults, and to identify items to be replaced to correct the faults. So that a system may regain operational capability quickly when a failure occurs, the Army will rely heavily on “repair by replacement” at the user maintenance level. The repair-by-replacement approach for electronic units will be effective only if the Army can quickly identify and replace faulty parts. For this reason, the Army must have automatic diagnostics that are both effective and reliable.

GAO undertook this review because the Army spends billions to maintain its weapons and is depending more and more on automatic diagnostics to detect and isolate weapon system failures.

This report focuses on problems the Army is having with automatic diagnostics, actions the Army is taking to overcome the problems, and improvements needed to prevent or minimize similar problems when acquiring future weapons.

Background

The Army’s maintenance philosophy is to minimize weapon system downtime by quickly replacing malfunctioning parts, preferably at the user level.

Since many Army weapons use built-in test equipment and external automatic test equipment to identify faulty parts, successful maintenance depends heavily on automatic diagnostics.

Using a case study approach, GAO analyzed the automatic diagnostics of six major Army weapons systems: Patriot, Hawk, and Pershing missile systems; Multiple Launch Rocket System; Apache helicopter; and Abrams tank to assess the Army’s progress in identifying and resolving automatic diagnostic problems.

GAO also considered the results of related studies and Army initiatives to improve automatic diagnostics and advance test technology.

Results in Brief

The Army’s automatic diagnostic equipment is having problems detecting and isolating weapon system faults. Substantial sums are being spent to improve diagnostics and increase other aspects of support. The Army has initiated actions, such as developing testability standards, developing standard test equipment, and promoting automatic

test technology to address these problems. These actions, when fully implemented, should help to mitigate the Army's diagnostic problems.

Principal Findings

For the systems GAO studied, performance of automatic diagnostics varied by weapon and test. However, generally, neither built-in nor external diagnostics performed as expected during key operational tests. Also, operational testing of some diagnostic systems had not been performed when GAO completed its work.

In some cases substantial sums were being spent to improve the diagnostic software or to increase other aspects of support. For example, overcoming shortfalls in Patriot's built-in test equipment required the Army to upgrade the software, add another level of maintenance, and increase maintenance training. Initial investment cost for these changes was about \$94 million.

Historically, diagnostic shortfalls have been attributed to developers' lack of emphasis on maintainability when the weapon system was being designed. Contractors placed little emphasis on testability because the government's evaluation yardstick was system performance.

In its case studies, GAO found that contractual diagnostic requirements were not specific; contractors were not given quantitative data or procedures for making trade-offs between use of built-in or external diagnostic equipment; testing of diagnostics was limited and lagged behind system testing; and contractors had little incentive to meet expectations.

In 1985, the Army adopted a military standard that provides uniform procedures and methods for establishing a testability program. Among other things, the program is intended to ensure that testability is emphasized early in the design phase, that diagnostic requirements are specific, and that evaluations are performed throughout the development phases.

Recommendations

Among other things, GAO recommended that the Secretary of the Army direct the U.S. Army Materiel Command to give special attention to providing development contractors, where possible, with specific automatic diagnostic requirements; establishing and following formal plans when monitoring the development of the diagnostics; and using contract incentives and penalties, where possible, to encourage contractors to meet requirements. Other recommendations are shown on p. 39.

Agency Comments and GAO's Evaluation

The Department of Defense (DOD) concurred or partially concurred with all of GAO's recommendations (See app. II.) In its draft report, GAO suggested that contractors be provided with specific automatic diagnostic requirements. However, DOD noted that this could be interpreted as requiring arbitrary requirements before needed analyses are completed. GAO modified its recommendation to delete this inference. In its draft report, GAO had also proposed that the Secretary of the Army direct the Commander, U.S. Army Materiel Command to ensure that testability is emphasized during the acquisition process. DOD stated that the Army Materiel Command already recognizes that testability needs to be emphasized and therefore direction is not warranted. GAO agreed with DOD and deleted this proposal.

DOD correctly pointed out that GAO based its recommendations on weapon systems which began development in the 1960s and 1970s. GAO selected these systems as case studies only to illustrate why automatic diagnostic shortfalls occur and to provide this information so that similar problems are avoided in the development of future weapon systems. GAO clarified its report.

DOD also provided additional information, explanations, and clarifications which GAO incorporated where appropriate

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Abbreviations

AMC	U.S. Army Materiel Command
ATE	Automatic Test Equipment
BIT/BITE	Built-In Test/Built-In Test Equipment
CTS	Contact Test Set
DOD	Department Of Defense
EQUATE	Electronic Quality Assurance Test Equipment
GAO	General Accounting Office
IFTE	Intermediate Forward Test Equipment
LRU	Line Replaceable Unit
MLRS	Multiple Launch Rocket System
PCB	Printed Circuit Board
STE-X	Simplified Test Equipment-Expandable
TMDE	Test, Measurement, and Diagnostic Equipment
TPS	Test Program Sets
TRADOC	U.S. Army Training and Doctrine Command

Introduction

The Army spends billions to support its weapons. While support costs are based on many factors, the overall cost to support a weapon is heavily influenced by system maintainability. Maintainability is defined as “a characteristic of design and installation which inherently provides for the item to be retained in or restored to a specified condition within a given period of time”, using a specific maintenance concept.

The Army’s maintenance philosophy is to maintain and repair equipment close to the point of malfunction, preferably at the user or organizational maintenance level. The objective is to maximize combat effectiveness by minimizing weapon system downtime. To do this, the Army will rely heavily on repair-by-replacement, which for electronic units will be effective only if the Army can quickly identify and replace faulty line-replaceable-units (LRUS).

The maintenance philosophy for some of the newer Army weapons emphasizes the use of built-in test/built-in test equipment (BIT/BITE) and external automatic test equipment (ATE) to detect and isolate problems in weapons. Built-in electronic test equipment is used to detect and isolate system failures at the organizational level. While ATE may be used to supplement built-in diagnostics at the organizational level, it is generally used to detect and isolate faults at the other maintenance levels—direct support and general support.

The Army recognizes the importance of effective test equipment and the use of automatic diagnostics. In the past few years, it has implemented the standard ATE concept, limiting unique test equipment development and fielding; revised policies and guidance, elevating the importance of testability and support considerations in early system design and development; and funded new test technology initiatives, advancing the technology and use of automatic diagnostics.

Objectives, Scope and Methodology

In congressional hearings, the Army acknowledged that it was having problems with automatic diagnostics in one advanced air-defense weapon, the Patriot, which would cause the support cost for this system to increase substantially. Since the Army spends billions to maintain its weapons and will be fielding several more new weapons having automatic diagnostics, we initiated this review to determine whether other systems were having similar problems. Specifically, we wanted to determine the Army’s problems with automatic diagnostics for forward maintenance of electronics equipment; what the Army was doing to overcome

them; and what can be done to prevent or minimize similar problems when acquiring future weapons.

We limited our detailed examination to six weapons—the Patriot and Hawk air defense systems, the Multiple Launch Rocket System (MLRS), the Pershing missile system, the Apache helicopter, and the Abrams tank. We chose these systems for our case studies because they illustrated

- weapons having automatic diagnostics for the electronic equipment,
- different types of weapons, that is, missiles, aircraft, and tracked vehicles; and
- weapons using system-unique and Army-standard test equipment.

In performing our review, we reviewed DOD, Army and major command directives, regulations, standards, guides, pamphlets, and prior studies addressing electronic test equipment, maintenance, and testability. We also interviewed Army and contractor representatives, and considered the results of related defense studies and Army initiatives to advance test technology and the use of automatic diagnostics. A bibliography of key studies, reports and other writings we used during our review is included as appendix I.

We did not examine the scientific merit of the diagnostic requirements for or the tests of the weapon systems. However, we obtained a technical review of our draft report from the Georgia Tech Research Corporation, which is experienced in developing and reviewing automatic diagnostic systems.

When focusing our work to identify potential causes for the diagnostic shortfalls, we used the following assumptions.

- Maintainability is a key aspect of weapons development which should be emphasized as early as possible in design and development.
- Automatic diagnostic requirements should be specific.
- The Army should provide quantitative data and guidance for the developing contractor to follow when deciding on and incorporating automatic diagnostics.
- The Army should monitor the contractor's efforts to design in automatic diagnostics and test the diagnostics before producing the weapon system.
- Contractors might be responsive to monetary incentives and penalties.

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- **Contractors should be held accountable for meeting diagnostic requirements.**

Our review, which covered the period February 1985 through March 1986, was performed in accordance with generally accepted government auditing standards.

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Problems With Automatic Diagnostic Systems

The Army's automatic diagnostic systems are having problems detecting and isolating weapon system faults. Costs to overcome the diagnostic shortfalls are difficult to quantify and vary by weapon. However, if the diagnostic problems are not resolved, the Army will have trouble maintaining and supporting these new weapons. Additionally, the Army will have to provide more repair parts and maintenance personnel, which could significantly increase the support costs for some of the Army's new weapons.

Diagnostic Performance Not Meeting Expectations

Generally, neither built-in nor external diagnostics performed as expected during the key operational tests managed by the Army's independent tester, the Operational Test and Evaluation Agency. However, opinions on performance often differed significantly depending on the office interpreting the test results. Performance also varied by type of test. Army project office representatives acknowledged that the diagnostic expectations¹ were arbitrary and often stated as goals rather than requirements.

Bite Performance Evaluations Depended on Test Interpreter

The project offices and the independent tester at times had different opinions as to how well BITE performed during operational tests. But, regardless of the interpretation, systems usually did not meet expectations.

For example, the Multiple Launch Rocket System's built-in diagnostics were expected to isolate 90 percent of all electronic failures to a faulty LRU. Also, false removals—removal of good LRUs—were expected to be no more than 7 percent. As shown in table 2.1, the independent tester reported that during operational tests, the system fell substantially short of meeting these expectations. Yet, according to the Project Office's interpretation of the same tests, BITE came close to meeting the false removal expectations.

Table 2.1: Multiple Launch Rocket System: Comparison of Reported Bite Performance

Figures in Percentages			
	Expectation	Independent tester	Project office
Fault isolation to one LRU	90	15	Not assessed
Maximum false removals	7	54	8

¹Expectations is used here and throughout this chapter in a generic sense. In some of our case studies diagnostic needs were stated as requirements and in others as goals.

Specifically, the independent tester reported that (1) built-in diagnostics had correctly isolated 34 of 232 faults in 54 LRUS to a specific LRU, providing a 15-percent correct isolation rate, and (2) 29 of 54 LRUS removed during the test were serviceable, indicating a 54-percent false removal rate. False removals increase the maintenance work load and the amount of repair parts needed

Automatic fault isolation was not assessed in the Project Office's analysis of the above operational tests. But, according to its analysis, good parts were removed in only 6 of 75 incidents, providing a false removal rate of only 8 percent. The analysis recognized, however, that had false removals due to low voltage been included, the false removal rate would have been 16 percent. Nonetheless, this rate is still significantly lower than the 54-percent rate reported by the independent tester.

