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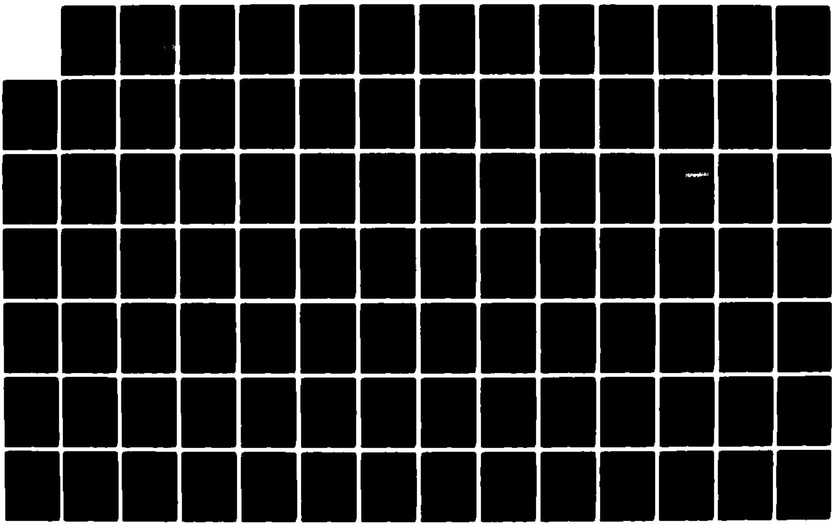

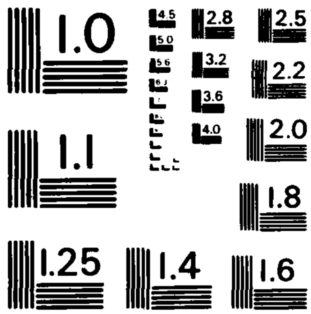

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FIX-FORWARD: A COMPARISON OF THE ARMY'S REQUIREMENTS AND CAPABILITIES FOR FORWARD SUPPORT MAINTENANCE

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PREFACE

This study addresses only one element of fix-forward: maintenance capability. The Army's ability to provide forward support maintenance depends on other factors as well:

- supply support
- recovery capability
- command, control and communications
- mobility of maintenance support teams
- other combat service support roles
- ability to operate in nuclear, biological or chemical warfare environment.

Within this limited framework, the study examines three basic questions:

- What is fix-forward?
- Does the Army possess a fix-forward capability?
- What inhibits fix-forward?

Most of the data in this study were collected in 1981. Some changes have occurred in the Army's overall concept of wartime maintenance support since then. While the changes do not materially detract from our observations, the reader should be aware of the following:

- The Army is de-emphasizing use of the term "fix-forward"; instead, the term "forward support maintenance" has been adopted. We use the terms interchangeably.

- The Materiel Development and Readiness Command has issued a directive for the institution of Battlefield Damage Assessment and Repair Technical Manual Task Groups at the commodity-oriented Materiel Readiness Commands. The task groups will be responsible for producing new technical manuals for battlefield expedient repairs.

- The Deputy Chief of Staff for Logistics has taken a number of initiatives strengthening direction to and review of maintenance concepts and capabilities:

-- Establishment of a basic support structure composed of three categories of maintenance (unit, intermediate, and depot) in lieu of the present four categories (organizational, direct support, general support, and depot). The intermediate maintenance category comprises forward and rear units. Forward units are mobile and support maneuver elements on a one-to-one (divisional) or area (nondivisional) basis. Rear intermediate maintenance units use semi-fixed facilities and support the theater supply system.

-- Adoption of the forward support maintenance concept using teams deployed forward from intermediate maintenance units: in support of specific weapon systems (divisional forward intermediate), for battle damage assessment (nondivisional forward intermediate), and for area support (rear intermediate).

-- Rejection of restructured general support as originally conceived.

-- Revision of maintenance policy (AR 750-1) emphasizing that civilian maintenance personnel will work forward of the corps rear boundary only as an exception.

-- More involvement of the user through better communication (vertical maintenance management concept), active solicitation of suggestions and feedback (Supply and Maintenance Assessment and Review Teams), and establishment of Army Maintenance Board, chaired by the Training and Doctrine Command.

Thus, some of the specific observations in this report may have been overtaken by events. However, the findings, conclusions and recommendations remain valid.

EXECUTIVE SUMMARY

The Army's fix-forward concept of maintaining tactical weapons is patterned after the methods used by the Israeli Defense Force during the 1973 Middle-East War to repair and return to combat 2700 failed or damaged tanks in the first two weeks. The concept emphasizes the performance of repairs on-site or as far forward as possible, rather than retrograding inoperable weapon systems for repair. The objective is to minimize the time that failed or battle-damaged systems are inoperable, thereby maximizing the time they are available for combat. Our review of Army maintenance practices, including support of seven new systems, reveals that the Army's capability to "fix-forward" falls far short of its needs.

The Army's forward-echelon maintenance units, primarily organizational-level units, are unable to perform the maintenance needed to return equipment rapidly to operational condition. In peacetime, operational readiness objectives are achieved by shifting the maintenance burden from organizational maintenance units to direct support units. In wartime, direct support units soon would be overloaded and maintenance work would be deferred or shifted to maintenance units further to the rear -- opposite to the forward echelonment of maintenance envisioned by the framers of the fix-forward concept.

The major inhibitor to the attainment of fix-forward capability is the inability of organizational maintenance personnel to diagnose the causes of system failures quickly and accurately. The inability is attributable to three factors: (1) the weapon systems' designs make troubleshooting difficult, (2) much of the Army's test equipment either is unsuitable for use at the organizational level or is unavailable for use because it cannot be

supported logistically, and (3) organizational maintenance personnel do not have the training or experience needed to become effective troubleshooters.

Battle-damage assessment and repair was a key element in the Israeli fix-forward concept. It is also key in the U.S. Army's concept; but, except for helicopters, the Army has so far given little attention to developing the training, repair techniques, tools, and repair kits needed for battle-damage repair.

Whether the Army needs fix-forward capabilities is not an issue. Weapon system inventories are too small to replace weapons that fail or are damaged in battle. In war, they must be repaired quickly and returned to combat. Otherwise the fighting capability of Army units will shrivel. To achieve fix-forward, the Army needs to do four things:

(1) Dramatically improve the capabilities of forward-echelon maintenance units, especially organizational-level units, by providing better training, test equipment, and test equipment support.

(2) Establish battle-damage assessment and repair capabilities.

(3) Clarify fix-forward maintenance policy, including its implications for task allocation, level of repair analysis, and wartime workload analysis.

(4) Provide intensive management of the key system characteristic influencing fix-forward potential: testability.

Achievement of fix-forward is within the authority, responsibility and capability of the Army. Although we discovered voids in DoD policy that need filling -- more explicit and comprehensive direction on direct maintenance and assignment of battle-damage restorability responsibility to program managers -- the fix-forward problems and their solutions are within the Army. The Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics) needs only to give the Army encouragement and support to build the forward-maintenance capability it so badly needs.

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1. FIX-FORWARD CONCEPT AND MAINTENANCE DOCTRINE

CONCEPT DESCRIPTION

The Department of the Army has no approved definition of fix-forward. The concept originated within the Training and Doctrine Command (TRADOC) in the mid-1970's, supplementing existing maintenance policy. The basic thrust of that policy has always been authorization of maintenance tasks to the lowest level of maintenance capable of performing the tasks. TRADOC's fix-forward concept extends this policy by emphasizing the need to perform repairs as far forward as possible, moving maintenance support teams forward when needed instead of retrograding inoperable weapon systems. In other words, fix-forward does not affect existing maintenance allocations (who is authorized to do what), but only the location where maintenance is to be performed. Furthermore, fix-forward does not imply one specific location, but represents an *echelonment* of maintenance support forward on the basis of equipment repair times and combat conditions.

TRADOC summarizes its fix-forward concept as follows:

> "Maintenance Support Forward. When equipment requires repair, damage assessment will be performed by the organizational maintenance team to determine appropriate disposition based on extent of damage and combat situation. Every effort will be made to repair equipment as far forward as possible to reduce the time required to return it to battle. This is the essence of the fix-forward concept. Controlled exchange of parts will be considered prior to evacuation, but parts will not be removed from a system that can be repaired quickly. Weapon systems which have suffered extensive damage will serve as a source of repair parts. Implementation of the fix-forward concept calls for employment of maintenance contact teams from corps and division maintenance units in forward areas to assist mechanics assigned to combat units." (FM 100-5, "Operations," Draft Revision, September 1981)

The objective of fix-forward is to minimize weapon system turnaround time so as to maximize combat time. Fix-forward thus provides formal recognition of a subtle change in the criterion measure of weapon systems support: from peacetime measures of maintenance efficiency to measures of maintenance effectiveness (number or percentage of unserviceable weapon systems returned to combat per unit time).

RATIONALE AND EVOLUTION OF CONCEPT

TRADOC'S fix-forward concept can be traced to the 1973 Middle-East War, which demonstrated the lethality of the modern battlefield. The Israeli Defense Force (IDF) repaired and returned to combat a very large number of tanks using a fix-forward strategy -- 2700 tanks in the first two weeks, including both reliability failures and battle damage. This entailed:

- Maximum repairs on-site or as far forward as possible: Company level ordnance personnel were consolidated with battalion ordnance platoons to provide a pool of maintenance personnel from which detachments were sent forward as needed for on-site repairs, often within 2-3 kilometers of the forward edge of the battle area.

- Battle damage assessment and evacuation directly to the appropriate level for repair: Lines of communication to fixed workshops for serious battle damage repair were relatively short.

- Augmentation of maintenance skills forward: Small teams of trouble-shooting experts were dispatched from central depots as needed.

- Augmentation of maintenance skills in division and corps units: Teams of maintenance technicians were sent in advance to those locations where trouble was expected.

Lessons learned from that war included: the need to revise historic attrition factors; the recognition that increased lethality reduces battle damage restorability in the field (e.g., 50% of the battle damaged M48/M60 tanks were not repairable and 10% required over one month for repair, as compared with World War II (WWII) experience when 65% of battle damaged tanks were rehabilitated by field maintenance); the need for battlefield recovery of repairable tanks requiring special skills (the IDF now has a 3½-month course for E-5 level personnel in recovery units); and the need to better exploit cannibalization as a source of parts (cannibalization was improvised during this war, but the IDF is now teaching this skill to maintenance personnel).

Fix-forward was formally adopted as U.S. Army doctrine with the publication of FM 100-5, "Operations" (July 1976) and FM 100-10, "Combat Service Support" (April 1976). The concept (without being explicitly referred to by name) also was reflected in a major revision of AR 750-1, "Army Materiel Maintenance Concepts and Policy" (April 1978). The earlier version of the regulation prescribed the following policy in developing maintenance concepts for new systems:

> "Maintenance tasks and their associated resources will be allocated within the maintenance structure by appropriate level of repair analysis (LORA) to assure attainment of established readiness goals and minimize operating and investment costs for equipment maintenance support." (AR 750-1, 1972)

The revised regulation includes "repair as far forward as possible" as a general policy; states "the objective of minimizing the operating and support cost segment of life cycle costs" in developing maintenance concepts; and offers the following specific guidance:

> "Combat developers and materiel developers will strive to incorporate the following precepts in preparing maintenance concepts:
>
> (1) Minimize the need for using units to disassemble equipment to perform maintenance tasks.
>
> (2) Perform corrective maintenance below general support (GS) by the replacement of modules and electronic board/cards.
>
> (3) Use of highly mobile maintenance support teams by support maintenance units to make repairs on-site." (AR 750-1, 1978)

CONCEPT EVALUATION

The Army evaluated the fix-forward concept in the Division Restructuring Study (DRS) initiated in 1977. The study, however, assessed a combination of several concepts that were keyed to weapon system oriented support, in contrast to the Army's traditional functional organization of maintenance support. The DRS organizational structure provided a consolidated maintenance company to each maneuver battalion (with more maintenance personnel than in the existing H-series tables of organization and equipment (TOE)) to perform both organizational and limited direct support (DS) maintenance. Each company was organized in a main maintenance platoon and a variable number of company maintenance teams to fix-forward, each team headed by a "master mechanic" (i.e., an E-6 level mechanic trained in both automotive and turret maintenance for a specific weapon system). The divisional forward support companies were smaller in size than the H-Series TOE, but organized into more platoons with more mobility. In the division support area, the heavy and light equipment maintenance companies were increased in size, but the aviation maintenance and missile support companies remained unchanged. In total, then, DRS shifted maintenance personnel to the battalion area and added mobility (armored carriers) and skills; and it reduced maintenance personnel in the brigade support area (while adding mobility) for an overall increase in the number of maintenance personnel in a division.

DRS was field tested over a period of 22 months terminating in August 1979. It was estimated to provide an increase in operational availability of 14% and was favorably evaluated: "Fix, fuel, arm and feed forward concepts enhance combat effectiveness and logistical efficiency." ("Summary of Findings," August 1979.) Nevertheless, the Army had to back away from fully implementing the study findings due to constraints on total division size. The planned changes in organizational structure of the heavy division (Division 86) retain several of the DRS concepts, but not the shift of DS maintenance tasks from DS forward support companies to the battalion maintenance organization.

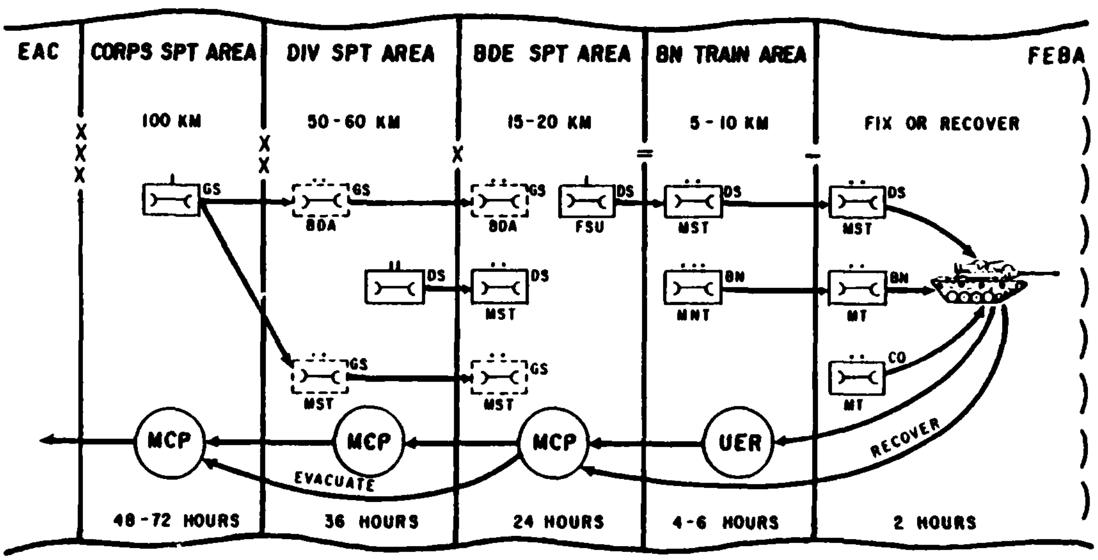
Another major study of Army logistics was recently completed under the direction of General Guthrie ("Army Logistics 1981," August 1981). The study noted that fix-forward is not new but has been done since WWII, usually in attack or stable defense situations, using ad hoc teams without having the people and equipment specifically provided in the TOE. The study concluded that the fix-forward doctrine is currently poorly understood and needs clarification; that probable recovery vehicle losses in high-intensity warfare may severely limit the recovery capability; that further study is required to address the impact of nuclear/biological/chemical warfare on fix-forward; but that the fix-forward doctrine is sound as orientation for maintenance support.

MAINTENANCE DOCTRINE

The U.S. Army Ordnance Center and School (USAOCS) was the first TRADOC organization to incorporate the general fix-forward concept into its maintenance doctrine. The USAOCS's fix-forward doctrine for tanks and ground mobility equipment provides a good example of what fix-forward means. For other types of systems, the specific fix-forward strategies will differ as a function of system characteristics (mobility), employment category (divisional versus non-divisional), density and maintenance support concept.