Similarly, the Project Office and independent tester's assessment of Patriot's performance during a follow-on evaluation to the full production decision varied significantly. While the independent tester reported that 63 percent of the faults had been correctly isolated by organizational maintenance, the Project Office's Reliability, Availability, and Maintainability Group reported that 85 percent of the faults had been correctly isolated. The group leader recognized, however, that only 34 percent of the faults were detected automatically, which is significantly less than the 75- to 99-percent expectation.

Bite Performance Varied by Test

BITE performance also varied by test. But the diagnostic systems performed better in contractor-directed tests, and in most cases later test results indicated that performance had improved.

For example, Pershing's BITE is expected to isolate 95 percent of all missile faults. As shown in table 2.2, BITE correctly diagnosed most of the faults in the contractor-directed tests. Yet, in the operational tests, BITE was considered unreliable and frequently made incorrect diagnoses

**Table 2.2: Pershing Missile System:
 Comparison of Bite Fault Isolation
 Performance**

Test director	Date	Percentage of correct diagnoses
Contractor	January 1982	98
Contractor	May 1983	88
Independent tester	January 1983	59
Independent tester	October 1983	Not quantified

While no quantitative BITE performance data was accumulated during the October 1983 operational test, the Test Director commented that the maintenance concept was less than adequate. He noted that on many occasions, BITE had failed to identify the correct maintenance action, resulting in missile sections and other major assemblies being sent to direct support maintenance for unnecessary troubleshooting and testing.

Like the Pershing, Patriot's BITE performance also varied by test. After improvements, Patriot mechanics were expected to detect, isolate, and repair 99 percent of all "mission essential" failures at the organizational maintenance level using battalion resources. To do this, BITE was expected to detect 99 percent of all failures and automatically isolate between 75 and 99 percent of the failures to an LRU. The organizational mechanic would isolate the other failures, using BITE supplemented with organizational test equipment and manual procedures. Specially trained and equipped mobile maintenance teams from intermediate maintenance would identify and correct those faults (1 percent) not detected by the organizational mechanics.

The more recent test results showed improvement, but automatic fault isolation was still substantially less than expected, as shown in table 2.3.

2.3: Patriot: Fault Detection and Isolation

Figures in Percentages

Test ^a	Fault detection			Fault isolation		
	Automatic	Manual	Total	Automatic	Manual	Total
1	76	0	76	22	10	32
2	52	15	67	10	4	14
3	46	22	68	15	7	22
4	88	5	93	62	7	69
5 ^b			99 ^c	34	51	85

^aTests are listed in chronological order

^bThis information is based on the 35 faults used in the Project Office test analysis. Using a universe of 116 faults, the independent tester reported a combined manual and automatic fault isolation rate of 63 percent

^cProject Office representatives could not segregate the automatic and manual fault detections

As indicated in table 2.3, the inability to automatically isolate faults was a major shortfall in Patriot's built-in diagnostics. While improvements continue, some Project Office representatives now think that the automatic fault isolation expectations may never be met and that they were unrealistic, considering the state of the art of built-in diagnostics. When commenting on fault isolation expectations, the Project Manager explained that Patriot's current fault isolation goal, using both automatic and manual means, was 90 percent and that this goal was expected to be achieved through the changes then being made, such as improvements in software.

External Automatic Test Equipment Is Also Having Problems Meeting Expectations

External automatic test equipment is also having problems meeting expectations. For example, Pershing's external tester—Systems Component Test Station—isolates failures occurring in the missile, launcher, platoon control assemblies, and selected printed circuit cards. Specifically, the tester is expected to isolate 90 percent of all singularly occurring faults in these components to the defective printed circuit board (PCB) or module, and the remaining 10 percent to not more than two parts.

In its first test, the tester isolated only 10.5 percent of failures to the defective part. Problems continued in later tests, as evidenced by the independent tester's comment that performance could not be assessed, primarily because 51 percent of the fault detections required contractor support. While some improvement has been demonstrated, Pershing's external tester isolated only 21 percent of faults to the defective PCB or module in an October 1985 test.

Table 2.4 compares fault isolation expectations with the tester's performance reported by the Army Test and Evaluation Command in October 1985.

Table 2.4: Pershing's External Tester: Fault Isolation Expectations and Performance

Number of units	Fault isolation	
	Expectation	Performance
One PCB or module	90	2
Two PCBs or modules	10	4
Three PCBs or modules		1
Failed to isolate faulty part		3

As shown in table 2.4, the tester had major problems identifying the defective part. While the system is expected to isolate all faults to no more than two parts, in these tests the system could isolate only 61 percent of the faults to fewer than three. This meant that for 39 percent of the faults, three or more parts had to be removed, replaced, and tested in order to identify the defective unit.

The Project Manager no longer thinks the tester will be able to meet expectations. According to a Project Office electrical engineer, the fault isolation expectations are unrealistic and efforts are underway to lower them. Table 2.5 shows the changes being considered.

Table 2.5: Pershing's External Tester: Comparison of Isolation Expectations and Proposed Changes

Number of units	Fault isolation	
	Required	Proposed
One PCB or module	90	4
Two PCBs or modules	10	4
Three PCBs or modules		1

Actions and Costs to Overcome Shortfalls Vary by Weapon

Generally, the project offices could not specifically identify the costs that would be incurred to overcome the diagnostic shortfalls. However, in some cases, significant amounts were being spent to overcome the shortfalls; in other cases, little was being done to correct problems.

Overcoming Shortfalls Can Be Costly

Because of diagnostic shortfalls, the Army proposed major changes to Patriot's diagnostic software: to add another level of maintenance with external automatic test equipment and to increase organizational maintenance training. According to testimony before Congress, development and procurement costs for these changes, which include missile "recertification" facilities, would exceed \$406 million.

Representatives from Patriot's Project Office could not segregate the cost by element, but they stated that much of the cost was for the missile "recertification" facilities, which they believed were not required to correct the diagnostic shortfalls. We found that the estimated cost for research and investment to improve the diagnostic software and to add the intermediate maintenance will cost at least \$32 million and \$62 million, respectively. The life-cycle cost will be substantially more since 157 additional military personnel will be required for intermediate maintenance. This alone will cost about \$6 million (in 1982 dollars) each year.

For the Abrams tank, corrective actions to overcome diagnostic shortfalls started early and are still being made. For example, five organizational and three direct support test sets were initially developed to support the Abrams. During testing, the test sets were found to be unreliable and were seldom used. In 1979, \$12 million was programmed to redesign and consolidate the test equipment. An additional \$1.2 million was provided to develop backup manual fault isolation procedures.

Numerous actions, including software improvements, are still being taken to correct shortfalls and to enhance the organizational mechanic's ability to troubleshoot the Abrams. These improvements will cost over \$78 million.

Some Diagnostic Shortfalls Are Not Being Corrected

Efforts to overcome Hawk's BITE shortfalls (its failure to achieve the 90 percent automatic fault isolation expectation) are primarily concentrated in rewriting software. The Project Manager could not tell us how much the software improvements would cost or to what extent the improvements would correct the problems.

However, the problems cannot be resolved with only software changes. To meet the 90-percent automatic fault isolation expectation, additional test points will have to be added to the missile display console. But, according to the contractor's Program Manager and Project Office Test and Quality Assurance representatives, adding additional test points

would not be cost-effective. Using contractor estimates, the Hawk Project Manager explained that research and development to bring the console up to specifications would cost between \$4 million and \$8 million, depending on the technical approach used. Overall costs had not been estimated, nor had the effects of not upgrading the system (e.g., the need for more parts or reduced readiness) been assessed.

When commenting on the impact of not meeting expectations, the Missile Logistics Center explained that the failure to meet the 90-percent fault isolation expectation would have a "large impact" on spares procurements. Also, manual fault isolation procedures would have to be expanded to compensate for the shortcomings, since all faults would have to be identified by some means.

The Hawk Project Manager agreed that more spares would be needed as a result of not meeting the automatic diagnostics expectation. But, he said that the increase would not be major, as indicated by the Missile Logistics Center. Neither the Project Manager nor the Missile Logistics Center provided analysis to support its position. A representative of Hawk's Ground Support Branch estimated that the increase in spares would be no greater than 20 percent. The Project Manager further explained that this assumed that soldiers would not follow suggested manual fault isolation procedures, which stipulate that soldiers are to

"Try the first LRU in the fault list, if this does not fix the fault, replace the original part and return the part to supply stockage and try replacement of the next part on the fault list . "

Similarly, the Pershing Project Manager acknowledged that Pershing's external tester had not performed as expected. He told us that while some improvements had been made, the tester would not be upgraded to meet expectations because upgrading would require a costly redesign of both hardware and test adapters. The Chief of the Program Management Office estimated that the government's cost to improve the tester would be \$15 million to \$20 million. However, no formal assessment had been made to estimate the cost of upgrading the tester or to determine the effects of the tester not meeting performance expectations.

Underlying Causes for Diagnostic Shortfalls

Based upon our detailed examination of the development and production of six weapon systems, we identified reasons for some of the weapons' diagnostic shortfalls and related problems. Even though the six weapon systems began development in the late 1960s and early 1970s, we believe the reasons identified have applicability to other weapon systems entering development subsequent to these systems. It is not our intent to imply that the diagnostic shortfalls which occurred on these six weapon systems could have been avoided. Rather, our objective is to illustrate what problems did occur and provide this information so that similar problems are avoided in the development of future weapon systems.

Specifically, we believe that some diagnostic shortfalls and related problems can be avoided or minimized if the Army

- places greater emphasis on diagnostics early in the program acquisitions,
- does a better job of specifying diagnostic requirements,¹ and
- conducts more thorough and earlier oversight and testing of diagnostics in weapons development programs.

Contractor and Army personnel told us that if contractors had been provided incentives for meeting automatic diagnostic requirements and held accountable when expectations were not met, diagnostic shortfalls and related problems might have been minimized.

Earlier studies have reported similar conclusions. Appendix I provides a bibliography of all studies considered.

Diagnosics Not Emphasized During Weapons Acquisition

We found that diagnostics were not always adequately emphasized during a weapon's acquisition. Unless testability is designed into the system in the early stages of development, it may be too costly or not even possible to design-in testability at a later date.

For example, in developing the Abrams, the only constraints imposed on the developing contractors during the Abrams advanced development phase were the prioritized design constraints and strict cost limitations.

¹Requirements, if contained in contracts, can be legally binding and used to enforce accountability for meeting standards. Expectations, as used in chapter 2, may not always be enforceable.

In the interest of containing costs, all aspects of integrated logistics support, including diagnostics, were postponed until the full-scale development phase. The request for proposals advised the contractors not to be concerned with support equipment, including test sets. With this decision, diagnostics and related support fell behind and consistently lagged behind the weapon's development.

For the Apache, a contractor representative told us that testability had not been enforced when the Apache was being designed. He explained that the hardware design and testability engineers needed to work side by side as the system was being designed and that this had not happened on the Apache. Generally, he said, testability is stressed only by those design engineers who are familiar with and care about maintainability. He explained that testability and use of automatic diagnostics must be designed in as the system is being designed. Testability redesigns are too costly.

Some Project Office representatives acknowledged, however, that maintainability and automatic diagnostics did not receive the emphasis given to cost, schedule, and performance. For example, Patriot software engineers told us that the Army should have emphasized internal automatic diagnostics more during the early phases of system development. Emphasis on Patriot's diagnostics began after the system was designed and then only after the contractor had identified major shortfalls in the diagnostics.

Requirements Are Ambiguous, and Army Gives Contractors Little Guidance on Diagnostics

Contractors generally determine how and to what extent automatic diagnostics are used in identifying and isolating weapon system faults. This occurs because the diagnostic requirements in Army regulations, weapons system requirements documents, and development contracts are, in most cases, ambiguous and the Army provides little quantitative data or guidance for contractors to follow when deciding on and applying automatic diagnostics to a weapon system.

Through a literature search (see app. I) we identified the necessary attributes which should be included in design requirements. None of the design requirements, as shown in table 3.1, for the six weapons we reviewed included all of these attributes.

Table 3.1: Design Requirements for Automatic Diagnostics

Attributes	Number of systems having requirement	
	BITE	ATE
Percent of faults to be detected	1	1
Percent of faults to be isolated	4	3
Percent of faults to be isolated to one, two, three, or more parts	2	2
Percent of false diagnoses or removal of good parts	1	1
Time to diagnose faults	0	0
Personnel skill levels	0	0

As shown in table 3.1, in most cases, Army requirements were limited to overall percentages of faults isolated. This allowed the contractors to decide how and to what extent built-in and external automatic diagnostics were to be used.

Diagnostic Requirements Are General and Nonrestrictive

Army regulations at the time of our review stated that “Maintenance support guidance will encourage the use of...built-in test equipment (BITE), self-diagnostic capabilities, and automatic test equipment...” The regulations further specified that the use of BITE would be maximized for identifying and isolating failures, as justified by “cost effectiveness, mission requirements, and technical feasibility.” The regulations also encouraged the use of external automatic test equipment. Automatic diagnostic requirements were stated in general terms in weapon system requirements documents and development contracts.

The following examples are cited to illustrate the types of problems that can occur when diagnostic requirements are not specified.

The Patriot’s materiel need document specified that “the design of the system will make extensive use of built-in test equipment....” It provided no quantitative requirements for using automatic diagnostics.

The Project Office could not locate the initial systems specification and development contract. But our review of the contractor’s February 1968 maintainability program indicated that the early development contract had not included specific requirements for the use and performance of automatic diagnostics.

Review of the current system specification, dated December 1982, disclosed that the revised diagnostic requirements were more specific than

earlier requirements in that they generally specified the percentage of faults that would be detected and located using automatic built-in test equipment. The specifications stated that for all singularly occurring faults that directly affected tactical systems effectiveness,

"...not less than 99 percent will be detected by BITE supplemented by operator and mechanic procedures . . . not less than 75 percent will be localized by the operator using BITE . . . not less than 99 percent will be localized by the operator/mechanic using enhanced BITE, supplemental built-in test equipment, supplemental computer directed procedures and limited organizational test equipment . . ."

Although an improvement, the requirements do not specify what percent of the faults will be isolated to one LRU, two LRUS, three LRUS, etc. Also, the requirements do not limit false diagnoses, the removal of good LRUS, the time it takes to diagnose the faults, or the personnel skill levels to operate and interpret the diagnostics. The absence of these requirements could allow a contractor to design a system that isolates faults to an excessive number of LRUS, has an unacceptable false alarm rate, and takes highly skilled technicians too long to isolate the faults once they are detected.

Some Project Office engineers and the Director for Combat Development also believe that Patriot's design requirements for automatic diagnostics should have been more precise and that the lack of specificity contributed to some of the problems the Army had with Patriot.

For the Hawk, the BITE requirements specify that

"BITE shall be capable of isolating 90% of the failures to a single Battery Replaceable Unit (BRU) Of the remaining 10%, BITE shall isolate 75% to a group of not more than 5 BRUs The remaining failures shall be isolated by organizational maintenance personnel using fault isolation procedures and, if necessary, external test equipment . . ."

These requirements lack specifics, such as the percent of false diagnoses allowed, personnel skill levels needed, and the time allowed to diagnose faults. The Project Manager agreed that the requirements lacked specificity. Personnel skill levels are understood to be compatible with current skill levels at Hawk's organizational level He also explained that the time to diagnose faults was included in the system's average-time-to-repair requirement, which is contained in the contract.

Initially, the Project Manager and his personnel argued that the contractor could be held accountable for meeting the implied requirements

of 100 percent of faults detected and no false diagnoses and that the average-time-to-repair requirement sufficiently quantified the time needed for diagnostics. They later agreed that holding the contractor accountable would be difficult, if not impossible. They also recognized that soldiers could meet the repair requirement by “wholesale” replacement of parts instead of following the more time consuming manual fault isolation procedures and that this could increase the number of good items being returned for repair.

When we completed our fieldwork, serviceable returns of the major Hawk components ranged from 13 to 35 percent. While no limits were placed on the contractor, the contractor’s Program Manager told us that with improved BITE the serviceable returns should go down. He predicted a 13- to 18-percent serviceable return rate after the improvements for the major items.

A Project Office representative from the Logistics Management Division told us that testing each Hawk part costs from \$600 to \$900 depending on the contractor doing the testing. Based on these prices, the cost of good parts being returned for maintenance could be substantial.

Army Guidance for Making Trade-Off Analyses Is Limited

Army regulations require development contractors to perform various trade-off analyses to determine the most desirable support concept. However, the Army did not provide quantitative data and trade-off requirements that would help the contractors optimize the use of automatic diagnostics. Additionally, the contractors were not required in their contracts to make a trade-off analyses between built-in and external test equipment.

Project Office representatives could not provide us with the trade-off studies made to determine the optimum level and usage of automatic diagnostics for the systems we studied. They stated that these decisions were generally left to the contractors’ discretion and that Army guidance had been limited to those general requirements specified in the required operational capability documents or materiel needs documents.

The Army Missile Command recognized that the Army needed a model to help users and contractors select a cost-effective test policy, particularly for internal versus external test equipment. The Command contracted for a study of existing Army procedures and models to determine an effective means of applying automatic fault diagnosis to a weapon system.

The study contractor found that the Army had no model for making diagnostic trade-offs. Instead, the military and commercial test equipment literature addressed procedures and methodologies to optimize a particular facet of built-in test circuit design. Instead of quantitative data, mathematical tools, and trade-off procedures, the contractor found only general guidelines and some "do's and don'ts." The contractor also found that life-cycle cost data were elusive and inaccurate and that cost data for built-in diagnostic equipment did not exist.

The study and computer model were completed in September 1984. While this is a first step, the computer model is of little value without quantitative operational data. For the Army to actually achieve a cost-effective test policy and make the appropriate trade-offs, test equipment cost and performance data must be accumulated and provided to the development contractors. According to DOD, the Army is beginning to collect such data.

Limited Oversight and Testing

Decisions affecting system testability and the use of automatic diagnostics must be considered and made when the weapon system is being designed and developed. Project offices, however, generally do not establish and adhere to a formal plan for monitoring a contractor's design and development of automatic diagnostics as a system is developed.

The Army oversees a contractor's efforts to design in supportability through periodic system design reviews and logistics status reviews. These reviews generally do not adequately address system testability, particularly the use and performance of automatic diagnostics. Additionally, the logistics reviews are frequently performed after the weapon system design is firm. We also found that the testing of diagnostic equipment is sometimes limited and unrealistic.

No Formal Plans for Monitoring Development of Automatic Diagnostics

For the systems we reviewed, none of the project offices had established and followed formal plans for overseeing contractors' progress in developing automatic diagnostics, nor could they provide us with the agendas or the results of the system design reviews. Some project representatives acknowledged, however, that the design reviews concentrated on the system design, giving little or no attention to assessing system testability and automatic diagnostics, particularly during early development.

For example, Patriot representatives from both the Hardware and Software Divisions told us that they had no formal plan for overseeing the contractor and that the initial engineering development contract did not require reviews of the diagnostics during early system design reviews. Moreover, the contractor was not required to report progress or problems with the automatic diagnostics. Consequently, the design of the system was essentially completed before the Army was aware of the diagnostic shortfalls.

Similarly, the Hawk Project Office did not establish and follow a formal plan to oversee the contractor's progress in designing and developing Hawk's automatic diagnostics. The Project Manager told us that a formal plan was not required or needed and that like all other requirements, automatic diagnostics were monitored based on available staffing.

Hawk Project Office representatives from the Product Assurance and Test Division told us that BITE was sometimes reviewed during periodic visits to the contractor. They told us that the reviews were often informal and that no structured approach was followed. The reviews and subsequent results were not documented.

According to these representatives, BITE received very little attention during the early program reviews and the primary emphasis was getting the system to work. They told us that, historically, maintenance policy has been reactive, not proactive, in that emphasis is first placed on building the system and then on supporting it. The program review minutes tend to support these observations; emphasis during the program reviews appeared to be directed toward system development, giving little attention to system support. One Project Office representative explained that the Army primarily accepted what the contractor reported up to the point of testing.

While the Pershing Project Office did not establish and follow a formal plan to oversee the contractor's progress in designing and developing automatic diagnostics, Project Office representatives from the Test and Evaluation Branch believe that the Army adequately monitored the contractor's efforts during the system design reviews even though no major changes in diagnostics had resulted from the design reviews.

Additionally, the Test and Evaluation Command recommended in its October 1985 report that the Army get more involved with and better control the development of the software for Pershing's external tester.

Reviews and Testing of Diagnostics Performed Too Late to Influence System Design

The Materiel Readiness Activity performed Logistics Status Reviews on five of six weapons we reviewed, but attention to diagnostics varied by system. However, all the reviews were performed late in the development phase, after the system design was firm, and four reviews were completed after the Army had made its production decisions.

In the Pershing review, the Activity also expressed concern about the lag in testing Pershing's diagnostic equipment. Because of the lag, the Activity questioned whether sufficient time would be available to make any needed changes to the test equipment before the planned initial operational capability date.

The lag in testing Pershing's diagnostic equipment is not unique. As shown in table 3.2, Army automatic diagnostics were generally tested late in the weapon system development program. In most cases, production decisions had been made before the Army completed its initial testing of the automatic diagnostics.