USAOCS fix-forward maintenance doctrine is illustrated in Figure 1-1. Shown are the echelons of maintenance support, their notional distances from the forward edge of battle area (FEBA) and repair time limits for a stable FEBA (in active defense where the FEBA may retrograde several kilometers per day the notional time limits are, of course, much shorter). Repairs of a disabled tank would be attempted first on-site by the crew with assistance from the company maintenance team or a team sent forward from the battalion maintenance platoon. If repair is beyond their capability or the repair time is beyond the stated limit of two hours, the tank would be recovered to the unserviceable equipment rally (UER) point in the battalion trains area or the forward maintenance collection point (MCP) in the brigade support area, depending on the extent of repairs required.

FIGURE 1-1. FIX-FORWARD MAINTENANCE DOCTRINE FOR TANKS/GROUND MOBILITY EQUIPMENT



BDA = BATTLE DAMAGE ASSESSMENT
EAC = ECHELONS ABOVE CORPS
MT = MAINTENANCE TEAM (ORG)
MST = MAINTENANCE SPT TEAM (DS or GS)
MCP = MAINTENANCE COLLECTION POINT
UER = UNSERVICEABLE EQUIPMENT RALLY POINT

SOURCE:
U.S. ARMY ORDNANCE CENTER AND SCHOOL (1980)

At the UER point, disabled tanks would be repaired by maintenance personnel of the battalion maintenance platoon augmented with DS maintenance support teams as needed. The principle would be to do mission essential maintenance only and to use controlled exchange of parts (if no parts are available) in order to turnaround the maximum number of tanks. Empirical evidence suggests that the combined application of organizational and DS maintenance skills is the most effective form of maintenance. Disabled tanks not repairable within 4 to 6 hours (due to earlier maldiagnosis of repairs required, lack of parts, lack of skills, or capacity limitations) would be recovered further back to the forward MCP. Recovery is a user responsibility performed by recovery teams of the battalion's maintenance platoon using available recovery vehicles; alternatively, "self-recovery" is used when the disabled tank is mobile, or "like-recovery" may be necessary if recovery assets are inadequate.

At the forward MCP, operated by the DS forward support unit, senior technicians (teams sent forward from corps GS or division maintenance battalion) would conduct battle damage assessment and triage, deciding which tanks can be repaired at that location; which tanks are repairable but need to be evacuated to division or corps shops; and which tanks should not be repaired but cannibalized for undamaged components or parts. The maintenance workload would be carried by the DS forward support unit personnel left to operate the MCP (notionally, 50% is deployed forward to the UER) augmented as far as possible by DS maintenance support teams from the division support area. (Additional support from GS maintenance support teams also is part of USAOCS's doctrine.) Under the planned Division 86, two MCPs are planned per brigade. Evacuation is a combat service support responsibility and would be performed by the heavy equipment transporters included in the division support command TOE. It is contemplated that the bulk of items being evacuated from this forward MCP to the division support area would consist of components and assemblies, not end-items. Of course, this would depend on what is accomplished forward.

At the divisional MCPs, the maintenance activities would be similar to those at the forward MCPs, except that shop facilities would be better and repair time limits less constraining. Also, a portion of the workload would consist of off-equipment component repairs, whereas at the forward MCP most of the work would be on-equipment. Battle damage assessment teams would decide what needs to be evacuated to the corps support area.

GS units in the corps support area would operate MCPs and direct exchange facilities. Work evacuated to these units would consist of component repairs and, to a lesser extent, end-items with extensive battle damage. Equipment not repairable within the stated time limits would be either cannibalized or evacuated to echelons-above-corps.

2. FIX-FORWARD IMPLEMENTATION

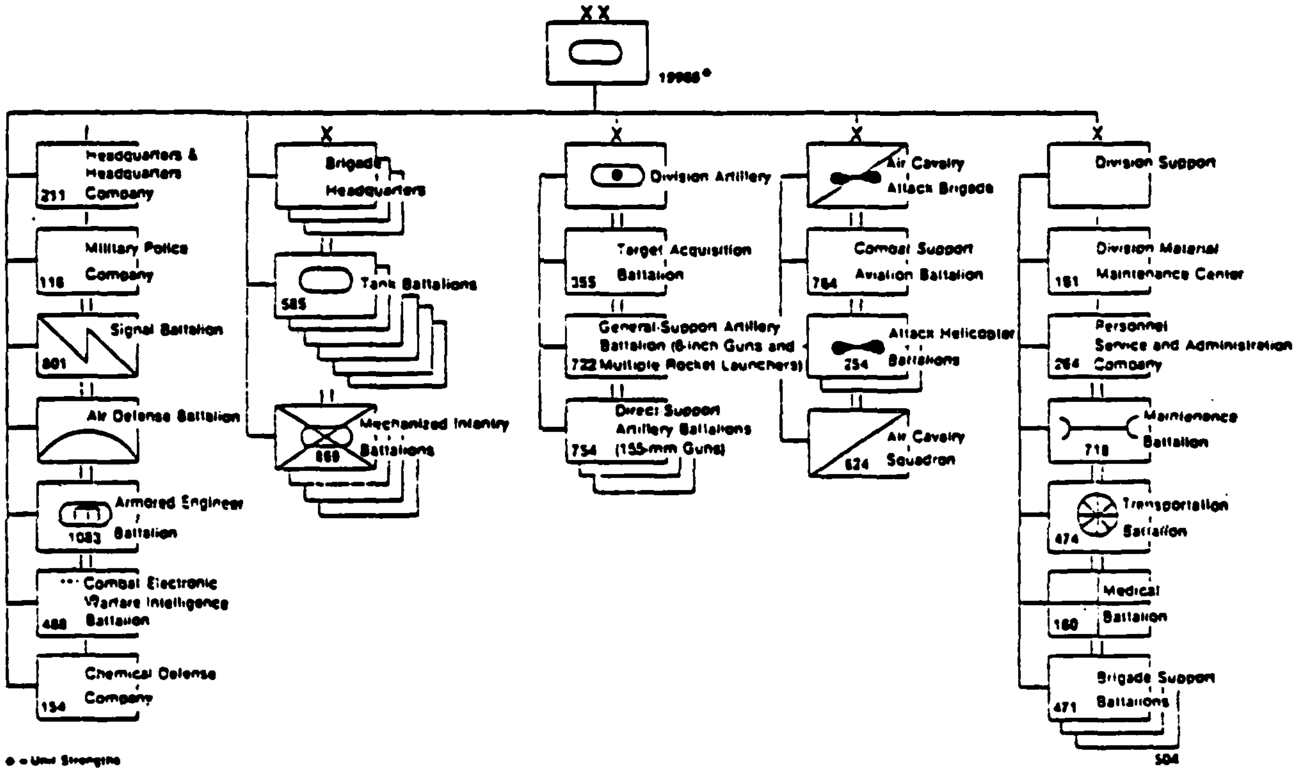
Implementation of the fix-forward maintenance concept in the Army has been slow and frustrating. In this chapter, we review progress in three areas: organizational structure, allocation of maintenance tasks and maintenance practices. In the next chapter, we examine a fourth area of implementation: new system support concepts.

ORGANIZATIONAL STRUCTURE

The Army's organizational structure planned for the mid-1980's consists of Division 86 for the ten heavy divisions; Infantry Division 86 for the six light divisions; Corps 86 for the European integrated battlefield and Contingency Corps for the Rapid Deployment Force; and echelons-above-corps structures for alternative theaters. The structure is the result of a thorough analytical effort by the Army to develop the most combat-effective organizations integrating the new weapon systems (those with a planned initial operational capability in or before 1986) and new operational concepts. The effort was initiated by TRADOC in 1976 with the Division Restructuring Study referred to earlier; continued with the analysis of battlefield developments plans; proceeded into a formal process of threat analysis, operational concept development, and force design; and was followed by computer-based simulations utilizing the scenario-oriented recurring evaluation system (SCORES) to support analytical evaluation and comparison to the existing structure.

The Division 86 structure (Figure 2-1) is quite different from the existing division (H-Series TOE). It reflects the following force-design principles: (1) maximum firepower forward; (2) fight with smaller, single-weapon companies; (3) arm, fuel, fix and feed forward; (4) organize for continuous combat operations; and (5) increase leader-to-lead ratios. To make fix-forward possible, the new structure provides better communications and more mobility (armored carriers) for maintenance teams. However, it does not provide a significant increase in maintenance capability, as measured by numbers of maintenance personnel and skill levels.

FIGURE 2-1. ARMORED DIVISION 86



For example, Table 2-1 compares the tank maintenance assets available at each forward echelon under the old structure (TOE 29-035H) with the Division 86 structure planned for implementation in 1984. (Armored Division TOE 29-255H was approved in 1981; it added a maintenance platoon for the divisional operational readiness float and technical inspectors to TOE 29-035H. The numbers and skill levels of maintenance personnel authorized under TOE 29-255H and planned for Armored Division 86 show little difference, except for a decrease at the brigade level.)

TABLE 2-1. DIVISION 86 CHANGES IN MAINTENANCE PERSONNEL

(Direct Maintenance Personnel Supporting Tanks)

SKILL LEVEL (PAYGADE)	"OLD" (H Series TOE, 1979)									"NEW" (J Series TOE, 1984)									
	Co		Bn		Bde					Co		Bn		Bde					
ENLISTED	63N	45N	63N	45N	63H	63G	45K	41C	34G	63E	45E	63E	45E	63H	63G	45K	41C	34G
SL50 (E8/9)			1									1		1				
SL40 (E-7)	1				3		1			1		2		1		2		
SL30 (E-6)				1	3		1					6		3		2		
SL20 (E-5)	1	1	3		12	2	6	1	1	1	1	2		11		6	1	
SL10 (E-3/4)	3	2	11	2	47	5	14	3	1	3	2	6	1	31	4	17	3	3
TOTAL MOS ENLISTED	5	3	15	3	65	7	22	4	2	5	3	17	1	47	4	27	4	3
WARRANTS	-		1		2					-		1		2				
TOTAL ECHELON	8		19		102					8		19		87				

MOS: 34G = Fire Control Systems Repairer (45G)
41C = Fire Control Instrument Repairer
45E = M1 Tank Turret Mechanic
45K = Tank Turret Repairer
45N = M60 Tank Turret Mechanic
63E = M1 Tank Systems Mechanic
63G = Fuel & Electric Systems Repairer
63H = Track Vehicle Repairer
63N = M60 Systems Mechanic

Table 2-1 should be interpreted with caution because end-items supported under the "old" and "new" structure are different, both in number and type. In the company area, the tank company maintenance section (old) supporting 17 M60 tanks is identical in composition to the maintenance contact teams of the new tank battalion supporting 14 M1 tanks. In the battalion trains area, the battalion maintenance platoon (supporting 54 M60 tanks) remains the same in total number of mechanics (supporting 58 M1 tanks) but shows an increase in skill levels due to the creation of a Quality Control/Technical Inspection section (1 SL40 and 5 SL30 system mechanics) in the new structure. In the brigade support area, the forward support company (DS) from the divisional maintenance battalion will be replaced by the maintenance company of the brigade support battalion (a new Division 86 organization). This company is organized into one core team and three maintenance support teams (one per maneuver battalion) to fix-forward. The composition of the maintenance support teams depends on the task force organization. Table 2-1 reflects a brigade of two tank battalions and one mechanized infantry battalion. The total number of maintenance personnel shows a decrease (based on an expected decrease in DS maintenance required for the M1 and infantry fighting vehicle compared to the M60 and M113A2) and the skill level distribution shows little change.

In the division support area (not shown in Table 2-1), changes in the numbers or skill levels of personnel also are insignificant. Clearly, the planned Division 86 structure does not offer a significant change in maintenance skills from that afforded by the currently authorized TOEs.

With regard to GS maintenance, previous Army studies have indicated the need to re-orient GS units in the corps area to a forward support role, with GS units in the communications zone (COMMZ) destined to a production-line component repair function in support of the supply system. The Army's planning efforts have followed this direction with the development of restructured general support maintenance support battalion organizations incorporating mobile DS/GS teams to provide on-equipment maintenance support forward in accordance with fix-forward doctrine. This direction, however, was seriously questioned by the Army Logistics 1981 study referred to earlier. That study concluded that GS component repair should not be done in the corps but should be moved to echelons above corps. It recommended that non-divisional DS maintenance in the corps be augmented to accomplish DS level battle damage repair, battle damage assessment and DS overflow from divisions, with a total elimination of GS units from the corps areas.

ALLOCATION OF MAINTENANCE TASKS

Whereas the new organization establishes the maintenance structure of the field army, it is the allocation of maintenance tasks among organizations that specifies how each weapon system will be supported by that structure. In the Army, that allocation is specified in Maintenance Allocation Charts (MACs). The MACs are the basis for authorizations of spare parts, tools, test equipment, technical manuals, and maintainer skills in each maintenance organization.

Chapter 1 summarized Army policy with respect to the allocation of maintenance tasks to maintenance categories and identified the key change introduced by TRADOC's fix-forward concept as making the physical location where maintenance will be performed a function of repair time and tactical conditions. In other words, fix-forward is viewed (and so advertised) as not influencing the MACs of existing equipments. Fact is to the contrary, because most MACs were developed under policies that are not necessarily supportive of fix-forward and have not necessarily been revised since they were fielded. A brief review of past changes in Army maintenance policy will clarify this.

With the disestablishment of the Technical Services in 1962, the Army introduced a functionalized maintenance system under the so-called "one-stop maintenance" concept. A few years later, the terminology used for identifying levels of maintenance changed from echelon to category, but the maintenance structure essentially has remained the same up to the present (see Table 2-2).

Originally, Army policy emphasized the need of moving maintenance to the lowest maintenance category or as far forward as possible:

> "The MAC identifies the maintenance operations to be performed and assigns each to the lowest level of maintenance capable of performing the task." (TM 38-715-1, "Provisioning Techniques," October 1965)

TABLE 2-2. CATEGORIES OF MAINTENANCE OPERATIONS (AR 750-1)

	ORGANIZATIONAL	DIRECT SUPPORT	GENERAL SUPPORT	DEPOT
Who	User	Maintenance direct support units Installation support maintenance shops	General support maintenance units Installation support maintenance shops	TDA activities Industrial-type activities Commercial contractors
Where	Equipment location Organizational maintenance shops	Mobile maintenance shops Fixed shops in installations Equipment location	Semi-mobile maintenance shops Installation maintenance shops Equipment location	Fixed plant-type facilities On site on exception basis
What	Preventive maintenance services Inspections Lubrication & cleaning Preserving Tightening Minor adjustment Replacement of components & assemblies Replacement of piece parts Evacuation of unserviceables	Diagnose and isolate equipment/components & assemblies malfunctions Adjust, calibrate & align components & assemblies Repair defective end items Operate a direct exchange activity Perform pollution evaluations of engine emissions Light body repairs Technical assistance Evacuate unserviceables	Diagnose and isolate equipment & components & assemblies malfunctions to the internal piece part level Adjust, calibrate, align & repair components & assemblies Repair/modify end-items/components & assemblies to the internal piece part level Heavy, body, hull, turret, frame repair Collect & classify unserviceable Class VII Evacuate disposable material Technical assistance	Overhaul end-items/components & assemblies repairs requiring manufacturers' tolerances Repairs requiring special environmental facilities Nondestructive testing of used parts Inspections/modifications requiring extensive disassembly or elaborate test equipment Cyclic overhaul & special maintenance programs Manufacture of parts not otherwise obtainable
How	Diagnosis & isolation of malfunctions Use of built-in test equipment, simple go/no-go indicators installed instrumentation & external diagnostic/fault isolation devices	Replacement of components & assemblies & piece parts Provide highly mobile contact teams Use of direct exchange & operational readiness float	Mobile contact teams replace components & assemblies & perform repairs not requiring restoration to original manufacturers' tolerances or specifications Operation of cannibalization point	Wholesale level direct exchange Restoration of unserviceables to prescribed levels of serviceability Modernization of serviceable assets
Why	Sustain materiel readiness	Support of user unit materiel readiness	Support of installation tion/command/local supply stocks; operational readiness float stocks of DS units & repair & return to user programs	Support of overall supply inventory Support of GS units

Or:

> "The MAC assigns authorized maintenance functions to each maintenance category. Maintenance functions will be assigned to the lowest maintenance category based on past experience in the following considerations: (a) Skills available, (b) Man-hours available versus maintenance function man-hour requirements, (c) Tools and test equipment authorized." (AR 310-3, December 1968)

Soon this policy resulted in significant backlogs at the organizational level, which was not equipped to handle the resulting workload. As a result, Department of the Army (DA) Deputy Chief of Staff for Logistics initiated in 1969 Project Maintenance Support Positive (MS+) which initially entailed an arbitrary rollback of 20% of organizational level work to DS. It also directed that piece part repair at lower levels of maintenance be limited. This maintenance rollback philosophy was continued in 1970, qualified by a statement that maintenance tasks should be assigned on the basis of cost-effectiveness (DA Circular 750-34, 1970). MS+ was restated in more specific terms in 1971 requiring that:

> "...maintenance repair tasks (be allocated to the) level best qualified, responsive, and cost-effective to perform the work without reducing readiness." (DA Circular 750-38, 1971)

The following year, this circular was superseded by the regulation on Army Materiel Maintenance Concepts and Policies which directed:

> "Maintenance tasks and their associated resources will be allocated within the maintenance structure by appropriate level of repair analysis to assure attainment of established readiness goals and minimize operating and investment costs for equipment maintenance support." (AR 750-1, June 1972)

At this point, it is important to point out that the impact of MS+ varied with commodity command. The thrust of MS+ was twofold. The primary thrust was directed toward fielded systems to reduce organizational workloads by reallocating maintenance tasks on the basis of cost-effectiveness -- the first time this criterion was applied to MAC development. The extent to which this was possible was very much influenced by the type of weapon system or commodity involved: systems characterized by high maintenance intensity (ground mobility equipment such as tanks and trucks) were the primary ones affected, while MS + had little or no impact on communications-electronics equipment. With hindsight, Army logisticians feel that this thrust of MS+ was not very successful and could have been handled in a different way with better results (e.g., by bringing more maintenance resources forward where needed). The secondary thrust of MS+ was directed to new systems in development through its emphasis on the need to reduce organizational maintenance workload by stressing modular design with a remove/replace, no-repair concept at organizational level.