Table 3.2: Production Decisions and Initial Testing of Automatic Diagnostics

Weapon	Date of production decision	Date automatic diagnostics initial testing completed			
		Operational		Fault insertion	
		BITE	ATE	BITE	ATE
Abrams	April 1979	May 1981	May 1981	None	None
Apache	April 1982	^a	^a	None	None
Hawk	December 1985	October 1985	October 1987	April 1985	None
M&FS	May 1980	December 1982	None	None	None
Patriot	September 1980	March 1980	None	February 1981	March 1986
Pershing	December 1981	August 1982	May 1983	January 1982	November 1982

^aBITE testing was waived during formal operational tests. Certain aspects of the ATE were tested, but many were not tested and those that were had to be changed.
Note: Testing results available or scheduled as of February 1986.

Testing Sometimes Limited and Unrealistic

Three of the six weapons—Patriot, Hawk, and Pershing—were not tested using dedicated fault-insertion programs (i.e., faults were manually inserted for detection and isolation), and some diagnostic tests performed were unrealistic and limited.

Patriot's first contractor's fault insertion tests to evaluate BITE were not randomly selected or based on expected failure rates. The contractor

chose many of the faults because they were easy to create. Patriot representatives from both the Hardware and Software Divisions acknowledged that the faults used by the contractor did not adequately represent the potential faults that the system would have and that the system would be expected to detect and isolate.

Initial testing of Hawk's improved built-in diagnostics was limited to 135 faults. Both the Army Materiel and Test Evaluation Directorate and the contractor subsequently questioned the adequacy of this testing.

The Test Directorate expressed several concerns about the contractor's fault insertion tests, including the following:

"The contractor was allowed to be the test conductor and in effect could not be expected to maintain an objective and unbiased attitude because of his vested interest in the outcome of the test. The contractor's only concern was meeting the stipulations of the contract."

According to the contractor the fault insertion tests dictated by the Army were not representative of failures that would occur because they were not weighted by expected failure rates. Also, the contractor believes too few faults were inserted to determine the system's true fault isolation capabilities. The contractor maintains that a realistic test of the system's fault isolation capabilities would cost too much and delay system development too long.

Subsequently, the Project Manager told us that testing of 68 more faults had been completed and that the information was available prior to the production decision in December 1985. In his opinion, testing of the built-in diagnostics had been sufficient. However, the test results may not be indicative of the system's fault isolation capabilities because faults were not randomly selected based on expected failure rates.

Operational tests also had limitations. For example, the Pershing operational assessment was performed without a full set of test equipment. Further, the personnel were "handpicked" on the basis of demonstrated skill and motivation and all maintenance above the operator/crew level was performed by the contractor. Similar conditions existed in a later operational test. For example, numerous test adapters and software for the automatic test equipment were not available for testing.

The availability of test program sets (TPS)² for key operational tests was a problem for most systems we reviewed. As shown in table 3.3, many TPS still had not been delivered when we completed our fieldwork.

Table 3.3: Comparison of Forward Support TPS Required and Delivered

System ^a	TPS	
	Required	Delivered
Apache	53	9
Hawk	160	0
MLRS	15	4
Patriot	207	0
Pershing	36	36

^aAbrams did not require TPS at the forward support areas

Views on Incentives and Accountability

An obvious benefit of designing testability into a weapon system is that, when deployed, the weapon will be easier to maintain. Not so obvious, however, is how to provide contractor encouragement to design the system with testability in mind. Because this debate has continued for years, we interviewed numerous DOD and contractor representatives to obtain their thoughts on this issue. Some individuals suggested using contract incentives and warranties as encouragement to contractors. These individuals were of the view that contractors are in business to make money and that monetary incentives may be one way to encourage contractors to do a better job of designing in testability.

Others believed that holding the contractor accountable for meeting requirements was more appropriate. They stated that incentives are not justified in that contractors should not be rewarded for doing what they are supposed to do.

The Project Manager for the Multiple Launch Rocket System stated that fee incentives are a useful tool but great care needs to be exercised when applying them. He indicated that fee incentives should be limited to selected areas that need emphasis. Otherwise the purpose of the fee incentives would be diminished.

Representatives from the rocket system's Integrated Logistics Support Division explained that monetary incentives would motivate contractors

²TPS are used in conjunction with ATE to detect and isolate failures within a component being tested. Generally, TPS consist of (1) a software test program, (2) test accessories, (3) documentation that includes technical manuals, and (4) integrated logistics support of the test accessories.

to design in testability and maximize the use of automatic diagnostics. However, the incentives would have to be administered properly and the automatic diagnostic requirements or design goals would have to be specific and measurable. Otherwise, the Army would find it difficult to determine the incentive fee and keep the contractor from circumventing the intent of the incentives. Also, the requirements would have to be specified in the development contract.

Conversely, representatives from the Pershing Project Office generally agreed that specific incentives for diagnostics should not be used in weapons development contracts. They believed that the contractor should not be given an additional reward for work being done under contract.

We also received a variety of comments and opinions on the issue of holding the developing contractors accountable for meeting diagnostic requirements, including the use of warranties.

Most persons generally agreed that accountability should be stressed. However, as some Army representatives acknowledged, contractors cannot be held accountable if the diagnostic requirements are not specific. Even then, with cost contracts, decisions have to be made between accepting the systems as provided or holding the contractor accountable and paying the contractor's costs of meeting the requirements.

The Army often has to decide between accepting less than expected or incurring additional costs. In the case of Patriot, for example, the Program Manager decided that the diagnostic shortfalls were significant enough to justify additional expenditures totaling more than \$32 million. Project office representatives told us that they had no choice because the diagnostics as initially designed were considered unacceptable. The Army, they said, had no way of forcing the contractor to meet requirements without spending additional money because the development contract was a cost contract.

Similar decisions had to be made on the Hawk program. The Project Manager estimated that the research and development costs to bring the built-in test capabilities up to specifications would be between \$4 million and \$8 million, depending on the technical approach used. While overall costs had not been projected, the Project Manager decided that the changes would not be cost-effective to the government and decided not to hold the contractor accountable. However, the cost of not upgrading

the system (e.g., the need for more parts or reduced readiness) had not been assessed.

In the case of Pershing, Project Office representatives from the Test and Evaluation Branch told us that it would be unfair to hold the contractor accountable since the Army's evaluation criteria were system schedule, missile accuracy, and range within a design-to-unit-production cost constraint. In addition, the Project Manager explained that he did not think it was prudent to require the contractor to meet the requirements because of the additional costs the government would have to incur under the cost-plus-incentive-fee contract. A representative from the Program Management Office estimated that it would have cost the Army \$15 million to \$20 million.

Army Initiatives to Advance Automatic Diagnostics

The Army, recognizing the importance of effective automatic diagnostics has taken actions to (1) centralize test equipment management, (2) develop standard test equipment, (3) elevate the importance of testability considerations in early phases of weapon system design and development, and (4) promote automatic test technology. These initiatives stem from the Army's earlier study of Army test equipment.¹

Army's Move Toward Central Management

The Army has recognized the need for central test equipment management for over 15 years. Central management is needed to ensure the necessary oversight and direction for Army test equipment.

The March 1967 Army Logistics Fault Malfunction Diagnostic Study was one of the first broad studies of the Army's Test, Measurement, and Diagnostics Equipment (TMDE) program. The study identified deficiencies across the full spectrum of TMDE management and use and underscored the fact that the Army lacked a central management system to direct overall TMDE efforts. In November 1967, the Army reviewed the study findings and recommended establishing a central TMDE management system.

Additional studies, reviews, and evaluations followed. While several initiatives resulted from these studies, management deficiencies continued. This prompted the Assistant Secretary of the Army to direct a full assessment of the Army's TMDE posture with emphasis on management. This assessment was performed by a specially formed Department of the Army TMDE Action Team. The team issued its final report in June 1982.

Concerning management, the study team found that

"the Army TMDE program lacks overall direction TMDE efforts are oriented first to the needs of a particular developer, user, mission, etc , and secondly to the total Army Every commodity command is developing, fielding, and supporting TMDE.. "

The study recommended establishing an Army-wide management structure, as did earlier studies. The Secretary of the Army agreed with the recommendation. By Secretary of the Army Charter, dated April 27, 1982, the Commanding General of the Army Materiel Development and Readiness Command, now known as the Army Materiel Command, was

¹ Army Deputy Chief of Staff for Logistics, Department of the Army Test, Measurement and Diagnostic Equipment Action Team (DATAT) Final Report (June 1982)

designated as the Executive Agent responsible for establishing the central management organization and overseeing implementation of the study recommendations.

In response to Secretary of the Army direction, the Office of Executive Director for TMDE was established. The TMDE Executive Director's responsibilities include establishing TMDE policy and procedures, overseeing ATE standardization, and coordinating TMDE technology and development. However, the Executive Director is not provided Army-wide funding data related to the acquisition of TMDE.

The Materiel Command has recognized the need for Army-wide TMDE budgetary information related to the acquisition of TMDE. To provide this information, the Command requested a revision in an Army accounting classification system to include a separate accounting for TMDE. According to the Command, this would provide the TMDE Executive Director a consolidated management tool to

- manage the Army TMDE program;
- plan, program, and budget for all TMDE requirements;
- provide oversight on TMDE operations and resources; and
- elevate TMDE visibility.

The Army accounting system had not been revised when we completed our review.

Development of Standard ATE

The Army has had some success in its attempts to develop and encourage the use of standard general-purpose automatic testers. However, the delays in getting the standard ATE developed and fielded required the developers of some of the Army's newer weapons to develop and field unique test equipment.

Also, as it is now being designed, the standard equipment for the forward maintenance areas will be incapable of testing some Army equipment. Additionally, the contact test set (a portable tester) appears to duplicate capabilities of the standard test equipment being developed for the organizational maintenance levels.

Background and Status of Standard ATE Program

The origin of the standard ATE program is a March 1975 Letter of Agreement to investigate and develop a "family" of standard test equipment for use at the various maintenance levels. Army policy now requires the

use of standard ATE. Waivers are granted, however, when more cost-effective test equipment is identified and approved

For depot and general support maintenance activities, the Army chose the Electronic Quality Assurance Test Equipment (EQUATE).

The standard test equipment for direct support maintenance levels is known as Intermediate Forward Test Equipment (IFTE). It consists of a mobile shelter-mounted Base Shop Test Facility and a portable Contact Test Set. The Army has also decided to make the IFTE Commercial Equivalent Equipment ATE standard for depot level maintenance application. Plans show production beginning in early 1988 and deployment beginning in February 1990.

The standard ATE being developed for organizational maintenance is known as the Simplified Test Equipment Expandable (STE-X). According to the required operational capability document, STE-X will provide organizational maintenance a state-of-the-art, general-purpose automatic tester to allow rapid forward repair of sophisticated weapons. An early cost assessment indicated that the 20-year life cycle (development, investment, and support) cost for 2,000 units would be about \$180 million.

IFTE's Contact Test Set
Capabilities Similar to
STE-X

The Army has under development two different test sets— IFTE's Contact Test Set (CTS) and the STE-X—which appear to have duplicate capabilities. Although they have other uses, each will be capable of troubleshooting (identifying and locating) failures to the line replaceable unit level of repair.

Some Army officials stated that the STE-X would have to be upgraded to perform the diagnostics required by the CTS. Upgrading the STE-X may cost less than developing the CTS and would reduce the number of testers the Army has to support.

Project Offices May Not Use
IFTE

For some of the newer Army weapons, unique test equipment will be developed, procured, and fielded before IFTE is available. Additionally, most project offices participated little in the IFTE planning and development and did not provide their specific test equipment requirements to the developer or formally agree to use IFTE.

The Army planned to have four of the six systems we reviewed use IFTE, but only the Hawk Project Office had a Memorandum of Agreement with the IFTE developer to provide specific test requirements. Abrams, MLRS, and Apache had no formal plans to convert to IFTE, and their participation in the program appeared to have been minimal.

Abrams Project Office representatives and users told us that they had no formal plans to use IFTE. They said that even if Abrams converted to IFTE, little savings would be realized because essentially all the electronic parts to use the existing test equipment and maintenance concept would have been procured before IFTE was available.

Similarly, Apache and MLRS representatives acknowledged that their participation in the program had been limited and that they had no plans to convert to IFTE. They told us that even if they converted to IFTE, little savings would be realized because electronic parts to use the existing equipment would be bought before IFTE was available. MLRS representatives explained that some minimal savings may occur in the out years since procurements for replacements could be reduced

For those project offices that already have test equipment and related support items, converting to IFTE may not be cost-effective. Equipment users and maintainers will have to be retrained, system technical manuals and maintenance charts revised, and TPS translated and validated

Additionally, based on the engineering development contract, IFTE will not be able to test electro-optical equipment. Without this capability IFTE will not be able to replace some test equipment as planned.

Design for Testability Concept

DOD initiated the design for testability concept in 1978. Basically, it will require weapon designers to incorporate provisions for improved testing in their designs early in the weapon system acquisition process. The concept relies heavily on built-in test features and automatic test equipment. It will require designers to evaluate each subsystem or component and add test circuitry or equipment where feasible. The goal is to reduce field testing time, improve diagnostic capabilities, and consequently reduce maintenance time.

The Joint Logistics Commanders Panel on Automatic Testing has laid the groundwork to implement the concept through various initiatives, including the drafting of a military testability standard for designing

electronic systems. This military standard was adopted by the Army in 1985. It provides uniform procedures and methods for establishing a testability program. The requirements of the testability program are

- preparation of a testability program plan;
- establishment of sufficient, achievable, and affordable testability requirements;
- integration of testability into equipments and systems during the design process;
- evaluation of the extent to which the design meets testability requirements; and
- inclusion of testability in the program review process.

Work of the Army Test Technology Team

Prior to 1982 there was no focal point for test expertise and no Army-wide test technology program. As a result, each Army laboratory separately pursued testing needs. In addition, the complexity and sophistication of emerging Army systems and the rapid advance in new technology require weapons developers to be more knowledgeable about testing methods, particularly in making trade-offs between built-in and external automatic test equipment. These are two reasons why an Army-wide test technology base program is needed, according to the Army's TMDE study team.

To implement the study team recommendation, the Army established a test technology team in 1982 with members from the various Army commands. The team is led by the Army's Test, Measurement, and Diagnostic Technology Laboratory reporting to the Executive Director, TMDE. Among other things, the team was to

- establish Army-wide test technology goals and objectives,
- prepare and recommend an Army-wide unified technical approach for test technology research and development, and
- develop and update test technology requirements and funding.

One of the first steps was to determine the Army's test technology needs. To do this, the team asked the various Army commands to identify their test technology and funding requirements for fiscal years 1985-89.

Initially, the plan was to present an Army-wide profile of the requirements and funding. The input from the various commands was to be prioritized and presented to the Army Materiel Command as the Army's

test technology program. But, because of the many unfunded requirements, over \$145 million, the team decided to present only the needs of the Communications and Electronics Command in the initial program and add the other requirements over the next several years. All Army needs have yet to be consolidated and presented as a unified, Army test technology program

According to the Army, funding continues to be a problem. For example, a "white paper" highlighting the test technology base program of two primary laboratories showed a significant shortfall in funding. According to this paper, neither of these two laboratories had funding for basic research or applied research. Yet for fiscal years 1985-90, they have identified a need for \$28.4 million for basic and applied research. Similarly, over this same period, these two laboratories estimated a need of \$71.3 million for technology prototypes, while the Army anticipates funding only \$20.3 million. Overall, about 20 percent of the estimated requirements for these two laboratories will be funded

Conclusions and Recommendations

Conclusions

The electronic maintenance of the newer, more sophisticated Army weapons will depend heavily on automatic diagnostics to quickly identify and replace faulty line-replaceable units. However, the diagnostic systems are having problems detecting and isolating weapon system faults. While the cost to overcome the shortfalls is difficult to quantify, substantial sums are being spent in some cases to improve the diagnostics and increase other aspects of support. If the problems are not corrected, the Army may have trouble maintaining and supporting its new weapons.

Although underlying causes of the diagnostic shortfalls we identified are difficult to establish, we believe some of the problems can be avoided or minimized. Automatic diagnostics need to be appropriately emphasized during system acquisition; contractors need to be provided more specific diagnostic performance requirements; and the Army also needs to provide contractors with quantitative data and procedures to determine the trade-offs between built-in and external diagnostics. Additionally, there is a need to monitor the contractors' efforts to design in testability and require early and thorough testing of diagnostics.

The Army can also do more to ensure that contractors meet requirements which are specific, achievable, and affordable. Options for consideration include offering incentives for designing in testability and automatic diagnostics and holding contractors accountable for meeting requirements.

The Army has recognized the importance of effective automatic diagnostics and has issued the military standard for a testability program which, if applied and enforced, would help to mitigate many of the problems we found during our review. Among other things, the standard calls for establishing sufficient, achievable and affordable requirements, and preparation of a testability plan.

Standard equipment such as IFTE should be designed to meet the needs of expected users and remain technically advanced. The Army planned to use IFTE for four of the six systems included in our review, but only one had a memorandum of agreement with the IFTE developer to provide specific test requirements. Also, because IFTE will not be able to test electro-optical equipment, it will not be able to replace some test equipment as planned.

In transitioning to the IFTE, care must be taken to ensure that IFTE replaces existing test equipment only when it is cost-beneficial. For

those project offices that already have test equipment and related support items, converting to IFTE may not be cost-effective because of the potential need to retrain equipment users and maintainers, revise system technical manuals and maintenance charts, and translate and validate TPS.

IFTE's CTS appears to duplicate capabilities of the STE-X, the Army's potential future standard electronic tester, at the organizational maintenance level. While Army officials told us that the STE-X would need to be upgraded to perform the diagnostics required by the CTS, we believe that its feasibility should be analyzed further, to include a comparison of the cost of developing and supporting the CTS with the cost of upgrading the STE-X.

Recommendations

We recommend that the Secretary of the Army direct the U.S. Army Materiel Command to

- provide development contractors, where possible, with specific automatic diagnostic requirements, along with guidance for making trade-offs between internal and external diagnostics equipment;
- establish plans for and monitor the development of diagnostics to ensure that diagnostics development and testing appropriately parallels system development and testing; and
- develop and evaluate the use of contract incentives and penalties, where possible, to encourage contractors to meet these requirements.

Regarding on-going standard automatic test equipment programs, we also recommend that the Secretary of the Army direct the U.S. Army Materiel Command to

- ensure that standard diagnostic equipment, such as the Intermediate Forward Test Equipment, is designed to meet user needs and remains technically advanced as long as it is being used;
- base decisions to convert existing weapons to IFTE on a case-by-case cost and effectiveness analysis; and
- assess CTS and STE-X capabilities and needs to determine the costs and benefits of supporting one standard tester.

Agency Comments and Our Evaluation

DOD expressed concern that our report will be interpreted to require establishing specific diagnostic requirements before the necessary analysis is completed and their feasibility assessed. According to DOD, the

systems we used as the basis for our recommendations started development in the late 1960s and early 1970s, and at that time technology difficulties in achieving high automatic diagnostic performance were not well understood. Thus, it is inappropriate to conclude that diagnostic shortfalls could have been avoided for the systems we reviewed. Furthermore, even for these "older" systems, improvements have been made in diagnostic performance over and above those cited in our report.

We selected older fielded systems for review as a baseline against which to demonstrate the types of problems that can occur when diagnostic requirements are not adequately considered or specified during the development of a system. We clarified the text of our report to ensure we do not imply that better specifications could have been developed for these systems. We realize improvements have been made. Also, as discussed in chapter 4, the Army has developed procedures to address the lack of specific requirements. However, these are new, and we were unable to fully evaluate their effectiveness.

DOD agreed with our findings with respect to automatic diagnostics test results, but did not agree that the Army will necessarily have trouble maintaining new weapon systems if the automatic diagnostics systems have problems; maintenance on the systems can be accomplished by means other than automatic diagnostic equipment. DOD also stated that because automatic diagnostics may have a lower rank order than other system characteristics does not mean that it is not important. DOD added that, in general, diagnostics are receiving attention in the acquisition process ranking order, either explicitly or implicitly, through such factors as logistics support reduction objectives or operating and support cost goals.

We agree that in certain situations fault diagnosis may be accomplished by means other than automatic diagnostics. However, certain systems with complex electronics can be tested only with automatic diagnostic equipment. Furthermore, for those systems where other means could be used, automatic diagnostic equipment may be quicker and more effective.

In pointing out that automatic diagnostics are not receiving adequate emphasis, we noted instances where testability had a lower priority than other weapon system characteristics. We have deleted that material from the discussion so as not to imply that the priorities should have been different.

DOD agreed that better analyses are needed to determine the trade-offs between built-in and external diagnostics, and said that the Army is beginning to collect data and develop models to facilitate such analyses

DOD also agreed that earlier testing could result in finding diagnostic problems earlier, but noted that we had not recognized the latest (mid-1986) test results for the Hawk, which showed that the diagnostics were acceptable. The issue being addressed in the report was not that shortcomings could not be overcome but, rather, that early and realistic testing, is essential for developing effective and reliable diagnostics.

With respect to the issue of standard test equipment, DOD advised that the Army has recently developed a program that balances the need for such equipment with cost-effectiveness. DOD also advised that the Army has established a separate funding line for electro-optics, which should lead to development of this capability. We did not validate the Army's program and therefore cannot attest to its merits. However, it appears to be an appropriate step.

DOD agreed with our recommendations to establish plans to monitor diagnostics development, to ensure that IFTE conversion decisions are made on a case-by-case basis, and to assess CTS and STE-X capabilities. DOD disagreed with our specific recommendation to provide contractors with automatic diagnostics requirements (because of the concern cited earlier about arbitrarily imposing requirements prior to completion of the necessary analyses). We did not intend to suggest an arbitrary assignment of requirements and have adjusted the wording of our recommendation accordingly.