Overall, the MACs developed during the period 1969-1978 were strongly influenced by MS+ and the criterion of cost-effectiveness as expressed in AR 750-1. The effect was a rollback of maintenance workload (particularly, from organizational to DS) compared to MACs or maintenance concepts of the 1960's. In 1977, the U.S. Army Ordnance Center and School conducted extensive level of repair analyses for a sample of 50 end-items (including 21 ground electronics items) and found that significant numbers of maintenance tasks could be moved forward cost-effectively. This analysis suggested major shifts of maintenance tasks from DS to organizational, GS to DS, and depot to GS, to achieve significant increases in operational availability of the end-items at little incremental cost. Importantly, the study team found that existing MACs had the organizational level isolating system failures to replaceable components, but the DS level responsible for replacing those components -- a clear indication of peacetime stockage cost, not maintenance capability, driving the MAC. The study concluded that there is an "evident trend that a significant portion of maintenance tasks can and should be performed at categories further forward than those to which they are currently allocated in the available

MACs" ("Maintenance Categories -- A Substudy of the Maintenance Support Structure for Contingency Forces Study," Headquarters TRADOC, 22 June 1977). Some other findings of that study, equally important, were the lack of awareness by maintenance engineering activities of the importance of the MAC and the policies for maintenance task allocation and the lack of management review once MACs have been approved, so that they are seldom updated except in the case of major product improvements.[1]

Some of the recommendations of the TRADOC study were included in the 1978 revision of AR 750-1. However, instead of redirecting maintenance tasks to lower maintenance categories, the main thrust of the revision was to direct task performance forward by the use of contact teams from higher maintenance categories. The emphasis remained on the need to reduce organizational maintenance workload by prohibiting disassembly of replaceable modules and minimizing test equipment at the organizational level. The secondary thrust of the revision, more implicit than explicit, was to move maintenance task allocations from the higher end of the maintenance structure to lower categories (but above organizational) by eliminating acquisition cost of support equipment from level of repair analyses. This subtle change was induced by

[1]We note that, according to Army policy, reviews of MACs once every three years are optional, not mandatory. We also note that the maintenance concept for a weapon frequently changes from the original plan once a system is fielded due, for example, to engineering changes or a change in cost or scarcity of parts. For instance, printed circuit boards for many systems produced in the early 1970's were originally planned as throw-away items, representing the most cost-effective support concept at the time. Due to unanticipated rapidly increasing cost and/or material shortages, this concept was soon changed to depot level repair. Because this was not a product improvement, MACs may or may not have been updated accordingly. Spare parts authorizations are actually determined by the source, maintenance, and recoverability (SMR) codes of the supply system. In contrast to the MAC, the SMR codes are regularly updated to reflect parts demand experience or engineering changes. Thus, the SMR codes identify what is actually done; the MAC, what was originally planned. Initially, the two agree because they are the product of the same Logistic Support Analysis process.

replacing the term "investment costs" by "support costs" in the overall policy for MAC development.

The revised AR 750-1 implements the current fix-forward doctrine. In simple terms, it attempts to simultaneously achieve cost-effectiveness and the forward repair necessary to achieve wartime operational availability, without returning to the pre-1970 type of MAC. As a general philosophy, there is little reason for argument. When it comes to implementation, however, the Army has yet to address satisfactorily some key issues affecting maintenance task allocations.

One policy issue is the need to discriminate between on-equipment system repairs and off-equipment component repairs. Presently, the same fix-forward policy applies indiscriminately to both types of maintenance tasks. The objective of fix-forward -- end-item availability in wartime -- provides no sound basis for a general rule to move off-equipment component repairs as far forward as possible. In many cases, depending on weapon system characteristics, the opposite may be much more cost-effective in peace as well as wartime. We are not the first to raise this issue of maintenance task discrimination. Previous studies have urged the Army to emphasize decentralized on-equipment repairs and centralized, off-equipment component repairs (see, for example, D.B. Rice (Study Director), "Defense Resource Management Study," Final Report, February 1979).

A second policy issue is the need to provide for some degree of self-sufficiency when contact team support is cut off or disrupted in wartime. Again, the degree and methodology would depend on the characteristics of the weapon system involved. For example, TACFIRE is very dependent on contact team support under its present maintenance concept (which is not the way it was originally planned). Yet, in war a contact team may have great difficulty getting to the deployed location where its support is needed.

A third issue is the development and use of contingency MACs. Traditionally, the Army has developed wartime MACs tailored to certain scenarios for selected weapon systems. These contingency MACs differ significantly from the corresponding standard (peacetime) MACs. A good illustration is a comparison of the standard and contingency MACs for the M60A1 tank:

- Most on-equipment remove/replace tasks by MAC allocated to DS are reallocated to organizational level or crew (53% of DS workload).
- Most off-equipment repair tasks by MAC allocated to DS are reallocated to GS (15% of DS workload).
- The overall reallocation causes a 40% increase in crew workload, 7% increase in organizational workload, 70% decrease in DS, and 15% increase in GS.

This confirms the need to move on-equipment tasks down and forward, off-equipment tasks up and rearward. The existence of such contingency MACs provides prima facie evidence that the standard, peacetime MACs are deemed inadequate by the Army itself for wartime support. However, the detailed rationale and purpose of these contingency MACs remain a mystery to us. It is not clear who develops them and on what basis. No contingency MACs are available for the seven new weapon systems we reviewed in the course of this study. Contingency MACs are not used in determining the critical skill lists for training, nor are they used in the Army training and evaluation program, individual skill qualification tests, soldier's manuals, or in field training exercises such as REFORGER (return of forces to Germany).

The fourth issue is how level of repair analysis (LORA) should be used to make maintenance allocation decisions. Once the policy evolved to minimize support costs while attaining a required level of operational availability, the Army developed various LORA models as tools to aid in developing MACs for new systems (or evaluating MACs for fielded systems). The first models were developed around 1970. A comparison of these models and of the extent to which they accommodate different parameters influencing level of repair decisions is presented in Appendix C.

Such LORA models are applied as a standard procedure by the new system's prime contractor, who is tasked with development of a draft MAC. The draft is reviewed by the developer (more for completeness than anything else: the model determines the most cost-effective task allocation), included in the maintenance support package which is tested and evaluated in Operational Test (OT) II, reviewed by TRADOC and, after approval, finalized and published in the equipment technical manuals. TRADOC reviews may result in significant changes to the MAC. For example, in the case of the M1 tank, over 100 tasks were reallocated from depot to GS by TRADOC direction (in the spirit of fix-forward) overriding contractor objections that the support equipment associated with these tasks was not suitable for field army deployment.

The use of LORA to drive the MAC for a weapon system has become a mechanical process; the models have been refined to the point that MACs are computer-generated with little human intervention (except for the specification of input data). The models were designed as helpful tools, not as the decision maker. Certain parameters are not included or are poorly accommodated in the model logic; for example, suitability and support requirements of test equipment, mobility requirements, fitting a new system into an existing support structure, operational environment and efficiency of maintenance as functions of maintenance category, and long-term effects. The chief contribution of the models lies in their capability to provide rapid, comparison of alternatives and sensitivity assessments, but they are seldom used that way.

In short, for many Army systems the MACs -- the documents which specify the weapon systems' support concepts -- are inconsistent with fix-forward.

Because the Army's policy on allocation of maintenance tasks has see-sawed in the last 17 years and MACs are rarely updated, many MACs are obsolete, reflecting neither current policy nor current practices. Even when the Army has developed a contingency MAC that reflects the desired, wartime fix-forward practices, the contingency MAC has had no influence on maintenance training. The task allocation to implement fix-forward for new systems is confused because Army guidance on fix-forward does not discriminate between on-equipment and off-equipment repairs and because the level of repair analyses by system developers lead to task allocation decisions that frequently are changed when a system is fielded. In the next section, we will show how current maintenance practices also run counter to the fix-forward doctrine.

MAINTENANCE PRACTICES

The extent of fix-forward in war will depend on the ability of the forward echelons -- organizational and direct support maintenance -- to quickly and effectively repair end-items and return them to operational condition. It is evident from the Army's current maintenance practices that the forward echelons of maintenance, especially the organizational level, cannot or, for a variety of reasons, do not perform the maintenance tasks required to constitute a fix-forward capability. In fact, much maintenance workload that should be done forward is migrating to maintenance organizations in the rear.

Previous LMI studies have addressed maintenance performance problems at the DS and GS levels for tracked and wheeled vehicles (LMI Task ML804, "Combat and Tactical Vehicle Maintenance in the Army," Final Report, June 1979) and all maintenance categories supporting air defense missile and air defense artillery systems (LMI Task ML904, "Army Electronic Equipment Support Options: Air Defense Systems," Interim Report, May 1980). For the present study, we extended our base of knowledge by visiting in May 1981 a small sample of U.S.

Army Europe (USAREUR) units to gather information on aviation maintenance (aviation unit maintenance (AVUM), divisional aviation intermediate maintenance (AVIM), and corps AVIM), and organizational level maintenance of tracked vehicles. Although we found morale much improved compared to 1979, maintenance task performance at the organizational level could only be characterized as poor. Some indicators of maintenance performance which are important in the context of fix-forward are summarized below. (Appendix B provides more detailed information.)

For Army helicopters, the following indicators of maintenance performance are available:

- Maintenance-Related Mishaps: The U.S. Army Safety Center accumulates data on Army-wide aviation mishaps by category (accident, incident, forced landing, precautionary landing, other) and aircraft type, and identifies which are maintenance-related based on user or investigative reports. Overall, the mishap rate for each aircraft type shows an increase with age of the aircraft; the data also suggest a rough relationship between mishap rate and system complexity. About 11% of all mishaps are maintenance-related; of those mishaps which are classified as accidents, about 20% are maintenance-related. Table 2-3A summarizes the available statistics. Of particular concern is the steady increase in the maintenance mishap rate (number of maintenance-related mishaps per 100,000 flight hours) over the last few years. Because most of the maintenance errors (about 71%) are attributed to the mechanics, the data clearly indicate a decrease in maintenance performance, if not maintenance skills. A comparison with the mishap rates occurring in civilian aircraft operations is, of course, invalid due to different operational requirements which are much more severe for military operations. The percentages of mishaps attibutable to maintenance, however, provide a valid comparison of the quality of maintenance, including technical inspection and supervision. Table 2-3B shows that the Army's percentage of mishaps which are maintenance induced is more than twice that for general aviation, while its maintenance mishap rate is about fifty times that for general aviation. The mishap rate for general aviation has shown a steep decrease over the last ten years; however, the data are insufficient to identify a trend in the maintenance mishap rate for general aviation: most of the civilian aviation mishaps are pilot-related (general aviation: 83% of all mishaps, 88% of fatal accidents; air carriers: 39% of all mishaps, 62% of fatal accidents). Overall, we believe the data clearly indicate that Army aviation has a serious maintenance problem.

- Pre-Flight Abort Rate: Data on mission aborts prior to takeoff are not accumulated by the Army. The units visited quoted rates varying

TABLE 2-3. MAINTENANCE-RELATED MISHAP STATISTICS

A. SUMMARY STATISTICS

Equipment Category	Total Mishaps (Time Period)	Mishap Rate (per 100,000 Operating Hrs)	Maintenance Related Mishaps (% Total Mishaps)	Maintenance Mishap Rate (per 100,000 Operating Hrs)	Trend In Maintenance Mishap Rate
U.S. Army[1] Aircraft	14,732 (Jan 74 - Mar 79)	204.6 (5 yr. average)	1,663 (11.3%)	23.1 (5 yr. average)	Increasing for Rotary Wing by 20% Per Year Compounded
U.S. Air[2] Carriers	363 (Jan 70 - Dec 79)	0.61 (10 yr. average)	1 (3%) (1979)	0.014 (1979)	No Trend
U.S. General Aviation	4,023 (1979)	18.10/9.28 (1970/1979)	213 (5.3%) (1979)	0.49 (1979)	No Trend

B. U.S. ARMY MAINTENANCE MISHAP STATISTICS BY HELICOPTER TYPE

Helicopter Type	Maintenance Mishaps	Attribution by Personnel Category[3]					Trend Line[4] of Maintenance Mishap Rate
		Mechanic	Technical Supervisor	Avionics/ Electrician	Maintenance Supervisor	Other Support Personnel	
UH-1	687	789	131	6	48	34	1974: 12 1979: 24
OH-58	262	267	104	10	104	8	1974: 8 1979: 27
AH-1	242	241	36	1	7	2	1974: 48 1979: 68
CH-47	200	174	54	14	35	11	1974: 40 1979: 86
Average Attribution	1391 = 100%	70.9%	15.7%	1.5%	9.3%	2.6%	1974: 12 1979: 30

C. CLASSIFICATION OF U.S. ARMY AIRCRAFT MISHAPS

Classification	Total Aviation Mishaps (Jan 74-Mar 79)	Maintenance-Induced Mishaps			Rates (100,000 Flight Hours)	Percentage of Total Mishaps With Maintenance Causes
		Total	Fixed Wing (1.0M Flight Hours)	Rotary Wing (6.2M Flight Hours)		
Accident	426	92	14	78	1.3	21.6%
Incident	1,112	186	26	160	2.6	16.7%
Forced Landing	586	85	2	83	1.2	14.5%
Precautionary Landing	12,403	1,214	211	1,003	16.9	9.8%
Other	205	86	19	67	1.2	42.0%
TOTAL	14,732	1,663	272	1,391	23.1	11.3%

[1]Source: Study of Army Aircraft Maintenance-Error Mishap Experience. U.S. Army Safety Center, Fort Rucker, Alabama, 1980.

[2]Source: Annual Review of Aircraft Accident Data, National Transportation Safety Board, NTSB-ARC-81-1, November 1981.

[3]Numbers of maintenance errors committed exceed numbers of maintenance-induced mishaps, because a mishap can result from more than one maintenance error, e.g., mechanic and technical inspector.

[4]Trend line data are based on a best fit linear approximation of the quarterly maintenance mishap rates as determined by the U.S. Army Safety Center (first quarter 1974 -- first quarter 1979).

from "minimal" to 40%. Rates above minimal would indicate potential problems with pre-flight or daily inspections performed by the crew chief and/or lack of feedback from pilots (no documentation of observed discrepancies in flight or "squawks").

- Mission Abort Rate, Maintenance-Induced: Data on mission aborts which are flight safety related are included in the U.S. Army Safety Center database referred to above; those which are not flight safety related (e.g., mission payload such as the M65 TOW missile system (TMS) on the AH-1S) are not, and as a matter of fact, missions may not necessarily be aborted for non-flight-related subsystem failures. Thus, accurate data on mission-abort rates and the percentages attributable to maintenance are not accummulated. What we do know is that 10% of all forced or precautionary landings actually executed are caused by maintenance errors (Table 2-3C).

- Pre-Flight and Daily Inspections: No direct measures are available to evaluate crew chief task performance other than the time spent doing it (an input measure). According to senior maintenance technicians, the times required for a good inspection are as follows:

	Pre-Flight	Daily Inspection
UH-1	0.5 hours	2 manhours (crew chief)
AH-1	1.0 hours	3 manhours (crew chief)
CH-47	4.0 hours	6 manhours (crew chief & flight engineer)

  The actual time spent by the typical crew chief on daily inspections is 15 minutes for UH-1/AH-1 helicopters. It is noteworthy that TM documented checks required for daily inspection amount to 13.5 hours for the UH-1 (those for the AH-1 do not include time standards in the TM). The crew chief billet is an E-5, but many billets are filled by E-4s, and not all units have a crew chief for each tail number. Many supervisors believe that the billet should be upgraded to an E-6; others feel that available time rather than lack of experience is the constraint on task performance. Whatever the cause, there is unanimous agreement that daily inspections are conducted poorly causing deferrals of maintenance. This is seen as one of the root causes for the excessive duration of phase inspections.

- Phase Inspections: In the late 1970's, the Army went from periodic maintenance inspection to phase inspection under the principles of reliability-centered maintenance, to reduce the amount of preventive maintenance and improve operational availability. For example, for the AH-1, after every 150 flight hours the aircraft is moved from the flightline (flight platoon) to the hangar (AVUM) where certain portions of the system are checked out in accordance with TMs. The planned time for each phase inspection was about one week. Actually, the present duration the AH-1 spends in phase inspections in USAREUR units is on the average 46 calendar days, ranging from one to two months. Reasons for this degradation of the phase inspection system include: deferred maintenance (poor daily inspections); little advance planning of parts requirements; excessive personnel turbulence due to military occupational specialty diversions; insufficient technical inspectors to provide in-phase inspections (they perform only a pre-phase and end-of-phase inspection); and poor maintenance skills of AVUM personnel (primarily apprentices) requiring about four times as long as standard task times, with much work to be redone when it is rejected by quality control (an E-7).

- Corrective Maintenance: *The troubleshooting of failure* symptoms observed on the flight line or in-phase inspection is normally done by the flight platoon sergeant (E-7) or technical inspector (E-6). Maintenance personnel in grades E-5 or below simply lack the necessary experience. In special cases (some TMS failures and most wiring problems), the warrant officer is needed to assist.

- No Evidence of Failure (NEOF) Rate: Due to inadequate diagnostic capability, components removed from the aircraft are often serviceable and should not have been replaced. Corpus Christi Army Depot inspection reports show the following false removal rates: helicopter engines - 23%; transmissions - 38%; gearboxes - 46%. The reason for these high NEOF rates is the lack of validity of the diagnostic techniques used in determining component replacement, and the lack of a test stand at AVIM to screen components prior to evacuation to depot. Similarly, Pirmasens Missile Repair Activity (PIMRA) reports show a NEOF rate of 45% (3 years average) of the line-replaceable units (LRUs) removed from the M65 TMS. In the last year, this rate has been reduced to 25% by using an AH-1S helicopter as a flying test bed at corps AVIM to screen suspect LRUs prior to evacuation to PIMRA.

The above observations (supplemented with Tables B-1 and B-2 in Appendix B) indicate that maintenance capability at AVUM is extremely weak and unable to support a fully mission capable rate of 75% for the AH-1 even with a flying schedule of only 11 hours per month. Most of the avionics maintenance must be evacuated to AVIM because of a lack of organizational maintenance skills. This, in turn, is the primary reason for maintenance backlogs at AVIM. Exercise data suggest that the surge capability is equally weak: a one-week exercise, during which the flying hour program is quadrupled, quickly exhausts available parts so that cannibalization is necessary; AVUM personnel work 16 hours per day during such an exercise; and afterwards, it takes three months to catch up and get back to normal. In a wartime surge, however, the required flying hours would be double the hours exercised and would have to be sustained for at least the first month.

For tracked vehicles, some of the indicators of maintenance performance are as follows (see, also, Appendix B):

- Operator-Induced Failures: Both intentional abuse (lack of responsibility, lack of supervision, and reverse incentives giving the operator time off when the vehicle is not operational) and unintentional misuse (lack of training and inadequate testing or licensing procedures) occur frequently. Army estimates (Table B-3) are that 50% to 75% of component replacements are due to improper operation or lack of operator checks and services. Table 2-4 provides specific data on engines and transmissions for a recent time period in USAREUR. Operators also neglect performing before-during-after operations ("pre- and post-op") check and basic services. As a result, minor problems (leaking filters, low coolant or lubricant levels) become major component failures. The implications are unnecessary increases in maintenance workloads and decreases in time between overhaul of major components; e.g., 38% of M60 tank engines have a time between overhaul of less than 12 months, 88% less than 24 months (corresponding to about 1200 miles or 200 operating hours) compared to similar engines in civilian use with warranties of 100,000 miles and overhaul cycles in excess of 150,000 miles.

TABLE 2-4. OPERATOR/MAINTENANCE INDUCED FAILURES

Depot Inspection Mainz Army Depot (Oct 80-Mar 81)	Item			
	6V53 (water-cooled engine, M113)	8V71T (water-cooled engine, M109)	1790-2C (air-cooled engine, M60)	TX 100-1 (transmission M60)
Total Number Received	806	134	213	529
Number Overhauled	683	132	205	517
Below-Depot Repairs	40	1	1	3
No Evidence of Failure (% total received)	83 (10.3%)	1 (<1%)	7 (3.3%)	9 (1.7%)
Percentage Distribution of Overhauls by Cause:				
- overheated	52.6%	26.7%	2.9	N/A
- dust ingestion	8.3%	21.4%	58.5%	N/A
- hydrostatic (DS)	1.8%	1.5%	13.7%	N/A
- improper maint. (ORG)	12.5%	24.5%	5.4%	29.5%
- long idling	-	8.4%	0.5%	N/A
- other	10.1%	9.9%	6.3%	64.2%[1]
- formal wear and tear	14:7%	7.6%	12.7%	6.3%

[1]Consists primarily of broken transmission housing.

- Scheduled Maintenance: Scheduled maintenance services (quarterly, semi-annual, and annual services) by organizational level mechanics are performed poorly, not in accordance with TMs.

- Corrective Maintenance: Needed corrective maintenance is deferred. If operators notice a problem and are willing to exert the effort to report it, they have difficulty communicating it to maintenance;

problems must be reported and described on DA form 2404 as the Army has no post-op debriefing system. Most of the corrective maintenance that is performed by organizational mechanics takes place when failures are detected in quarterly services. Diagnosis of failures in fuel or electrical systems is normally done on a trial-and-error basis by replacement, not with the aid of available test, measurement and diagnostic equipment (TMDE) and troubleshooting procedures documented in the TMs. One reason is that the main piece of test equipment for the engine (the simplified test equipment-internal combustion engine or STE-ICE) is too time consuming to use.

- Troubleshooting: The ability of organizational maintenance personnel to troubleshoot M60A1/A3 turret failures is marginal. In 30 to 50% of the cases, a DS contact team from the forward support company is required to do it for them (for the Improved TOW Vehicle, 100% of the failures require troubleshooting assistance). The DS individual who does it is invariably of skill level 3 or above, usually the technical inspector.

In sum, for both aviation and tracked vehicles, the desire to fix-forward is frustrated by the inability of organizational units to effectively perform preventive and corrective maintenance. Current maintenance practices compensate for the deficiencies -- primarily deficiencies in maintainer skills -- by shifting the maintenance burden to DS or divisional AVIM units. In peacetime, that works; reported mission-capable rates generally meet or exceed DA goals. However, the maintenance is not being performed by the personnel who are supposed to do it or who will have to do it during war. In wartime, DS divisional AVIM units soon would be overloaded and maintenance work would be deferred or shifted to maintenance units further to the rear -- just opposite to the forward echelonment of maintenance envisioned by the framers of the fix-forward concept.

3. NEW SYSTEM SUPPORT CONCEPTS

Support concepts of new weapon systems must be compatible with the existing maintenance support structure and conform to existing policy, if problems with implementing those concepts are to be avoided when the systems are fielded. New system support concepts, therefore, tend to reflect (not necessarily replicate) the overall maintenance structure associated with the systems they are replacing, with some changes in maintenance allocations as may be dictated by hardware design characteristics. Major technological changes, however, sometimes are exploited to improve maintenance support at less cost by changing the support structure.

EVOLUTION OF SYSTEM SUPPORT STRUCTURES

The Army's original, standardized, functionalized maintenance support structure (Table 2-2) evolved over years of experience with ground mobility equipment -- equipment characterized by high density of end-items, high mobility of using units, high-maintenance intensity (large numbers of maintenance personnel, long repairs, large quantities of bulky assemblies and parts), and an absence of highly complex maintenance tasks. The Army's standard echelonment of maintenance support, with four categories of maintenance, had proven its operational and support effectiveness for this type of equipment. With the introduction of new systems possessing different attributes, either in terms of employment concept (density, mobility) or hardware characteristics (maintenance intensity, complexity) or both, the Army has moved away from its functionalized maintenance doctrine and structure towards a commodity orientation of maintenance support. Thus, over the past 15 years, more and more exceptions to the basic structure have evolved: for example, organic, dedicated, DS units for missile systems; a two-level structure for fixed-site signal equipment; and a three-level structure for aviation. Army helicopters were initially supported using the standard, four-level support structure, but this proved ineffective. By moving some DS tasks to the units (aviation unit maintenance or AVUM) and combining the remaining DS tasks with those of GS into a new intermediate category (aviation intermediate maintenance or AVIM), the helicopters' operational availability was increased while maintenance manpower requirements were reduced.

Thus, today's maintenance support structure in the Army is, for good reason, commodity-oriented. The new weapon systems we examined in the course of this study continue this trend towards increased tailoring of the support structure:

- The new helicopters UH-60 BLACKHAWK and AH-54 APACHE conform to the AVUM-AVIM-depot support structure.
- The new tracked vehicles, M1 ABRAMS tank and M2 BRADLEY infantry fighting vehicle conform to the standard four-category support structure, organizational-DS-GS-depot.
- The new air defense missile system, PATRIOT, has a weapon-system peculiar, three-category support structure, organizational-intermediate-depot, where the intermediate support element only provides backup on-site support to the organizational level, while all off-equipment component repairs are allocated to depot or in-theater special repair activity.
- The new air defense command and control system, AN/TSQ-73 MISSILE MINDER has a weapon-system peculiar, two-category support structure, organizational-depot.
- The new field artillery command and control system, AN/GSG-10 TACFIRE (the only new system not replacing an existing one), as far as its electronics is concerned, has a weapon-system peculiar, three-category support structure, DS-GS-depot (organizational maintenance is limited and performed by the operators).

Fix-forward, as both an operational and maintenance policy, came too late to influence the design characteristics of these new systems: all were in full-scale engineering development or approaching production by the time the fix-forward concept was promulgated in 1976. As a consequence, fix-forward itself did not have a direct impact on these new systems; no fix-forward requirements were included in the contracts. However, their support concepts do reflect both the trends in new system technology and the difficulties in supporting complex systems.

SUPPORT CONCEPTS OF NEW SYSTEMS

A support concept may be defined in terms of two characteristics:

- The level of indenture of items removed and replaced on the weapon system. System design specifications influence what this level is (replacement concept).
- The level of maintenance authorized to do removal and replacement on-equipment, and the level responsible for off-equipment component or module repair. Maintenance doctrine influences the maintenance allocation charts (MAC).

The replacement concepts for the seven new weapon systems are illustrated in Table 3-1. Replacement at the component level is referred to as "box" replacement, at the module level as "board" replacement. The standard, modular design approach of electronics equipment, using today's technology, generally results in an on-equipment box replacement concept with off-equipment box repair through board replacement, and depot level repair or throwaway of boards. As shown in Table 3-1, some of the new systems deviate from this concept. In the case of the M2, some of the components in the turret (those which are TOW components) are actually not removed and replaced, but repaired on-equipment through board replacement. The two command and control systems, TACFIRE and MISSILE MINDER, were both designed with a board replacement concept. That worked for the latter but not the former; in operational TACFIRE units most replacements are actually done at the box level. In the case of PATRIOT, most of the items removed/replaced in the system are circuit boards; some are module assemblies (boxes).

TABLE 3-1. ON-EQUIPMENT REPLACEMENT CONCEPTS FOR NEW SYSTEMS

LEVEL OF INDENTURE	EXAMPLES						
WEAPON SYSTEM	UH-60	AH-64	M1	M2	TACFIRE	TSQ-73	PATRIOT
END-ITEM	Helicopter	Helicopter	Tank	IFV	Fire Direction Center	Air Defense Command Post	Engagement Control Station
SUBSYSTEM	Avionics	Fire Control (FDLS Multiplex System)	Fire Control	TOW	Computer	Automatic Data Processor	Weapons Control Computer
ASSEMBLY	ANS-128 Doppler Radar	Target Acquisition Designation Sight (TADS)					
SUBASSEMBLY		Night Sensor					
COMPONENT	Computer[1] Display Unit	FLIR[1]	Thermal[1] Electronics Unit	Control[1] Guidance Electronics	Mass Core Memory Unit	Memories	Module Assembly
MODULE	Circuit Board	Circuit Board	Circuit Board	Circuit Board	Circuit Board[1]	Circuit Board[1]	Circuit Board[1]
BIT-PIECE PARTS	SEE NOTE 2						

[1]Indenture level for on-equipment removal and replacement.

[2]Technology determines what this is: vacuum tubes, discrete solid state devices, integrated circuitry ("chips"), or "true" piece parts such as resistors or capacitors. The term is used in the generic sense of parts which are not repairable but throwaway, not in the sense of elementary electronic functions.

[ ] Current on-equipment replacement concept for given examples.

The maintenance support concepts, insofar as the electronics equipment is concerned, are summarized in Table 3-2. The systems are, to a variable degree, dependent on support from outside the unit (contractor, DS, or GS), or must be retrograded for some failures as repair times exceed fix-forward time limits at the organizational level (six hours for ground equipment, eight hours for aviation). The table also shows rough estimates of the efficiency of on-equipment maintenance, as measured by false removal rate (percentage of items removed from the system, replaced by spares, but showing NEOF when subsequently tested at a higher maintenance category), and the maintenance categories where components and modules are repaired.

TABLE 3-2. NEW SYSTEM SUPPORT CONCEPTS (ELECTRONICS EQUIPMENT ONLY)

(Rough Percentage of Corrective Maintenance Actions by Maintenance Category)

SYSTEM/ SUBSYSTEM	ON-EQUIPMENT		PERCENT FALSE REMOVALS	OFF-EQUIPMENT[1]				
	Unit (ORG or AVUM)	Fwd. Support or Retrograde[2]		"BOXES" DS[3]	"BOXES" GS[3]	"BOXES" Depot[4]	"BOARDS" GS[3]	"BOARDS" Depot[4]
AH-64 MISSION PAYLOAD (FDLS)	95%	5%	30-35% (boxes)	80%	—	20%	30%	70%
UH-60 AVIONICS	98%	2%	15-20% (boxes)	20%	—	80%[5]	—	100%
M1	85%	15%	10-15% (boxes)	100%	—	—	0%	100%
M2 TURRET	95%	5%	5-10% (boxes)	100%	—	—	95%[6]	5%
M2 TOW	5%	95%	5-10% (boards)	100%[7]	—	—	0%	100%
PATRIOT	85%	15%	15-20% (boards)	—	—	100%	—	100%
MISSILE-MINDER	70%	30%	30-35% (boards)	Not Applicable			—	100%
TACFIRE (FDC)	40%	60%	0% (boxes) / 30% (boards)	80%	—	20%	80%[6]	20%

[1] Percent of LRUs (SRUs) repaired by echelon, not weighted by failure frequencies.

[2] Percent corrective maintenance actions either requiring non-organic support from forward support teams or contractor, or in excess of fix-forward time limits (ground: 6 hours; air: 8 hours). Percentages are based on testability characteristics and assume requisite skill levels.