DOD partially concurred with our recommendation for incentives and penalties, pointing out that incentives are useful only when requirements can be delineated and are achievable. We believe DOD should develop and evaluate their use in appropriate circumstances. DOD also partially concurred with our recommendation to design standard diagnostic equipment to meet user needs, stating that, as built-in automated diagnostics technology improves, the need to technically advance standard equipment may diminish. Therefore, the need to continually improve standard equipment needs to be examined on a case-by-case basis. We agree that there should be a trade-off between the state-of-the-art and capability of built-in automated diagnostic equipment.

In our draft report, we had also proposed that the Secretary of the Army direct the Commander, U.S. Army Materiel Command, to ensure

that testability is emphasized during the acquisition process. DOD concurred and stated that the Command had already recognized the need to emphasize testability. We agree that actions (including the development of a testability standard) have been initiated, and therefore we are not making a recommendation on this matter.

Our draft report contained a proposal that the Army assess the need for and, if benefits outweigh costs, determine the most appropriate means of obtaining Army-wide TMDE budgetary information. Because DOD concurred and stated that a TMDE financial information system is in order, we are not making a recommendation on this matter.

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Comments From the Office of the Under Secretary of Defense, Acquisition



ACQUISITION

OFFICE OF THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301

23 FEB 1987

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and
International Affairs Programs
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of Defense (DOD) response to the General Accounting Office (GAO) draft report "WEAPON SYSTEMS: Shortfalls in Automatic Fault Diagnostics Increase Army Support Costs," dated November 17, 1986 (GAO Code 393057/OSD Case 6823).

While the Department has no argument with the overall GAO thrust that automated diagnostic requirements be specified and contractual incentives be provided, the DOD is concerned that the report will be interpreted to require establishing these requirements before the necessary analysis is completed and their feasibility assessed. The systems the GAO used as the basis for its recommendations started development in the late 1960's and early 1970's, at a time when the technology difficulties in achieving highly automated diagnostic performance were not well understood. It is only recently that industry and the DOD have jointly reached a consensus on a possible approach for contracting for development and delivery of the diagnostic capabilities. The Under Secretary of Defense (Acquisition) has recently asked the Services to apply and tailor this approach, as described in model statements of work, to a wide variety of programs. Through this process the Department expects to evolve an approach that should result in improvement of the acquisition process for weapon system diagnostics.

In conclusion, the GAO report does not reflect the many ongoing actions the DOD and Army have undertaken to address the critical area of diagnostics. Under these circumstances, with some minor exceptions noted in the report, the DOD does not believe further direction of the Army is warranted.

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Specific responses to findings and recommendations are attached. The opportunity to respond to the draft report is appreciated.

Sincerely,

A handwritten signature in black ink, appearing to be "J. G. ...", written in a cursive style.

Attachment
as stated

GAO DRAFT REPORT DATED NOVEMBER 17, 1986
(GAO CODE 393057) OSD CASE 6823

"WEAPON SYSTEMS: SHORTFALL IN AUTOMATIC FAULT DIAGNOSTICS
INCREASES ARMY SUPPORT COSTS"

DEPARTMENT OF DEFENSE COMMENTS

* * * * *

FINDINGS

- o **FINDING A: Dependence On Automatic Diagnostics.** The GAO observed that the overall cost to support a weapon is heavily influenced by system maintainability. The GAO reported that, as a result, the Army is implementing a "forward support" maintenance concept, which will rely heavily on repair-by-replacement. The GAO concluded, however, that this approach will only be effective for electronic units if the Army can quickly identify and replace faulty line-replacement units (LRUs). The GAO noted that for some of the newer Army weapons, the use of built-in test/built-in test equipment (BIT/BITE) and external automatic test equipment (ATE) is emphasized to detect and isolate problems. According to the GAO, the former is used at the organizational level, while the latter is generally used to detect and isolate faults at other forward maintenance levels--i.e., direct support and general support (although it may be used as a supplement at the organizational level). The GAO observed that the Army spends billions to maintain its weapons and will be fielding several more new weapons having automated diagnostics. The GAO noted that its examination was limited to six weapons--the PATRIOT and the HAWK air defense systems, the Multiple Launch Rocket System (MLRS), the PERSHING missile system, the APACHE helicopter and the ABRAMS tank. The GAO generally concluded that the electronic maintenance of the newer, more sophisticated Army weapons will depend heavily on automatic diagnostics and that the Army's automatic diagnostic systems in the forward areas must be effective and reliable. (pp. 1-3, p. 51/GAO Draft Report)

DOD RESPONSE: Concur.

- o **FINDING B: Diagnostic Performance Not Meeting Expectations.** The GAO found that, generally, neither the built-in nor the external diagnostics performed as expected during the key operational tests managed by the Army Operational Test and Evaluation Agency. The GAO also found that test results varied according to the interpreter. The GAO observed that

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the MLRS built-in diagnostics were expected to isolate 90 percent of all electronic failures to a faulty LRU. According to the GAO, the independent tester reported that the system fell substantially short of this, while the Project Office interpreted the same test as having come close to expectations. (The independent tester reported a 15 percent rate for correct isolation and a 54 percent rate for false removals.) The GAO noted that, for the PATRIOT, the Army acknowledged in congressional hearings it was having problems with automatic diagnostics. The GAO also noted that, while the independent tester reported 63 percent of faults correctly isolated by organizational maintenance, the project office reported 85 percent. In addition the GAO found that BITE performance varied by test. The GAO cited, for example, the PERSHING BITE correctly diagnosed most faults in contractor-directed tests, yet was considered unreliable in its operational tests. Also, while more recent tests of the PATRIOT BITE showed improvement, the GAO found that performance was still substantially below expectations in automatic fault isolation. The GAO concluded that there is a basic shortfall in the PATRIOT built-in diagnostics. In addition, the GAO found problems in ATE. The GAO cited, for example, the PERSHING external tester. Although expected to isolate 90 percent of all singularly occurring faults to the defective part, in its first test it isolated only 10.5 percent and problems continued in later tests. (The GAO noted that the Project Manager no longer thinks this tester will be able to meet expectations.) The GAO concluded that, although it only reviewed a small sample of weapons systems, the problems it observed illustrate the type of problems that could exist on any Army weapon system using automatic diagnostics. The GAO also concluded that diagnostics systems are having problems detecting and isolating system faults and, if the problems are not corrected, the Army will have trouble maintaining and supporting its new weapons, particularly using "forward support." (pp. 2-11, p. 51/GAO Draft Report)

DOD RESPONSE: Partially concur. The GAO findings on the automatic diagnostic test results are correct, as far as they go. The GAO, however, has not reported on the subsequent Army efforts to improve performance or the alternative diagnostic approaches being developed by the Army. Therefore, the DOD disagrees with the GAO conclusion Maintenance of systems can be accomplished by means other than automatic diagnostics. Therefore, the GAO conclusion that the Army will have trouble maintaining and supporting new systems if the automatic diagnostic systems have problems may not be correct nor was it supported by specifics for the six operational systems reviewed.

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- o **FINDING C: Diagnostic Shortfalls Increase Support Costs.** While actions and costs to overcome diagnostic shortfalls vary by weapon, the GAO found that, generally, the project offices could not identify specific corrections and costs to overcome these shortfalls. The GAO noted that all project offices advised they were improving automatic diagnostics, while only half were also increasing other support. The GAO also found that, in some cases, significant amounts were being spent to overcome shortfalls. The GAO cited, for example, that the Army had to make major changes in the PATRIOT diagnostics software, add another level of maintenance, establish missile "recertification" facilities and increase organizational maintenance training, in order to overcome diagnostic shortfalls. The GAO observed that, according to congressional testimony, such changes would increase development and procurement cost by more than \$406 million. Representative from Patriot's office could not segregate the cost by element, but they maintained that much of the cost was for missile "recertification" facilities. Also, for the ABRAMS tank, the GAO noted that corrective actions to overcome diagnostics shortfalls started early and are ongoing, with an overall cost in excess of \$78 million. The GAO also found that some diagnostic shortfalls are not being corrected. The GAO reported that efforts to overcome HAWK's BITE shortfalls are primarily concentrated in rewriting software, but the problems cannot be resolved with only software changes, since additional test points will also have to be added to the missile display console (at an estimate cost of between \$4 million and \$8 million). The GAO observed there are contradictions--i.e., the Missile Logistics Center explained that failure to meet 90-percent fault isolation would have a large impact on spares procurements, while the Project Manager told the GAO the impact would not be major. The GAO reported that the PERSHING Project Manager said the tester would not be upgraded to meet expectations because of costly redesign (estimated at between \$15 million and \$20 million) for hardware and test adapters. The GAO concluded that, while cost to overcome shortfalls is difficult to quantify, substantial sums are being spent to improve diagnostics or increase other aspects of support. The GAO further concluded that the Army will have to provide more repair parts and maintenance personnel, and this could also significantly increase the support costs for some of the Army's new weapons. (p. 2, p. 5, pp. 11-14, p. 51/GAO Draft Report)

DOD RESPONSE: Concur.

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- o **FINDING D: Diagnostics Not Emphasized During Weapon Acquisition.** The GAO found that diagnostics and related equipment carried a lower priority than other aspects of the weapon's acquisition, particularly cost, schedule and system performance. (The GAO noted that other studies had reported similar findings.) The GAO cited, for example, that the ABRAMS' materiel need document included a priority list of 11 design characteristics to be traded off to meet the design-to-unit cost goal, and the lowest priority was "compatibility with associated equipment," which included diagnostics and related support equipment. The GAO found that all aspects of integrated logistics support were postponed on the APACHE, until the full-scale development phase. The also GAO found, that maintainability ranked sixth, following such things as flight performance, firepower, and survivability. The GAO noted that a contractor representative said that testability had not been enforced when APACHE was being designed, but that testability and the use of automatic diagnostics must be designed as the system is being designed. For other systems, the GAO noted Project Office representatives acknowledged that maintainability and automatic diagnostics were not emphasized as much as cost, schedule, and performance. The GAO concluded that underlying causes of diagnostics shortfalls are difficult to establish; however, automatic diagnostics did receive less emphasis than other aspects of acquisition, particularly in the early design phases. The GAO further concluded that some diagnostics shortfalls could have been avoided or minimized had the Army placed greater emphasis on diagnostics early in the program acquisition. (pp. 15-17, pp. 51-52/GAO Draft Report)

DOD RESPONSE: Partially concur. Ranking order of desired system characteristics does not imply that a lower order characteristic is not important. In the cases reviewed by GAO, the rank order did not say that testability was not important but that combat capability has a higher priority. In general, diagnostics is getting attention in the acquisition process ranking order, either explicitly, or implicitly through such factors as "logistic tail" reduction objectives or operating and support cost goals.