[3] For aviation, read DS = Divisional AVIM, GS = Corps AVIM.

[4] Depot category includes SRAs in overseas theaters (PIMRA, PCMC, PFASC in USAREUR).

[5] Allocation influenced by RIW contracts for new avionics and to be revised in the future.

[6] Currently depot but moved to GS when AN/MSM105(V)1 fielded at GS.

[7] Component repair through (1) board replacement done on-equipment by DS team, using TSTS; or (2) component replacement by organizational level and off-equipment component repair at DS. Concept (1) applies to three components of the TOW, concept (2) to the fourth component.

In comparison to the support concepts of the systems they replace, the new system support concepts exhibit a definite trend of moving off-equipment component repairs forward, while the dependence on forward support from outside the unit for on-equipment component (module) replacements is less for some, more for other systems. A brief summary of the key features of each system's support concept serves to illustrate these changes.

AH-64

Compared to its predecessor, the AH-1S TOW COBRA, the AH-64 represents a quantum leap in sophistication (combat capabilities), a significant increase in mission-payload complexity (number of modules and their interconnectivity), and a careful design approach to reduce maintenance difficulty through a state-of-the-art, distributed built-in test known as the fault detection/localization system. Contractual requirements for the latter were tight but have not been achieved. The projected testability shortfall must be compensated through the supply system, i.e., increased stockage of LRUs, to achieve required system availability. To minimize the associated stockage cost, the support concept calls for module repair as far forward as possible: LRU repair in divisional AVIM, printed circuit board (PCB) repair in corps AVIM, utilizing a large automated test station which was not designed for use outside fixed-plant installations. The support concept of the AH-64, compared to that of the AH-1S, moves a portion of depot level off-equipment tasks forward to division and corps AVIM. Some on-equipment tasks (complex weapon diagnostics) allocated to AVIM in the AH-1S MAC (but actually done at AVUM if not collocated with AVIM) are allocated to AVUM in the AH-64 MAC: a move forward on paper, but little change in practice for on-equipment maintenance.

UH-60

Compared to its predecessor, the UH-1, the UH-60 provides much increased capabilities, but the increase in complexity is relatively small. As a utility helicopter, the platform has no weapon suite. Technology advances have been exploited to improve the reliability and maintainability of the turboshaft engine and the avionics (navigation), the only complex subsystems aboard, compared to those on the UH-1. Emphasis on maintainability during the acquisition program has paid off in a well-maintainable system with good fix-forward potential. Some avionics maintenance tasks currently performed by AVIM for the UH-1 (but authorized at AVUM by MAC) can now be performed at AVUM through the built-in test provided in the modernized avionics -- a move forward of a few on-equipment maintenance tasks in practice, though no change on paper. To further improve the overall (i.e., in-theater) fix-forward potential and operational availability, the Army needs to do three things it has not elected to do so far: (1) field a mobile engine test stand at corps AVIM to increase engine-diagnosis capability in-theater and prevent evacuating good engines diagnosed as faulty to Continental United States (CONUS) depot; (2) replace the present chip detection system (which is supposed to detect impending failures in engine, gearboxes, and transmission) by a more advanced system which was tested and demonstrated by Aviation Research and Development Command's (AVRADCOM's) Applied Technology Laboratory in 1979, in order to reduce or eliminate nuisance warnings, associated precautionary landings, and resulting downtimes; and (3) reassess the validity of the Army Oil Analysis Program as a basis for repair decisions.

M1 Tank

The increased combat capability the M1 provides over the last modification of the M60 series, the M60A3 (Tank Thermal Sight), is significant in terms of mobility and survivability. Attempts to counter the increase in complexity, however, were only partially successful: the built-in test is well behind the state-of-the-art so that system level troubleshooting relies to a large extent on using system-peculiar automated test equipment at the organizational level. Limitations to the latter are being addressed in the form of much-expanded troubleshooting aids (documented troubleshooting procedures) to accommodate the Army's philosphy of job design: organizational maintenance tasks are performed primarily by apprentice-level maintenance personnel. The net outcome is that a portion of on-equipment maintenance tasks requires DS assistance, just as for the M60A3 tank. Overall, the MACs for the two tanks and their distribution of maintenance tasks across the different maintenance categories are similar. A portion of M1 maintenance tasks originally planned for depot level has been moved forward to GS, but electronics GS-level repairs (PCBs) remain allocated to depot. Due to better diagnostics capability at the DS level through new automated test equipment, some comparable electronics maintenance tasks now performed further in the rear for M60A3 subystems were moved forward to DS for the M1.

M2 IFV

The new infantry fighting vehicle (IFV) is the first turreted vehicle for employment with the Army's infantry and thus hardly comparable to the M113 Armored Personnel Carrier. As a result of this quantum leap, the acquisition program received much more attention from the user representative (the TRADOC system manager) than is normally the case in the Army. That user emphasis, facilitated by an unusually well supported TRADOC system manager office, as well as the lesser complexity of the M2 compared to the M1, may be the reasons why the M2 is plagued less by maintainability problems than is the M1, even though system level troubleshooting has to overcome the same limitations as described for the M1 (limited built-in test as a result of limited contract requirements, more emphasis on design-to-unit production cost than on life cycle cost and obsolete built-in test technology, and a need to rely on the same type of automated test equipment as used for the M1). The maintenance support plan for the vehicle is similar to that for the M113; that for the turret is similar to the M1 except for the M2's TOW. The TOW subsystem has four major components. Three are repaired on-site by a DS missile maintenance team through replacement of faulty modules. To fault isolate failures, the team uses the TOW test set and diagnostics generated by the organizational maintenance test equipment. The fourth (and most expensive) component is replaced by organizational maintenance and repaired off-equipment in DS shop, using the same test equipment as for M1 components. Attempts by the M2 program manager to let the organizational level do more (namely, fault isolate to the module level within the four components (assemblies) of the TOW missile system) were frustrated by Army maintenance policy disallowing disassembly of components at the organizational level. In contrast to the M1, all electronic modules, if not throwaway, will be repaired at GS, not depot, as soon as the general purpose automated test equipment (MSM-105) is fielded.

PATRIOT

Probably the most sophisticated, tactical system the Army will be fielding in the 1980's, PATRIOT, is more complex than the system it replaces, the Improved HAWK (IHAWK). Design for maintainability, however, has been successful in reducing maintenance difficulty to a level comparable to that for IHAWK. The original support concept was three levels of maintenance: box removal at the organizational level, box repair at GS (combining the functions now performed at DS and GS for the IHAWK), and board repair at depot. While in full-scale engineering development, the program manager decided to eliminate the intermediate level and extend the built-in test to the board level where possible, resulting in a two-level support concept. Improved built-in diagnostics and off-line, computer-based troubleshooting aids have not achieved required performance levels. The recently revised support concept is compensating for the shortfall in testability through a "forward support element," a team of highly skilled technicians (one warrant officer and nine E-7s) to provide on-site assistance to organizational maintenance personnel who have lower skill levels and less experience. Compared to the IHAWK, all off-equipment component repairs have been moved to the rear (CONUS depot or in-theater special repair activity). On-equipment maintenance relies to some extent on forward maintenance support as it does for IHAWK, but most of the latter's testability problems are levied on the supply system. In sum, PATRIOT support moves off-equipment maintenance to the rear, while on-equipment maintenance relies on more back-up support (skills) but less stockage (parts) than for IHAWK.

MISSILE MINDER

This system has the lowest density of the seven systems examined: currently one per nondivisional air defense battalion, and plans are for further reduction to one per air defense group in USAREUR. The system is complex. The support concept from the start of the program was two-level, on-site and depot, utilizing built-in test and maintenance diagnostics software to provide automated fault isolation to the PCB level. Shortfalls in testability are significant, but they are compensated through a dedicated, on-site contractor technician. The support concept of the predecessor system included DS/GS maintenance. The lack of back-up support is evidenced by excessive downtime of the system when it fails. Mission availability is helped by relatively high reliability and capability to operate in degraded mode.

TACFIRE

TACFIRE underwent several support concept iterations which are described in Appendix E. Current support consists of (1) operators, who do preventive maintenance, but little corrective maintenance in the operational environment (when in garrison, they do more maintenance) and (2) a dedicated DS team which provides on-site support by removing/replacing failed components (major items, not boards). The DS team transports replaced components back to the division support area where a hot mockup is used to fault isolate the component to the board level. Faulty boards are evacuated to GS or depot; some items are contractor supported. TACFIRE cannot be compared with a predecessor system. The old FADAC computer (Field Artillery Digital Computer) was used only for ballistic computations; TACFIRE is a command and control system. Compared to earlier TACFIRE support concepts, organizational level tasks were moved back to the DS forward support team due to testability shortfalls and the capability of the system to be operated in degraded mode: for operator personnel, continuing a firing mission is more important than performing maintenance -- as long as the system is partially operational. As a result, the support concept changed from board replacement by the operator to box replacement by DS, with the latter conducting box repair off-site by replacing faulty boards, using a hot mockup (in lieu of the tactical system) for fault isolation and checkout.

RECAPITULATION

Our observations on the relationships, if any, between fix-forward and the support concepts of new weapon systems are summarized as follows:

- The replacement concept (box versus board removal/replacement for on-equipment system repairs) is influenced by many factors other than fix-forward; for example, technology, system employment concept, and cost. The only thing that counts for fix-forward is the ease of on-equipment maintenance as measured by repair (remove/replace) time. A replacement concept resulting in the shortest system downtime would be supportive of fix-forward, but otherwise there is no general rule for preferring one concept over the other.

- The support concepts of new systems exhibit a discernable trend of moving off-equipment component repairs forward compared to those of the systems they are replacing. This trend can be attributed to many factors, such as availability of test equipment, increasing cost of components (LORA decisions are heavily influenced by stockage costs of spares), and misinterpretations of the fix-forward concept on the part of system developers. Fix-forward, however, is exclusively concerned with minimizing weapon system turnaround time, that is minimizing on-equipment repair time and performing that repair as close as possible to the site where the failure occurred. Fix-forward, by itself, does not justify moving off-equipment component repairs forward.

- The fix-forward potential of the new systems depends heavily on the maintenance skills of organizational maintenance personnel. Current maintenance practices indicate serious problems with maintenance performance at that level. As a result, the dependence on maintenance support from higher maintenance categories for on-equipment maintenance would be correspondingly higher than depicted in Table 2-6.

The single, most important factor explaining excessive maintenance downtime and/or reliance on nonorganic support is a lack of diagnostics capability, the capability to localize and isolate a detected failure to the removable item (box or circuit board, whichever the maintenance concept is). None of the new systems reviewed were fielded with a diagnostics capability in consonance with requirements. Shortfalls occurred in all areas contributing to diagnostics capability: built-in test, test equipment, technical documentation, skill levels, and training. During the initial operational years, some of these voids were recognized and corrected. For example, the Army has spent much effort on improvements in troubleshooting manuals and test programs for the M1 and M2 since they went into full-scale production. Many voids, however, were never corrected. The available evidence and assessments of diagnostic shortcomings are addressed next.

4. DIAGNOSTIC CAPABILITY

INTRODUCTION

Fix-forward is predicated upon the mechanic's ability to recognize and interpret failure symptoms and to rapidly trace a system failure to the faulty module. In the absence of this diagnostic capability, on-equipment repair time will be too long to permit repair in or forward of the battalion trains area, necessitating recovery to the brigade support area. If done too frequently for too many weapon systems, retrograde to brigade support area would usurp the maintenance capacity needed for battle damage repair and, in turn, would trigger evacuation of end-items to the division rear even though they are repairable in forward areas -- an event which must be avoided if fix-forward is to be successful.

Diagnostic capability is a function of the testability characteristics of weapon systems, the suitability and availability of test equipment, and the troubleshooting skills of maintenance personnel. In this chapter, we examine each, giving examples of the major shortcomings that inhibit implementation of fix-forward and suggesting how to correct the situation.

TESTABILITY CHARACTERISTICS

The testability of a system can be measured in many different ways, but all refer to the ease, extent, and accuracy by which adequate system performance can be verified and failures detected and isolated to a level of indenture in consonance with the maintenance concept. Design for testability has evolved as a discipline to counter the effect complexity has on maintainability. Although earlier generations of weapon systems -- characterized by 100% analog design and low levels of interconnectivity -- were susceptible to manual troubleshooting using common TMDE and schematics, technology changes since the 1960's have permitted much increased sophistication in weapon system design but with an associated increase in inherent complexity. This development made manual troubleshooting impractical or impossible without diagnostic aids.

Diagnostic aids for system troubleshooting include built-in test (BIT), comprising both hardware and software; built-in test equipment (BITE), which is hardware devices; off-line electronic test equipment (ETE), which may or may not include diagnostic software for *automated fault localization*; and other diagnostic information media (beyond schematics), such as fault isolation procedures, fault catalogues, state tables, etc., which are normally developed in printed format but which, in the case of computer-based systems, can be diagnostic software. Stand-alone, computer-based diagnostic aids have so far not been adopted by any of the Services. Such aids (not test equipment because the device is not connected to the weapon system), however, have been applied to specific subsystems with testability problems for demonstration and test purposes.

Testability Deficiencies

For various reasons, weapon systems fielded in the late 1960's and 1970's exhibit serious deficiencies in testability. Common reasons include: lack of recognition of the need for diagnostic aids to compensate for increasing system complexity; low priority accorded maintainability; schedule compression and emphasis on design-to-unit production cost causing short cuts in maintainability design engineering efforts; and lack of visibility of the repercussions of testability shortfalls because of the limitations of maintainability demonstrations and development/operational testing practices. A more basic reason was the lack of knowledge of how testability requirements should be specified, tested, and evaluated. This is now being corrected. The Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics), Joint Logistics Commanders, and the individual Services have been sponsoring study groups on testability and automated testing. Drafts of proposed military specifications have been prepared, and BIT design guides have been published. The technical aspects of the problems have thus been addressed (not yet necessarily solved), but the institutional aspects remain.

The extent of shortfalls in testability of the weapon systems inventory in the 1980's and the repercussions this will have on fix-forward in combat are not well understood at many levels in the Army. Testability deficiencies are of two types. One is inability to ascertain with certainty whether or not the system is operable. Thus, an operator may believe a system works but finds out it does not when the capability affected by the (undetected) failure is needed. Or, conversely, the operator may get an indication that the system does not work properly while, in fact, it does. In either case, fault detection shortfalls degrade mission capability. The repercussion on fix-forward is, generally, an increased requirement for forward maintenance support to enable the system to resume its mission (specifically, if the system involved is highly mobile). A more serious repercussion is the increased chance of receiving battle damage.

The second type of deficiency is inability to isolate the fault once a system failure (or, out of tolerance condition) has been detected. This inability may manifest itself in several ways. When minimal system downtime has top priority, the mechanic has no choice but to guess the cause of the failure symptom, removing/replacing several modules to correct a single failure; this, in turn, shows up at higher maintenance echelons in terms of high NEOF rates of the modules received from the organizational level. That is, the supply system must compensate for fault isolation shortfalls. In cases where system downtime is less critical or where troubleshooting by trial-and-error is impractical due to tight supply, fault isolation shortfalls may be compensated by using expert technicians not organically available at the organizational level (e.g., DS technical inspectors and civilian technicians) or by accepting, for a percentage of system failures, system down times in excess of notional fix-forward time limits, necessitating recovery to the rear. Whatever the specific manifestation, fault isolation shortfalls detract from fix-forward because they either levy an extra burden on the supply system, or increase the requirement for forward DS maintenance support, or cause excessive on-equipment repair times requiring retrograde of the weapon system.

An assessment of the testability characteristics of the new weapon systems as well as a sample of currently fielded equipment is provided in Appendix A. Information for the new systems is summarized in Table 4-1. This table shows what the Army specified in contractual terms, what the current assessment is of testability performance for the mature system, and how the Army is compensating for testability shortfalls. The following comments explain the testability measures (contract requirements and testability achievement) used in Table 4-1.

Testability requirements may be specified in two ways: direct or indirect. Both were used by the Army in the acquisition programs of the seven new systems reviewed. Direct requirements specify what BIT/BITE must be capable of achieving; the measures used include: fraction of faults detected (FFD), fraction of false alarms (FFA), fraction of faults isolated (FFI), and fault isolation resolution (FIR). The meaning of these terms is explained in Appendix A. We will return to the question of how valid these measures are

TABLE 4-1. NEW SYSTEM TESTABILITY REQUIREMENTS AND PERFORMANCE

WEAPON SYSTEM/ SUBSYSTEM	CONTRACTUAL REQUIREMENTS (Organizational Level)	TESTABILITY ACHIEVEMENT	COMPENSATORY ACTIONS TAKEN
UH-60 (Total Aircraft)	$M_{max}(90\%) \leq 30$ min.	$M_{median} = 30$ min. NEOF(avionics) = 20% FAA(chip indicator) = 80%	New ETE for electronics control unit of turboshaft engine.
AH-64 (FDLS)	Distributed BIT: FFD/FFI = 95% FFA $\leq$ 2%	FFD/FFI = 65% FFA = 10%	ATE in Division AVIM to provide quick turnaround of LRU repairs.
M1	FFD = 90% MTTR = 1.4 MMH $M_{max}(90\%) = 4$ hrs.	FFD = 90% FIR(3) = 95% } STE FIR(1) = 50% } $M_{max}(90\%) \geq 6$ hrs.	Alternate troubleshooting procedures (manuals).
M2	$M_{max}(95\%) = 4$ hrs. Skill Level 10 at Organizational Maintenance	$M_{max}(90\%) = 4$ hrs.(E) FIR: Not Available	Alternate troubleshooting procedures (manuals).
TACFIRE	FFI = 90%	FFI = 60%	Change in maintenance concept: on-site DS contact team support.
TSQ-73	FIR(10) = 90% MTTR $\leq$ 35 min.	FIR(15) = 75% MTTR = 90 min.	Contractor technician on-site.
PATRIOT	FFI = 99%	FFI = 85%	Dedicated teams of trouble-shooters, one team (1 WO/9 E7) per 3 battalions.

later in this chapter. Two points are important. First, these testability measures are interrelated; e.g., requiring a highly sensitive BIT (FFD close to 100%) implies, generally, accepting a certain level of false alarms. Second, the FFI measure implies that failures are isolated by BIT to a single removable item, but in actuality BIT often does not do this. The second fault isolation measure is more specific, by identifying the size of the ambiguity group to which BIT localizes the fault; the mechanic must still manually fault isolate within that ambiguity group to the faulty module(s). Thus, a contract specification such as FIR(10) = 90%, as used for the TSQ-73 (Table 4-1), means that at least 90% of the detected failures must be fault isolated to an ambiguity group with an average size of ten or fewer removable items. Traditionally, the FFI measure is used in conjunction with a box replacement concept, while FIR is used with a circuit board replacement concept. Table 4-1 uses FIR in the "testability achievement" column for either concept because it is more specific than FFI.

Indirect measures do not explicitly address testability requirements, but do so implicitly by stating minimum maintenance performance levels (maintainability). Measures used in this regard include: mean time to repair (MTTR), maximum repair time at the 90th or 95th percentile of corrective maintenance actions, e.g., $M_{max}(90\%)$, and median repair time (M_{median}). This can be specified for each maintenance category. Conceptually, using the approach to testability requirement specification allows the contractor to focus the design effort on whatever is needed to achieve the level of maintainability specified. For relatively simple systems, this may work (e.g., UH-60); for complex ones, it does not (e.g., M1). (The comparison here is not between a helicopter and a tank, but between different systems within the same family.)

Other measures used in Table 4-1 for assessing testability achievement include NEOF rate, a term explained earlier. This phenomenon may be caused by many different factors; e.g., false alarm indications, intermittent failures, erroneous fault isolation by BIT, expediency to minimize downtime, unavailability of test equipment, improper test equipment/software tolerances at higher echelons, and lack of troubleshooting skills. Thus, NEOF rate is, by itself, a very imprecise indicator for attributing a testability problem to a cause. For example, in the case of the UH-60, the avionics package is shown to have a NEOF rate of 20% to 30% which is, in part, caused by the provisions of a current reliability improvement warranty contract with the manufacturer of the avionics in question (AN/ASN-128 Doppler radar receiver). The provisions require AVUM personnel to follow BIT indications and return boxes to the manufacturer without further testing. A review of Appendix A will be helpful to interpret Table 4-1 correctly.

In sum, none of the new systems achieved (or is expected to achieve) the level of testability specified in the prime contracts. This is not necessarily a cause for consternation. There are basic limitations to government acceptance tests and operational test and evaluation efforts: operational parameters receive more scrutiny than support parameters; testability is but one among numerous test issues; schedule and cost constraints limit test thoroughness; much of the diagnostics is not complete by the production milestone; and so on. These are facts of life. Holding the production decision until all testability requirements have been met may not be the wisest approach. What is more important is what the Army is doing or plans to do to compensate for known testability shortfalls. Such compensation must come from the other areas contributing to diagnostic capability: test equipment, technical documentation (troubleshooting aids), skill levels, and/or training. In this context, it must be realized that all of these are originally based on the assumption that the system meets its testability requirements. If there are shortfalls, corrective actions are needed in each of these areas. Table 4-1 shows what the Army is doing in this respect. In some cases, the focus is on troubleshooting aids (M1, M2); in other cases on new test equipment (UH-60), higher skill levels providing forward maintenance support (TACFIRE, PATRIOT), or accepting the penalty of increased spares but reducing the associated cost by moving component repairs forward (AH-64). In one case, the "solution" has been to provide on-site contractor support (TSQ-73).

In all cases, the actions taken to compensate for testability shortfalls are piecemeal and late. None extend to organizational maintenance skill levels or training, nor have advanced technology job aids been considered.

While some action is better than none, the unavoidable outcome is that operational availability of these weapon systems will suffer, especially in wartime. This is because the extent of fix-forward, as measured by the percentage of systems repaired in forward echelons (battalion) and returned to battle, will be less than expected on the basis of advertised testability specifications and the assumption that these systems perform as advertised. By taking a more comprehensive management approach to the issue of testability, we believe the Army could reduce the extent of testability shortfalls and develop, in a more timely and cost-effective fashion, compensatory programs to counter any shortfalls and ensure required diagnostics capability. An outline of what is needed is described next.

An Integrated Diagnostics Concept

In analyzing the problem of testability shortfalls, we draw attention first to the very limited testability specifications used by the Army in its full-scale engineering development contracts. In all examples, contracts either did not include minimum acceptable testability requirements at all or limited the requirements to two BIT performance measures: FFD and FFI (or, in a few cases, FIR). Only the advanced attack helicopter program used a tighter specification including false alarm rate. Furthermore, arbitrary values were specified for both: typically, 90% for fault detection and isolation, with some exceptions. To understand the fallacy of this approach, it must be recognized that contractors can meet such requirements by designing BIT which addresses only a portion of the total system. Entire sections with higher reliability modules, components, and their interconnections may be left out while still meeting the overall testability specifications. When, after fielding, failure modes appear that were not analyzed in design, or failure frequencies differ from original engineering estimates, the percentage of actual failures in areas not addressed by BIT may be more significant than expected, resulting in a lower than expected fraction of failures detected by BIT. Another factor is that FFD is ambiguous without further specification; it may be the fraction of all failures detected or the fraction of detectable failures detected. Thus, more precise specifications must be included in contracts to ensure testability.

Further insight into the suitability of different types of BIT performance measures is provided by Figure 4-1. That matrix is based on an industry review and taken from the referenced source with no change. The ranking in each matrix cell is the average of the rank order of each measure for each specification objective shown in the first column with its rank order based on suitability. The source reference defines the latter as follows:

uniqueness = 1
trackability = 2
demonstrability = 3
translatability = 4
ambiguity = 5
applicability = 6

For example, according to this survey, the most effective measures of BIT performance in terms of accuracy are the mean time between failure (MTBF), MTTR, and operational availabilty (A_o) of the BIT hardware and software.

We have circled the matrix cells associated with those specification objectives which are supportive of fix-forward and for those measures ranked highest in terms of suitability and/or specification objective, or ranked next highest in both. Thus, the figure identifies, for each of seven testability objectives, which are the two or three preferred (most effective) measures to specify or evaluate testability performance. We provide this example to illustrate that there is more to testability than specifying some arbitrary values for FFD and FFI. (The latter, in fact, does not appear in the preferred set of relevant measures.) This survey is not the final word, and

FIGURE 4-1. SUITABILITY RANKINGS FOR BIT PERFORMANCE MEASURES

SPECIFICATION OBJECTIVE	FFD	FFA	FFSI	TFD	TB	FB	TT	FIR(L)	FFI	TFI	MPSL	MTBF BIT	MTTR BIT	A_o BIT	MTTR	A_o	FFP	FEFI
CONTINUOUS PERFORMANCE	2	6		4		3	5									1		
ACCURATE STATUS REPORTING	(1)	4	(3)	6			5					2						
MINIMUM DOWNTIME					7			4	3	6			5		(1)	(2)		8
LIMITED SPARES								(1)										
MINIMUM SUPPORT COSTS		(4)	5					(1)	2									3
SPECIFIC SKILL LEVELS	(1)						7	3	4	8	(5)				(2)			6
SYSTEM LOCATION								(1)										(2)
BIT/ETE INTEGRAL TO SYSTEM		3	2									1						
ON LINE TESTING LENGTH / PERIODICITY					2	1												
SOFTWARE TESTING LIMITATIONS																	(1)	
UNDETECTED FAILURES	(1)			(2)			3											
BIT/ETE OPERABILITY ACCURACY		5	4									(1)	(2)	(3)				
R = AVERAGE RANKING BASED ON SUITABILITY AND SPECIFICATION OBJECTIVE																		

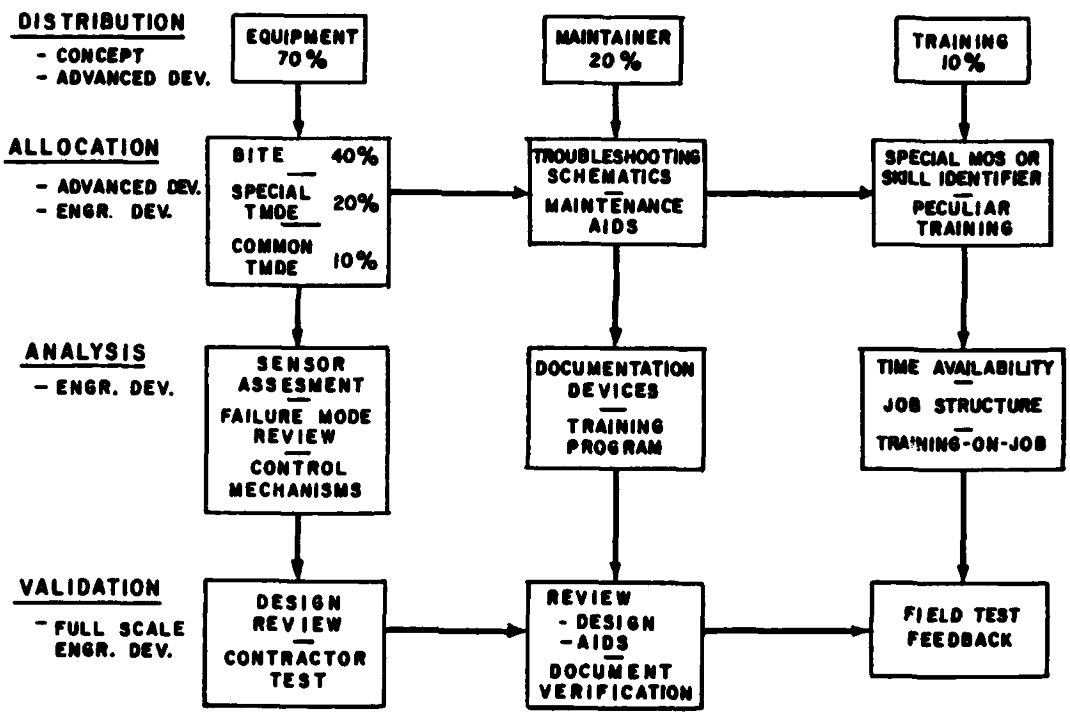
FFD – FRACTION OF FAULTS DETECTED
FFA – FRACTION OF FALSE ALARMS
FFSI – FRACTION OF FALSE STATUS INDICATIONS
TFD – FAULT DETECTION TIME (MEAN)
TB – BIT RUN TIME (MEAN)
FB – FREQUENCY OF BIT EXECUTION
TT – TEST THOROUGHNESS
FIR(L) – FAULT ISOLATION RESOLUTION
FFI – FRACTION OF FAULTS ISOLATED
TFI – FAULT ISOLATION TIME (MEAN)
MPSL – MAINTENANCE PERSONNEL SKILL LEVEL
FFP – FRACTION OF FALSE PULLS
FEFI – FRACTION OF ERRONEOUS FAULT ISOLATION

SOURCE: "BIT SPECIFICATION AND DEMONSTRATION TECHNIQUES," DANIEL GLEASON, ROME AIR DEVELOPMENT CENTER. PAPER INCLUDED IN: BUILT-IN-TEST EQUIPMENT REQUIREMENTS WORKSHOP. FINAL REPORT, IDA PAPER P-1600, INSTITUTE FOR DEFENSE ANALYSIS, AUGUST 1981 some rankings can be disputed. For example, the test thoroughness (TT) measure, defined as the fraction of the system addressed by BIT, based on our evidence, would be more suitable for achieving the design objective of minimizing undetected failures than would the fault detection time (TFD) measure shown with a higher ranking. Other relationships between these measures exist and must also be recognized; for example, requiring a high fault detection rate might normally induce a high false alarm rate unless the latter is explicitly limited by contract specification.

Rather than specifying arbitrary testability requirements in terms of various combinations of BIT performance measures, a better approach would be to require 100% diagnostic capability, with the contractor responsible for showing marginal cost trade-offs between BIT, ETE, troubleshooting aids, and training. Such an overall approach would provide a more timely, well engineered solution to the testability problem and result in more cost effective decisions regarding the capabilities required from each component contributing to total diagnostic capability (see Figure 4-2). Absent this approach, unanticipated testability shortfalls will be unavoidable and either neglected or compensated by bandaids, neither of which may be cost-effective. The Air Force is currently instituting an "Integrated Diagnostic Policy" requiring that 100% fault detection and isolation be a weapon system design parameter.

Implementation of the recommended approach would require a more serious, analytic effort throughout a weapon system acquisition program, not just front-end analysis. For example, it would entail the following: requiring in the original design contracts 100% diagnostic capability to be allocated among BIT, ETE and other aids based on cost trade-off studies; tightening the failure modes and effects analysis (FMEA) specifications and

FIGURE 4-2. SOLUTION APPROACH: A CONCEPT FOR 100% DIAGNOSTIC CAPABILITY



fully funding an FMEA program; considering implementation of a computer-based FMEA to permit better assessment of test point requirements and to provide continuity/configuration control from validation through fielding; using the FMEA not as a stand-alone deliverable item, but as input to BIT design, ETE requirements, other aids (technical publications) and skill training requirements; and monitoring performance of testability design, including a managed maturation program as needed, until feedback from the field demonstrates that testability requirements actually have been met.

For currently fielded systems with testability shortfalls, require an engineering review to determine cost-effective ways to overcome the shortfalls. Some systems will require new or improved ETE; some may require product improvements or enhancements to BIT software; some revisions to technical publications may suffice; and, in many cases, higher skill level training and revised manpower authorizations (higher skill levels) may be indicated. A pilot program of fielding a different type of diagnostic aid (stand-alone, micro-computer controlled diagnostic sofware) might be the best approach in selected cases. Responsibility for corrective action once a system has been fielded is dispersed among different organizations within the Army. Effective action may require changing existing lines of responsibility for post-fielding supportability improvement.

TEST EQUIPMENT REQUIREMENTS

For most of today's complex weapon systems, test equipment is not a convenience; it is a necessity. Fix-forward cannot be successfully implemented without test equipment that is both suitable for the environment in which it will be used and operationally available to the operators or to the maintainers who need to use it. For a variety of reasons, the Army's general purpose test equipment does not meet those criteria. The Army knows that and recently has taken some major steps to improve management support of general purpose test equipment. In Appendix D, we trace the history of the Army's current structures for management of test equipment and calibration. We discuss also the growing backlog and repair times for test, measurement and diagnostic equipment in USAREUR, the two major reasons for those trends -- poor supply support and shortages of skilled TMDE calibration and repair personnel -- and the Army's plans for correcting the situation. Since the Army is fully aware of those problems and embarked on a program to eliminate them, we shall say no more about them here, but refer the interested reader to Appendix D. Instead, we shall turn attention to special purpose test equipment and its shortcomings which inhibit achievement of fix-forward capability.