- o **FINDING E: Requirements Are Ambiguous.** The GAO found that, in most cases, diagnostics requirements in Army documents and development contracts are ambiguous, and the Army provided little quantitative data or guidance for contractors. The GAO reported that Army regulations state, "Maintenance support guidance will encourage the use of ... BITE, self-diagnostic capabilities, and automatic test equipment ..." (as justified by cost effectiveness, requirements, and feasibility) and that

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the regulations encourage the use of ATE. The GAO noted, for example, that the PATRIOT materiel need document provided no quantitative requirements for using automatic diagnostics. The GAO found that the requirements still do not specify what percent of the faults will be isolated to one, two or three LRUs, nor limit false diagnoses nor personnel skill levels required to operate and interpret the diagnostics. The GAO further found that for the PATRIOT (1) built-in diagnostics isolate to an average group of eight LRUs and as many as 30 LRUs, (2) time-to-repair requirements had not been achieved, (3) and about 40 percent of the LRUs returned for maintenance needed none, according to the prime contractor. The GAO reported that the Project Manager for HAWK agreed that diagnostic requirements lacked specificity, and that it would be difficult to hold the contractor accountable for meeting implied requirements of 100 percent of faults detected and no false diagnoses. The GAO reported that at the time it completed its fieldwork, serviceable returns of the major HAWK components ranged from 13 to 35 percent. (The GAO noted that a Project Office representative said testing of each part cost from \$600 to \$900, and, accordingly, costs of having good parts returned could be substantial.) Although prior studies cited design requirements that should be included, none of the six programs the GAO reviewed included all of them. In most cases Army requirements were limited to one requirement--i.e., overall percentage of faults isolated. (Other requirements cited in the studies were (1) percent of faults detected, (2) percent of faults isolated to one, two, three or more parts, (3) percent of fault diagnoses or removal of good parts, (4) time to diagnose faults, and (5) personnel skill levels.) The GAO concluded that contractors generally determine how and to what extent automatic diagnostics are used. The GAO also concluded that some diagnostic shortfalls could have been avoided or minimized had the Army done a better job of specifying diagnostics requirements. (p. 15, pp. 17-21, p. 51/GAO Draft Report)

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DOD RESPONSE: Partially concur. The approaches for specifying diagnostic performance have been a matter discussed within the technical community over many years. Also, design implementation of diagnostics is very difficult and the engineering approaches for achieving the specified high performance are just now evolving. It is only very recently that some agreement has been reached. Thus, the GAO conclusion that diagnostic shortfalls could have been avoided with better Army specification is inappropriate for the systems reviewed. These systems' diagnostic specifications were developed a number of years ago before the difficulties in achieving high automatic diagnostic performance were

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realized. Even for these "older" systems, however, improvements have been made in diagnostic performance above that reported by the GAO.

- o **FINDING F: Army Guidance For Making Trade-off Analyses Is Limited.** The GAO found that Army regulations expected the development contractors to perform trade-off studies to determine the most desirable support concept, but that the Army did not provide quantitative data and trade-off requirements that would help the contractors optimize the use of automatic diagnostics. In addition, the GAO found that contracts did not require contractors to make trade-offs between built-in and external test equipment. The GAO noted the Army Missile Command recognized that the Army needed a model to help users and contractors select a cost-effective test policy and contracted for a study, completed in September 1984, which produced a computer model for making diagnostics trade-offs. The GAO concluded, however, that this first step is of little value without quantitative operational data on test equipment cost and performance, which must be accumulated and provided to the development contractors. The GAO also concluded that some of the problems now being experienced could have been avoided had this been done. (pp. 22-23, p. 52/GAO Draft Report)

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DOD RESPONSE: Concur. The Army's test equipment program manager is beginning to collect data and develop models to support diagnostic tradeoffs and analyses.

- o **FINDING G: Limited Oversight.** The GAO observed that decisions affecting system testability and the use of automatic diagnostics must be considered and made when the weapon system is being designed and developed. The GAO found, however, that Project Offices, generally, do not establish and adhere to a formal plan for monitoring the contractor's design and development of automatic diagnostics as the system is developed. The GAO reported that none of the systems it reviewed had such a formal plan. The GAO noted, for example, that PATRIOT representatives advised they had no formal plan for overseeing the contractor and the initial engineering development contract did not require reviews of diagnostics during early system design reviews. Similarly, the GAO reported that the HAWK project office did not establish and follow a formal plan. The GAO noted that HAWK Project Office representatives indicated BITE received very little attention during early program reviews. The GAO concluded that some diagnostic shortfalls could have been minimized had the Army oversight of diagnostics been more thorough and done earlier in the program. (p. 15, pp. 24-26, p. 52/GAO Draft Report)

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DOD RESPONSE: Concur.

- o **FINDING H: Limited Testing.** The GAO found that the Material Readiness Activity performed logistic status reviews late in the development phase on five of the six systems it reviewed. The GAO noted that on the PERSHING, the logistics status review expressed concern about the lag in testing the PERSHING diagnostic equipment. The GAO found that of the six systems it reviewed, only the initial operational and fault isolation for HAWK BITE and the initial operational testing for PATRIOT BITE were performed before the production decision. In addition, the GAO found that three of the six weapons were not tested using dedicated fault-insertion programs, and some diagnostics tests were unrealistic and limited. The GAO also found that the PATRIOT's first contractor fault insertion tests were not randomly selected or based on expected failure rates, and initial testing of the HAWK's improved built-in diagnostics was limited to 135 faults. The GAO reported that both the Army Material Test and Evaluation Directorate and the contractor questioned the adequacy of the HAWK testing. The GAO concluded that some problems being experienced could have been minimized through earlier testing of diagnostics. (p. 15, pp. 26-29, p. 51/GAO Draft Report)

DOD RESPONSE: Partially concur. The DOD agrees that earlier testing could result in finding diagnostic problems earlier. In the cases reviewed, however, lack of early testing was not an issue for some of the systems. Also, the GAO report does not include the latest results (Mid-1986) of Hawk diagnostic testing, which shows that the diagnostics are acceptable.

- o **FINDING I: Little Incentive And Accountability.** The GAO found that for the systems it reviewed, the Army chose not to use monetary incentives to encourage contractors to design in testability and to meet diagnostic requirements. Similarly, the GAO found that the Army did not hold the developing contractors accountable for meeting requirements (in part because they were not specific). The GAO noted that, according to the Project Manager for MLRS, fee incentives are a useful tool, but must be applied very carefully. Conversely, the GAO reported that representatives of the PERSHING Project Office felt that specific incentives for diagnostics should not be used in weapons development contracts. The GAO observed that most persons agreed that contractor accountability should be stressed, but some pointed out that to do so, diagnostic requirements had to be specified. In addition, the GAO found that with cost contracts, the Army often has to decide between accepting less or incurring additional costs. (The GAO noted, for example, that the PATRIOT Program Manager decided to spend \$32 million

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to improve unacceptable diagnostics, while the HAWK Project Manager decided not to spend an estimated \$4 million to \$8 million to bring built-in test capabilities up to specifications.) The GAO concluded that some diagnostic shortfalls could have been minimized had contractors been provided incentives or held accountable. In addition, the GAO concluded that the Army can do more, once requirements are specific, achievable, and affordable, to ensure that contractors meet them, either by assessing monetary penalties or offering incentives for designing-in testability and automatic diagnostics. (p. 15, pp. 30-33, p. 52/GAO Draft Report)

DOD RESPONSE: Partially concur. The use of monetary incentives or other contractual approaches is useful to indicate where emphasis should be placed when diagnostic requirements can be adequately delineated and are potentially achievable. As previously noted this has not always been possible because of the uncertainties in the diagnostic area. In that situation monetary incentives will not help.

- o **FINDING J: Earlier Studies Have Identified Design And Testability Problems.** The GAO found that over several years, diagnostic and testability problems have been identified and reported by various organizations. The GAO reported that among these was:

- a 1980 joint industry/service group that reported the role of automatic diagnostics must receive greater consideration when the weapon is being planned and developed, because what happens in early development determines the future ability to maintain sophisticated systems;

- a 1982 report by the Test and Evaluation Director, Under Secretary of Defense for Research and Engineering, that stated the development and evaluation of built-in diagnostics has traditionally lagged behind the development and evaluation of the weapon system;

- a 1984 Sperry Corporation study that stated that many times the development pressure was only on the cost and performance of major hardware;

- a 1983 report by the Institute for Defense Analyses (IDA) stated, "Diagnostics and in particular built-in test could become the weak link in the support chain if substantial efforts are not mounted to modify requirements, design, specification, and maturation processes"

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- a 1984 study by the Logistics Management Institute (LMR) that revealed significant diagnostic shortfalls, particularly at the unit or organizational level; and

- a 1984 Natural Security Industrial Association's National Conference on "Supporting Weapon System Technology Through the 1990's" that concluded the DoD needed to (1) improve its present specifications and standards, emphasizing better means for specifying and validating testability and diagnostics, (2) create incentive and warranty contractual provisions emphasizing testability and diagnostics, (3) increase emphasis on testability, with front-end design rules, better specifications, and more up-front dollars, and (4) increase emphasis on testing and accepting diagnostic software. (p. 15, pp. 33-38/GAO Draft Report)

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DOD RESPONSE: Concur.

- o **FINDING K: Army's Move Toward Central Management.** The GAO observed that central management is needed to ensure the oversight and direction that Army test equipment deserves. The GAO noted that, in November 1967, the Army reviewed the findings of the Army Logistics Fault Malfunction Diagnostic Study and recommended establishing a central Army Test, Management and Diagnostics Equipment (TMDE) program. The GAO reported that the Office of Executive Director for TMDE was established with responsibilities including (1) establishing TMDE policy and procedures, (2) overseeing ATE standardization, and (3) coordinating TMDE technology and development. The GAO found, however, that the Executive Director is not provided Army-wide funding data related to the acquisition of TMDE, although the Army Materiel Command (AMC) has recognized the need for this information and requested a revision in an Army accounting classification system to include a separate accounting for TMDE. The GAO noted that, according to AMC, this would provide the TMDE Executive Director a consolidated management tool to:

- manage the Army TMDE program;
- plan, program and budget for all TMDE requirements;
- provide oversight on TMDE operations and resources; and
- elevate TMDE visibility. (pp. 39-41/GAO Draft Report)

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DOD RESPONSE: Concur.