Much of the special purpose test equipment in the field today was acquired as the cheapest option in a weapon system acquisition program. The equipment is factory checkout/quality assurance equipment which the contractor developed for his own use. It is often cheaper for the Government to procure it than to have MIL SPEC special test equipment developed for field maintenance support. Also, the need for test equipment is sometimes considered so late in the acquisition program that schedule constraints force the program manager into this option. Supportability of test equipment is never an issue in weapon system acquisition. The only circumstance enabling the user representative (TRADOC) to stop this type of support equipment from being fielded is when it does not work in operational testing. One noteworthy example is the kludge of M1 test equipment that was found totally unacceptable during OT II; the test failures resulted in an expedited program to develop what is now called the simplified test equipment (STE)-M1. Often, however, the support equipment is not tested during operational testing; for one reason or another, that portion of the test frequently is waived.

The consequence of fielding factory, quality assurance equipment as field army special-purpose test equipment is a diagnostic nightmare which is, in general, poorly apprehended. To illustrate, consider the test set guided missile system (TSGMS). The TSGMS is supposed to be used for troubleshooting and fault isolating the airborne TOW missile system (M65 TMS) installed on the AH-1 COBRA. It was fielded originally only at AVIM. Later, when M65 TMS BIT deficiencies were identified, it was fielded also at aviation unit maintenance (AVUM) (namely, for those attack helicopter companies without organic AVIM support, such as the air cavalry troops of the Armored Cavalry Regiments). Because of the BIT deficiencies, the test set had to be used to fault isolate over 90% of system failures. The test set (three large cases, each portable by two persons) is fragile; it cannot be transported by jeep without getting out of calibration, and it must be handled with care. It is also expensive: $360,000 per set. Because the M65 TMS BIT does not accurately report operational status of the system (about 15% of system failures and the interfaces with the aircraft wiring and power output from the DC bus escape BIT), the technical manual prescribes that the system must be checked out every 240 operating hours -- approximately every 300 flight hours. This requirement was based on early, demonstrated reliability of the TMS in excess of 250 hours MTBF. (The actual MTBF is currently less than 80 hours). Though the TMS is composed of only 9 LRUs, a complete checkout using the TSGMS requires two average skilled technicians (68J20) two days (10 hours hands-on; 12-16 hours elapsed time). Even when the official procedures are followed, fault isolation is inaccurate, as evidenced by a 45% NEOF rate of LRUs returned to Pirmasens Missile Repair Activity for repair. (This NEOF rate is a 3-year average; the data for 1981 suggest a downward trend.) Obviously, this type of test equipment may be useful in phase inspections but is totally unsuitable for fault isolating failures observed by the flight platoon (i.e., if the BIT detects a failure). Corrective maintenance, other than that during phase inspections, is therefore done by trial-and-error replacement of LRU -- the reason for the high NEOF rate of LRUs. The poor performance cannot be attributed to low "quality" of personnel or lack of training. It is purely the result of poor testability of the hardware and inadequate test equipment. The Army is paying for this in high demand for parts, low operational availability, and lack of fix-forward potential in wartime.

A unique category of special test equipment is the series of STE developed for M1, M2 and M3. This test equipment was developed when the contractor-developed peculiar test equipment did not perform satisfactorily during M1 operational testing (OT II, 1978). The STE-M1 (and its derivative, STE-M2/M3) is a modified version of the STE-ICE (internal combustion engine) which was type classified in 1978. The STE design philosophy was to provide the mechanic with a programmable test set which would automatically diagnose and isolate failures, thereby reducing skill level, training and experience requirements, and eliminating common TMDE without affecting diagnostic capability at the organizational level. Evidence shows that this philosphy was naive; STE does not and cannot substitute for skilled technicians.

The key element of the STE-ICE is the vehicle test meter (VTM). It is a small (12x9x8 inches), lightweight (12.5 pounds), hand-portable unit which incorporates a micro-processor. The unit can execute up to 100 diagnostic test programs under user control, displaying the results of each test on a small read-out screen on the VTM. The mechanic hooks up the VTM to the vehicle under test and uses a job aid to select the test programs to be run. Connection with the vehicle is either via a built-in connector for those vehicles designed to be tested by STE-ICE, or via a transducer kit for vehicles not equipped with such a diagnostic connector assembly. The job aid used depends on the skill level of the mechanic; novices use manuals, the next level aid is a vehicle test card guide, and experienced mechanics use plasticized flip cards. The VTM includes a self-test routine to detect hardware failures within the VTM. The diagnostic test programs fielded with the STE-ICE are capable of testing the following: engine power, compression unbalance, starter current first peak, starter circuit resistance, internal battery resistance, pressure, vacuum, AC or DC voltage and current, AC frequency, resistance, ignition dwell, and ignition breaker continuity/ resistance. In spite of this carefully engineered approach, the STE-ICE is little used by organizational units. (None of the units that we visited in

USAREUR use it except a headquarters company where its use was made mandatory by the commander.) Reasons for non-use are many: neither mechanics nor supervisors are trained to use it; alternate troubleshooting procedures are faster if performed by a skilled technician (the sole exception is compression unbalance); the concern of the motor pool sergeant is productivity, not teaching mechanics how to use test equipment. In one respect, the STE-ICE has a characteristic similar to that previously observed for peculiar test equipment: it is more suitable as quality assurance equipment in quarterly services or inspections than as a troubleshooting tool.

The STE-M1 is a more extensive programmable test set, designed to test the gas turbine engine, transmission, hull and turret electrical systems, and turret stabilization and fire extinguisher systems. The set and its accessories are packed in seven large, but portable, molded cases. Five of these cases contain adaptors and cables; two cases contain the test equipment proper. One of these contains the VTM and associated cables, transducer kit (for hook-up) and set communicator; the second contains the controller interface box with connectors to hook up to the VTM as well as the tank. The STE-M1 was intended for use in two modes: symptom-oriented testing (to isolate a detected failure) and performance-oriented testing (to check out operational status as done in preventive maintenance checks and services). One of the chief problems with using the STE-M1 in the first mode, however, is to decide where to hook it up to the tank. Due to the high degree of interconnectivity or integration of the tank subsystems and the limitations of BIT/BITE, the average mechanic has difficulty interpreting the observed failure symptom and matching it with one of the failure symptoms descriptions (over 250) listed in his job aid. Use of the STE-M1 is taught in the mechanic's entry-level training course. But failure symptom interpretation by the unskilled apprentice remains, in most cases, pure guesswork and this, of course, is reflected in extended troubleshooting time.

The second major problem with using the STE-M1 is that even after it has been hooked up correctly, 50% of the time it will not fault isolate to a single LRU. Instead, it will identify an ambiguity group, usually comprising three LRUs. The mechanic must proceed with alternative troubleshooting procedures to find the true culprit. Because the high cost of the LRUs makes the traditional trial-and-error approach unaffordable, the alternative procedures require using schematics and common TMDE.

The third problem with the STE-M1 is the quality of the test programs. Significant improvements have been made since (DT/OT III), but a number of problems remain. The test programs use what is referred to as a "top down serial logic." What this means in practice is that the program stops when it finds a failed component even if that failure is caused by failures or out of tolerance conditions in other components. Removal and replacement of the identified component does not solve the problem: the same component will keep failing until the other components which cause the problem have been replaced. The present testing logic never finds those. (In contrast, the test programs for the M2 and M3, taking advantage of the lessons learned on the M1, follow a different, "bottom-up logic"; i.e., in the presence of multiple failures, the root causes are identified and replaced first.) The limited memory capacity of the STE (8K bits) precludes further expansions of test programs.

The fourth problem with using the STE-M1 concerns the operational environment. The test set is bulky due to many cables and adaptors. When the equipment is hot, properties of the electronic circuitry change, but the testing logic is not programmed to accommodate such changes. As a result, STE diagnostics in those circumstances tend to be erroneous. Just relying on STE for diagnosing the problem requires waiting until the circuitry cools down. Another practical problem is the limited authorization of the STE. Lacking a serious analysis of test workload, the Army authorized one test set per company supporting 17 tanks. The consensus is that at least two sets are required to avoid waiting times, even ignoring the current support problems of STE itself.

Unfortunately, due to the complexity of the M1 design, even an experienced mechanic may have no choice but to use the STE for at least localizing the problem. It is not possible to exercise the option of not using the STE-M1 (in contrast to the STE-ICE) for a significant portion of the failure symptoms. Yet, the STE-M1 does not eliminate the need for skilled technicians to troubleshoot M1 failures.

TROUBLESHOOTING SKILLS

Even when weapon systems are designed with good testability characteristics and the test equipment is suitable and available, maintenance personnel must be proficient troubleshooters to make fix-forward work. More importantly, when testability and test equipment are poor, the skill of the maintainer must compensate to diagnose malfunctions and return the weapon system to serviceable condition. The high NEOF rates testify to the inability of Army mechanics, especially those at the organizational level, to troubleshoot effectively. The root causes of that deficiency are two: the manpower authorization system and the training system.

Manpower Authorizations

The methodology by which the Army determines maintenance manpower authorizations has been criticized for many years. The Army is aware of the shortcomings of the manpower authorization criteria (MACRIT) process, so we do not need to elaborate on this point. The Army is still testing a new approach using simulation models. We have no up-to-date information on the progress of this test which was planned for a brigade slice of equipments. The information we received from the Army Logistics Center (which is responsible for the effort) suggests that the new approach does not address relationships between skill levels, ability to perform a task, and maintenance task time. However, such refinements could be added to the model. We believe that the modeling approach would provide the Army with a much needed capability to assess maintenance manpower requirements, including those associated with different maintenance concepts, such as fix-forward.

The planned changes to the MACRIT process, however, do not affect the logic for skill level authorization which is based on staffing grade tables: skill levels authorized in a maintenance unit are more a function of the number of people with the same military occupational specialty (MOS) in the unit than the difficulty of maintenance tasks. Thus, because organizational level maintenance tends to be decentralized (i.e., many units comprised of small numbers of personnel) and higher maintenance categories increasingly centralized, journeyman or supervisor skill levels (E-5 and E-6) are scarce at the organizational level. Yet, the organizational level maintenance tasks are becoming more difficult due to testability shortfalls which are more serious at the system level (organizational maintenance) than at the component level (DS/GS maintenance). *The Army's philosophy* is that organizational maintenance be done, primarily, by skill level 10 (paygrades E-3 and E-4) personnel. There is a good reason for this philosophy: the personnel system and its pyramidal structure more or less mandates it under the present job design (MOS) structure. About 60% of the current Army personnel inventory is non-career personnel (i.e., with less than four years of service, excluding those who have extended their first-term enlistment contract beyond four years).

Because virtually all maintenance MOSs start at the bottom (i.e., accessions into each MOS are primarily at the E-1/E-2 level, directly from entry-level training), their career content reflects the Army-wide average. And because maintenance intensity is highest at the organizational level (roughly 80% of the maintenance manhours associated with a weapon system are consumed at the organizational level), most of the organizational maintenance billets must be skill level 10.

To illustrate this fundamental problem, we have analyzed the maintenance manpower requirements in the new Division 86 table of organization and equipment (TOE) structure (authorizations are influenced by the personnel inventory and tend to be somewhat less than TOE requirements, especially in the higher grades). We assumed a wartime situation with all maintenance teams deployed forward, including maintenance support teams and battle damage assessment teams from corps GS units. (For the latter, we used draft plan TOEs documented in: U.S. Army Logistics Center, "Restructured General Support, Maintenance Support Battalion, Automated Unit Reference Sheets," Fort Lee, VA, June 1981). Table 4-2 and Figure 4-3 summarize our findings pertaining to tracked vehicle and turret maintenance in the Heavy Division (six armor and four mechanized infantry battalions). Back-up data are included in Appendix E. We note the following:

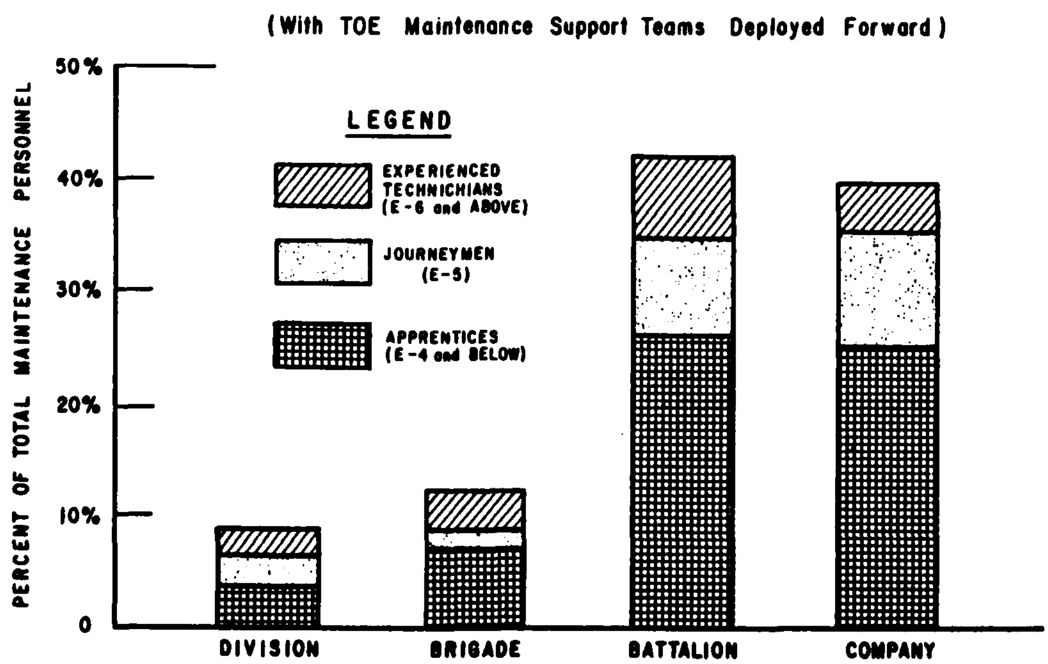
- On an individual maintenance unit basis, the skill level mix becomes richer further to the rear. Maintenance companies have one experienced technician (skill level 30 or 40), battalion maintenance platoons have six (including the Quality Control section which will perform battle damage assessment in wartime), brigade support battalions nine (not counting one E-8 supervisor and one warrant officer), and the divisional maintenance battalion sixteen (not counting three warrant officers).
- On a maintenance echelonment (geographical area) basis, however, the density of maintenance units in a division slice increases the closer one gets to the front: 1 maintenance battalion in the division area, 3 brigade support battalions in the brigade support area, 10 battalion maintenance platoons in the battalion trains area, and 40 maintenance companies in the company area.

TABLE 4-2. MAINTENANCE SKILL LEVEL DISTRIBUTION BY ECHELON (HEAVY DIVISION)[1]

MOS	DIVISION SUPPORT AREA	BRIGADE SUPPORT AREA	BATTALION TRAINS		COMPANY AREA	TOTAL
Tank Mechanics (63E, 63T)	—	--	184		264	448
Turret Mechanics (45E, 45T)	—	--	20		120	140
Mechanical Repair (63G, 63H)	43	65	124		--	232
Turret/Fire Control Repair (41C, 45G, 45K)	29	39	72		—	140
Total Maintenance Personnel: ORG	—	--	204		384	960
Total Maintenance Personnel: DS/GS	72	104	196		—	
Skill Level Distribution Within Echelon (%)			ORG	DS		
E-6/E-7	16.7%	26.0%	29.4	5.1	10.4%	15.5
E-5	22.2	11.5	13.7	24.5	25.0	20.8
E-4/E-5	61.1	62.5	56.9	70.4	64.6	63.7
TOTAL	100%	100%	100%	100%	100%	100%
Skill Level Distribution Across Echelon (%)						
E-6/E-7	8.1	18.1	47.0		26.8	100%
E-5	8.0	6.0	38.0		48.0	100%
E-3/E-4	7.2	10.6	41.6		40.6	100%

[1]Table assumes forward deployment of all TOE maintenance teams, including reinforcement from Corps Maintenance Support Battalion (RGS). For detailed backup data, see Appendix E. Data exclude TOW missile support.