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- o **FINDING L: Limited Success In Standard ATE Development.** The GAO reported that the origin of the standard ATE program is a March 1975 Letter of Agreement to investigate and develop a "family" of standard test equipment for use at the various maintenance levels. The GAO noted that Army policy now requires the use of standard ATE, except that waivers are granted when more cost-effective test equipment is identified and approved. (The GAO noted that for depot and general support maintenance activities, the Army chose the Electronic Quality Assurance Test Equipment (EQUATE).) The GAO reported that the standard test equipment for direct support maintenance is known as Intermediate Forward Test Equipment (IFTE), and also the Army has decided to make the IFTE Commercial Equivalent Test Equipment ATE standard for depot level. In addition, the GAO noted that the standard ATE being developed for organizational maintenance is the simplified Test Equipment Expandable, or the STE-X. For some of the newer Army weapons, however, the GAO found that unique test equipment will be developed, procured, and fielded before IFTE is available. The GAO also found that most project offices participated little in the IFTE planning and development and did not provide their specific test equipment requirements to the developer or formally agree to use IFTE. The GAO concluded that standard equipment, such as IFTE, should be designed to meet the needs of expected users and remain technically advanced. (The GAO noted that Army expected four of the six systems included in the review to use IFTE, but only one had a Memorandum of Agreement with the IFTE developer to provide specific test requirements.) Also, because IFTE will not be able to test electro-optical equipment, the GAO found, it will not be able to replace some test equipment as planned. The GAO also concluded that, in transitioning to the IFTE, care must be taken to ensure that IFTE only replaces existing test equipment when it is cost beneficial. The GAO further concluded that, for those project offices that already have test equipment and related support items, converting to IFTE may not be cost effective because of the potential need to retrain equipment users and maintainers, revise system technical manuals and maintenance charts, and translate and validate test program sets (TPSSs). The GAO observed that while the Army has had some success in its attempts to develop and encourage the use of standard general-purpose automatic testers, the delays in getting the standard ATE developed and fielded required the developers of some of the Army's newer weapons to develop and field unique test equipment. The GAO concluded, therefore, that this means additional costs will be incurred to convert to the standard equipment or it will not be used. (pp. 41-45, pp 52-53/GAO Draft Report)

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DOD RESPONSE: Partially Concur. The DOD does not agree with the GAO conclusion that "additional costs will be incurred to convert to the standard equipment or it will not be used." The Army has a program for the use of standard test equipment which balances the need for standardization against cost effectiveness. Specifically there is a formal AMC regulation that requires material developers to use standard test equipment (such as IFTE) unless there are cost-effectiveness reasons to consider a waiver. In addition, the GAO finding that the IFTE will not be able to test electro-optic equipment needs to be caveated. The Army has a separately funded line for electro-optics which should lead to development of this capability.

- o **FINDING M: IFTE Contact Test Set Capabilities (CTS) Similar To STE-X.** The GAO found that STE-X will be used by organizational mechanics to confirm readouts from built-in diagnostic equipment and troubleshoot failures to the line-replaceable unit of repair. The GAO found that CTS also will be used to troubleshoot failures to the LRU level. The GAO concluded, however, that the IFTE Contract Test Set appears to duplicate capabilities of the STE-X. The GAO further concluded that, while Army officials stated the STE-X would need to be upgraded to perform the diagnostics required by the CTS, the additional analysis should be performed as to its feasibility, including a comparison of the cost of developing another tester and supporting it with the cost of upgrading the STE-X. (p. 45, p. 53/GAO Draft Report)

DOD RESPONSE: CONCUR.

- o **FINDING N: Design For Testability Concept Needs To Be Enforced.** The GAO found that the DOD initiated the design for testability concept in 1978, which will require designers to incorporate improved testing early in the weapon system acquisition. The GAO also found that the Joint Logistics Commanders Panel on Automatic Testing has laid the groundwork to implement the concept through various initiatives, including the drafting of a military testability standard for designing electronic systems. The GAO noted this standard was adopted by the Army in 1985 and that it provides uniform procedures and methods for establishing a testability program. The GAO concluded that these standards, if applied and enforced, would help to eliminate many of the problems found during its current review. (The GAO noted that, among other things, the standard calls for establishment of sufficient, achievable, and affordable requirements, and preparation of a testability plan.) (pp. 45-46, p. 52/GAO Draft Report)

DOD RESPONSE: Concur.

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o **FINDING O: Test Technology Team Should Continue Its Work.**

The GAO reported that, because prior to 1982 there was no focal point for test expertise and no Army-wide test technology program, each Army laboratory separately pursued testing needs. In addition, the GAO noted that, according to the Army TMDE Study, the complexity and sophistication of emerging Army systems and the rapid advance in new technology require weapons developers to be more knowledgeable about testing methods, particularly in making trade-offs between built-in and external automatic test equipment. The GAO observed, however, that while the Army established a test technology study team in 1982, the team had not yet been able to consolidate and present all Army needs, or present them as a unified Army test technology program. The GAO noted that, according to the Army, funding continues to be a problem, with only 20 percent of the requirements of two Army Laboratories in this area being funded during the FY 1985 - FY 1990. The GAO further observed that, according to the earlier TMDE study, without a well-coordinated, Army-wide test technology research and development program, test technology will continue to move in many directions and result in inadequate, incomplete approaches to automatic testing problems. (pp. 46-48/GAO Draft Report).

DOD RESPONSE: Concur.

RECOMMENDATIONS

- o **RECOMMENDATION 1:** The GAO recommended that in future weapons acquisitions, the Secretary of the Army direct the Commander of the Materiel Command to ensure that testability is planned for and incorporated in the weapon designs and that diagnostics receive more emphasis, particularly early in the program acquisitions. (p. 53/GAO Draft Report)

DOD RESPONSE: Concur. This recommendation is moot. It is not necessary that the Secretary of the Army direct AMC to ensure that testability is emphasized in program acquisitions. The AMC has already recognized that testability should receive emphasis in program acquisition as evidenced by incorporation (November 1986) of testability as one of the critical events to be monitored in the AMC Program Manager, Materiel System Assessment (PMSA) system.

- o **RECOMMENDATION 2:** The GAO recommended that the Commander, Army Materiel Command, provide developing contractors with specific automatic diagnostic requirements, along with guidance for making trade-offs between internal and external diagnostics equipment. (p. 53/GAO Draft Report)

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DOD RESPONSE: Partially concur. The DoD recognizes that the Army must do a better job of specifying achievable and enforceable diagnostic requirements. The DoD disagrees with the specific GAO recommendation, because there is concern that it will be interpreted as requiring the application of diagnostic specifications before the needed analysis is completed. An industry/ DOD group, National Security Industrial Association integrated diagnostic working group, has developed an approach for developing realistic requirements based on engineering analysis along with making tradeoffs between built in diagnostics and external diagnostics capabilities (such as test equipment, technical manuals, and training). This approach was considered more realistic than arbitrarily specifying automatic diagnostic requirements as recommended by GAO. Within the DOD this approach is going to be used on a trial basis on a wide variety of acquisition programs as requested in USD(A) memo dated January 9, 1987.

- o **RECOMMENDATION 3:** The GAO recommended that the Commander, Army Material Command, establish and follow formal plans when monitoring the development of the diagnostics to ensure that actions are taken when needed as the weapons are being developed and that diagnostics development and testing parallels system development and testing. (p. 53/GAO Draft Report)

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DOD RESPONSE: Concur. Army has already begun to revise its guidelines to weapon system developers to consider design for testability in accordance with MIL-STD 2165 and will publish a regulation in FY 1987.

- o **RECOMMENDATION 4:** The GAO recommended that the Commander, Army Material Command, encourage contractors to meet requirements through options such as incentives and penalties. (p. 54/GAO Draft Report)

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DOD RESPONSE: Partially concur. Incentives could be considered under the conditions where diagnostic requirements can be delineated and are potentially achievable.

- o **RECOMMENDATION 5:** The GAO recommended that the Army assess the need for and, if benefits outweigh costs, determine the most appropriate means of obtaining Army wide TMDE budgetary information. (p. 54/GAO Draft Report.)

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DOD RESPONSE: Concur. The Army has assessed the need and concluded that a TMDE financial information system is in order. No further assessment is required.

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- o **Recommendation 6:** The GAO recommended that the Commander, Army Material Command, be directed to ensure that standard (IFTE) equipment such as the Intermediate Forward Test Equipment is designed to meet user needs and remains technically advanced. (p. 54/GAO Draft Report).

DOD RESPONSE: Partially Concur. The DOD agrees that IFTE should be designed to meet the user needs, and the Army is doing this. As the built in automated diagnostic technology improves, however, the need to technically advance the IFTE may diminish. The balance between improving IFTE capabilities versus the built in diagnostic needs to be examined on a case by case basis, and not arbitrarily directed as suggested by the GAO.

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- o **RECOMMENDATION 7:** The GAO recommended that the Commander, Army Material Command, be directed to ensure that decisions to convert existing weapons to IFTE are based on a case-by-case cost and effectiveness analysis. (p. 54/GAO Draft Report)

DOD RESPONSE: Concur. Army ATE Policy implemented 1 April 1986, specifically states "Programs which currently rely on the use of other ATE systems, which are planned to remain in service after FY 1992, must conduct appropriate analyses to determine cost and operational advisability of converting to IFTE support." No further action is contemplated on this recommendation.

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- o **Recommendation 8:** The GAO recommended that the Commander, Army Material Command, be directed to ensure that CTS and STE-X capabilities and needs are reassessed to determine the costs and benefits of supporting one standard tester. (p. 54/GAO Draft Report)

DOD RESPONSE: Concur. This will be done prior to FY 1988.

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Glossary

Automatic Test Equipment	Equipment that, with minimum human intervention, performs a predetermined test program to measure functional or static parameters, to evaluate the degree of performance degradation, or to isolate malfunctioning parts.
Built-In Test	An approach using equipment or self-test hardware and software that is designed into an end item so that all or part of it can be tested to detect, diagnose, or isolate malfunctioning parts.
Built-In-Test Equipment	Identifiable, removable equipment that is a part of an end item which is used to test that item.
Design for Testability	A design process to ensure that an item can be thoroughly tested, with confidence, using minimum effort.
Diagnostics	The processes and techniques used to detect and isolate the cause of malfunctions, including automatic built-in and external test equipment.
Equipment End Item	A final combination of assemblies, components, modules, and parts which is designed to perform an operational function.
Fault Insertion Test	Manually inserted faults for testing system diagnostics.
General Purpose Test Equipment	Test equipment which is used or could be used without significant modification to test, measure, and diagnose selected parameters for two or more end items or systems.
Line-Replaceable Unit/ Battery Replaceable Unit	A unit or part of an end item that is replaceable in the operational environment under field or combat conditions.
Maintainability	A characteristic of design and installation which inherently provides for an item to be retained in or restored to an operational condition within given period of time, using prescribed procedures and resources.

odule	An assembly containing a complete, self-contained circuit and consisting of a single printed circuit based on two or more printed circuit boards mechanically attached to one another and removable from the next higher assembly as a single unit.
erational Test	Addresses how well the system can be expected to perform in the operational or combat environment, how it should be employed, and whether the system can be operated and maintained effectively by military personnel.
inter Circuit Board	A board consisting of electrical components connected by conductive circuit paths printed or etched on the board to form an electronic circuit.
ystem Peculiar Test quipment	Test equipment that is designed specifically for support of and that is functionally restricted to one end item or system.
st, Measurement and agnostic Equipment	Any system or device used to evaluate the operational condition of an item or to detect and isolate actual or potential malfunctions.
st Program Set	The test package enabling a line-replaceable unit or printed circuit board to be tested or diagnosed by automatic test equipment. For field purposes, a TPS consists of an interface device, a test program (software), and documentation.
stability	A design characteristic which allows the status of a unit or part to be confidentially determined in a timely fashion.



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