FIGURE 4-3. DISTRIBUTION OF NUMBERS AND SKILL LEVELS OF MAINTENANCE PERSONNEL IN HEAVY DIVISION TO SUPPORT TRACKED VEHICLES



- The result is that, both in terms of absolute numbers and percentage distribution of skilled personnel, maintenance capability is clearly concentrated forward: the battalion trains and further forward areas have 82% of the total divisional maintenance personnel, 74% of the most experienced personnel (E-6 and E-7), and 82% of journeyman technicians (E-5).

- In spite of this forward bias, the percentage of personnel in each area who are apprentice-level technicians is virtually constant: 64% of maintenance personnel in the battalion trains area and further forward is apprentice-level, 63% of brigade support area personnel, and 61% of division support area personnel.

In other words, while the Army's logic for allocating skill levels on a micro basis (by unit) appears irrational, on a macro basis (divisional echelonment) it turns out to be very rational. The personnel system would not support increasing the mix of higher skilled personnel in forward areas without severely cutting into the little that is available in the rear. The dependence on maintenance performance by apprentice-level personnel in the forward areas is thus unavoidable without fundamental changes in the overall MOS structure.

The Army has attempted in some cases to influence the maintenance characteristics of a new weapon system by specifying explicitly in the development contract that the system be maintainable at the organizational level by skill level 10 personnel (e.g., in the case of the M2). If properly specified, tested, and evaluated, this would seem a good approach to effect a linkage between maintenance task difficulty and authorized skill level -- a linkage which is absent in the authorization process for reasons outlined above.

The scarcity of experienced personnel in forward maintenance units has one more untoward effect: it makes the conduct of effective on-the-job training (OJT) very difficult. The Army's growing reliance on OJT increases the need for higher skilled maintenance personnel, especially in organizational and forward direct support maintenance units.

Individual Technical Training

The Army's training approach is characterized by minimum entry-level, formal school training. This training is task oriented and limited to those tasks (especially in the area of safety) which cannot be taught in the field. Much of this training is self-paced. Most of the skill training requirements were exported to the field through development of extension training materials, soldier's manuals, Commander's Manuals, and "new look" technical manuals. The field units, however, were not provided with the means to conduct a supervised OJT program: they are already short of skilled technicians, and they interpret their mission as weapon system readiness, not personnel training, especially at overseas units with high readiness requirements. The OJT problem is exacerbated by relatively high personnel turnover and the increasing gap between skills and knowledge required and what is learned in entry-level training.

There are many different ways in which this situation could be improved. For example, some U.S. Army Forces Command (FORSCOM) units could be given the training mission at the expense of readiness, with advanced individual training (AIT) graduates first trained by FORSCOM before they are assigned to overseas units. (Of course, this would detract from the ability of FORSCOM units to meet contingencies.) Alternatively, the Army could adapt the Air Force's Field Training Detachment concept and provide OJT instruction staff (beyond the Modified TOE (MTOE)) to each divisional and non-divisional unit. Or the regional training centers such as the 7th Army Training Center (ATC) in Vilseck could be expanded with more mobile training teams and/or mandatory attendance at short technical courses for each maintenance MOS.[1]

In addition to beefing up OJT, higher skill level technical training at a formal school would seem a necessity. There are some skill level 3 courses for selected MOS which are technical, but the majority of higher skill level courses given today under the non-commissioned officer educational system consist of supervisory skills. There is a need for both. Fort Gordon recently started with a multi-level training concept. We believe such a concept needs to be applied Army-wide to all maintenance personnel: it keeps front-end training cost low and provides an incentive for reenlistment.

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[1]The 7th ATC training program was redirected in 1980 to a "train the trainer" concept. Previously it gave 4- to 6-week courses for organizational maintenance personnel, especially in troubleshooting. These courses were very well received, but the resulting improvement to maintenance performance was often small because the mechanics were not permitted by their supervisors to apply what they had learned. An additional factor was that unit commanders were reluctant to send their best mechanics to these courses, given the existing shortages and need to produce. As a result, students attending these "sustainment training" courses at 7th ATC tended to consist mostly of "turkeys," to quote the instructors. This explains the rationale of the train the trainer concept.

5. BATTLE DAMAGE ASSESSMENT AND REPAIR

The fix-forward maintenance concept is intended (1) to limit evacuation of not-mission capable weapon systems to the rear, both in terms of numbers of systems evacuated and depth of evacuation and (2) to repair systems rapidly, when they are repairable, and return them to combat. The concept emphasizes the need for battle damage assessment in forward echelons to determine which weapon systems can be repaired on-site, which are repairable but must be evacuated, the proper echelon to which repairable systems are to be evacuated, and which systems are not economically repairable but must be cannibalized for parts. Development of battle damage assessment and repair capabilities, however, has so far received little attention in the Army.

Battle damage assessment and repair are special skills that cannot be expected from maintenance personnel (be they organizational level mechanics or DS/GS repairers) without special training, documentation of field-expedient repair techniques in special manuals, peculiar tools and repair kits not required for peacetime maintenance support. For complex equipment, the limitations of automated tests (BIT or ETE) in fault isolating multiple failures, also play a role. Battle damage would normally include multiple failures, necessitating manual fault isolation procedures not necessary (and not documented) for peacetime reliability failures, which mostly occur as single failures.

The commodity commands, with support of the Army Materiel Systems Analysis Agency, do perform research on battle damage for each weapon system, but the effort is to determine combat parts stockage requirements. With the exception of one command, they have neglected other aspects of battle damage repair requirements.

The sole exception is the Aviation Research and Development Command (AVRADCOM), which has been sponsoring an active research and development program in helicopter battle damage repair by its Applied Technology Laboratory (ATL). This program includes development of a combat maintenance manual (planned for fiscal 1983) which includes structural, component and wiring inspection and repair techniques for currently fielded helicopters; procedures for efficient cannibalization of damaged aircraft; tools and test equipment required for battle damage repair; repair kits for hydraulics, electrical, and structural repairs; and design concepts for future Army helicopters to facilitate battle damage repair. The overall combat maintenance concept is based upon having skilled battle damage assessors available at the unit level to make accurate defer/repair/replace/cannibalize decisions; having the capability to return battle damaged helicopters within 8 hours (AVUM) or 24 hours (AVIM) to an operable condition sufficient for at least 100 hours combat operations or for a one-time flight to a back-up repair facility; and having a back-up facility for more extensive repairs and for validating field expedient repairs when lulls occur between surges. The latter facility is the Aviation Classification Repair Activity Depot (AVCRAD), composed of three National Guard AVIM units which will be located in the COMMZ. (We have not studied the composition, capability and planned operating procedures of AVCRAD. The similarly configured Combat Logistics Support Squadron in the U.S. Air Force incorporates detachments and teams to be employed forward with various levels of capability.)

The extent and methodology of implementing ATL's battle damage repair concepts insofar as training requirements are concerned, have not yet been determined by TRADOC. Teaching and practicing the requisite skills in peacetime will, of course, determine the success (or failure) of battle damage repair in wartime.

AVRADCOM and ATL deserve recognition for their efforts, and the helicopter battle damage repair program should receive continued, high-priority support. Similar efforts should be initiated by other commodity commands, especially the Tank Automotive Research and Development Command.

6. CONCLUSIONS

The Army needs a fix-forward maintenance capability. Inventories of weapons and other end-items are too small to replace those that fail or are damaged in combat. In war, the only way to keep combat units properly equipped will be through rapid repair, well forward in the battle area.

The Army's maintenance policy, doctrine, plans and guidance envision a fix-forward capability that would minimize the time major equipments are inoperable. But maintenance practices have not lived up to the intent of the policy, doctrine, plans and guidance: the Army's fix-forward capability falls far short of its needs. To correct the situation, the Army must take four actions:

(1) Dramatically improve the capabilities of forward-echelon maintenance units

(2) Establish battle-damage assessment and repair capabilities

(3) Clarify fix-forward maintenance policy

(4) Improve the testability of Army weapons.

The remainder of this chapter discusses each of the actions.

IMPROVE FORWARD ECHELON MAINTENANCE CAPABILITIES

The evidence is overwhelming: forward-echelon maintenance units, especially organizational level units, are not performing their missions effectively. Too much maintenance that should be done well forward is migrating to the rear, even in peacetime. The reason appears not to be lack of manpower, but inability to quickly and accurately diagnose equipment failures. In the past, rear-echelon maintenance units did the difficult component repairs requiring the highest skill levels. Today, the most demanding tasks, requiring the highest skills, are weapon system troubleshooting done by the organizational and forward direct support units. Yet most maintenance personnel in forward echelons are apprentices, grades E-3 and E-4. They were not taught troubleshooting in school, they have received little or no on-the-job training, and they have had insufficient experience to develop the skills on their own. Their test equipment and other diagnostic aids are often either unsuitable for the tactical environment in which they operate or inoperable for lack of spares or maintenance.

The Army must either change the manpower authorization criteria to allow assignment of higher grade (and, therefore, higher skilled) maintenance personnel to the organizational level or give the lower grade personnel better training in system troubleshooting. Concurrently, the Army must provide more suitable and available test equipment to forward-echelon maintenance units. By suitable, we mean equipment designed for the highly mobile, time constrained, and often hectic maintenance operations in maneuver battlalions. By available we mean well enough supported by maintenance and spare parts or by operational float equipment to assure it is operational when needed. These measures -- better training, better test equipment, and better support for test equipment -- are the keys to improving the effectiveness of forward-echelon maintenance units so they can, in fact, fix-forward.

ESTABLISH BATTLE DAMAGE ASSESSMENT AND REPAIR CAPABILITIES

Battle-damage assessment and repair are needed only during wartime, but the Army must plan and train for them during peacetime. Except for helicopters, the Army has done little to develop battle damage repair capabilities for major weapon systems. For the most part, the focus of the Army's battle-damage analysis has been limited to estimating war reserve spare parts requirements. For selected systems that would be especially susceptible to battle damage, the Army must expand its analysis to include inspection procedures for assessing battle damage, field-expedient repair techniques, special tools and repair kits. The Army must also decide which maintenance units and occupational specialties will perform battle damage assessment and repair and train them to do the job. A good approach might be to assign the mission to selected Reserve or National Guard maintenance units.

For future new systems, battle-damage repair requirements should be addressed as an essential program requirement. Systems should be designed for rapid replacement of damaged elements, and program managers should be responsible for developing battle damage assessment and repair capabilities.

CLARIFY FIX-FORWARD MAINTENANCE POLICY

The Army has espoused fix-forward for at least seven years, but much confusion remains about what it is and how it is to be implemented. To clarify its maintenance policy, the Army must first draw the distinction between on-equipment, or end-item, repairs and off-equipment, or component, repairs. The concept of fix-forward should pertain only to on-equipment repairs needed to quickly return end-items to operational condition. Off-equipment repairs should be done wherever they can be accomplished most economically (considering requirements for skills, test equipment, parts, etc.) without interfering with combat operations; that usually would not be forward in the battle area.

Next, the Army must revise its criteria for making level of repair and task allocation decisions to ensure that decisions made using those criteria are consistent with fix-forward. Special attention must be given to the repair time constraints of a fix-forward strategy and to the types of test equipment and maintenance skills that exist in forward-echelon maintenance units.

Finally, the Army must make realistic estimates of the wartime workloads of maintenance units and either size units to handle the load or reallocate tasks. The workload must include all wartime maintenance activities: repair of failed equipment, battle damage repairs, recovery operations, cannibalization, test equipment repairs, etc. Sizing of units and task allocation must take into account all constraints on the amount of productive time forward-echelon maintenance personnel can be expected to apply to maintenance tasks: travel time, unit movements, non-maintenance duties, etc.

IMPROVE WEAPON SYSTEM TESTABILITY

The inability of maintenance personnel to rapidly and accurately diagnose the cause of a system's failure is the biggest obstacle to fix-forward. Better training of maintenance personnel and better test equipment are needed and will greatly improve the situation. But the root cause of the problem is poor weapon system design -- design that does not permit rapid, accurate troubleshooting.

For most systems in the Army's inventory, the opportunity to improve testability through redesign has been lost. Shortfalls in testability must be compensated through improvements in maintenance diagnostics software, troubleshooting aids, training, and test equipment. Perhaps most important for current systems is a good analysis of their testability problems and redesign of the technical manuals, troubleshooting procedures and training courses; many are based on maintenance procedures that do not reflect the true -- experienced -- failure characteristics of the systems.

For new systems, the Army must approach testability differently than it has in the past. Rather than state specific requirements, such as BIT coverage and accuracy, early in the concept exploration and validation phases, it should specify a 100% diagnostic capability that is consistent with its fix-forward maintenance doctrine. Prior to full-scale engineering development, the system designer should justify, based on engineering trade-off studies, the planned allocation of diagnostics to BIT/BITE, electronic test equipment, and manual troubleshooting procedures. Prior to production, the program manager not only should validate via test and evaluation the most critical elements of the diagnostic capability, but should initiate a management plan to monitor and improve testability during follow-on test and evaluation and the early years of system operation. The management plan is especially important because diagnostics can only be thoroughly tested by operation of the system in the field by units which use them.

7. POSTSCRIPT: VOIDS IN DoD POLICY

The actions we have recommended to improve the Army's fix-forward capabilities are well within the Army's authority and responsibility. No change to DoD policy is required. However, the fix-forward story -- the issues, the problems, and the frustration -- deals with an important logistics responsibility that is sadly lacking DoD direction: direct maintenance.[1]

DoD Directive 4151.16, "DoD Equipment Maintenance Program," deals primarily with depot level maintenance. It alludes to direct maintenance only in paragraph VI.F.:

> "Equipment maintenance will be performed at the point of generation in order to assure attainment of established readiness objectives and to assure self-sufficiency among operating units. In those cases where costs to establish and sustain self-sufficiency at the point of generation would exceed benefits to be realized, equipment will be performed at other appropriate locations. Level of repair analyses will be performed to assure effective distribution of work among activities."

That paragraph is not only inadequate, it is wrong. Readiness objectives and self-sufficiency are achieved by a combination of repair and replacement of components that cannot be efficiently or effectively repaired by the operating unit. Cost is only one of many factors to weigh in deciding repair responsibilities. The purpose of level of repair analysis is to decide which maintenance echelon can most efficiently and effectively repair an item; it is not "...to assure effective distribution of work among activities."

In a previous report, "Surface Ship Intermediate Maintenance," LMI noted that "Current policy seems to foster a direct maintenance organization whose

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[1]Direct maintenance is all maintenance except that performed at the depot level (i.e., organizational and intermediate maintenance).

role is dictated more by peacetime cost-effectiveness considerations than by wartime readiness objectives." We recommended that "ASD(MRA&L) initiate a joint OSD/Service forum to discuss alternatives for improving the readiness of direct maintenance units to execute their wartime responsibilities."

The report set forth four key topics for the discussions: (1) performance of direct maintenance by military units during wartime, (2) establishment of mission requirements for intermediate maintenance organizatons, (3) prescription of consistent peacetime and wartime maintenance missions for all direct maintenance organizations, and (4) restriction of the direct maintenance roles of DoD civilian and contractor activities.

The Army's inability to achieve fix-forward capability underscores the need for more explicit and comprehensive DoD policy on direct maintenance. To the agenda suggested in "Surface Ship Intermediate Maintenance," we would now add: (1) distinction in maintenance policies and doctrines between repair of end-items and repair of components (i.e., between on-equipment and off-equipment repairs), (2) prescription of level-of-repair and task allocation criteria, and (3) assignment of battle-damage assessment and repair responsibility.

The last topic, battle damage assessment and repair, is especially important, not only to the DoD maintenance program, but to the design of weapon systems and their integrated logistic support (ILS). Systems susceptible to battle damage should be designed for rapid restoration to operational condition, but unless battle damage restoration measures coincide with reliability failure correction measures, they are apt to be given scant attention in either new acquisition or product improvement programs. (See the AH-1S helicopter example in Appendix F.) Yet, DoD acquisition policy ignores the topic.

The ASD(MRA&L) should fill that void by:

- Revising DoD Directive 5000.39, "Acquisition and Management of Integrated Logistic Support for Systems and Equipment," to assign program managers responsibility for battle damage restorability as an integral part of ILS, and

- Revising MIL-STD 1388, "Logistic Support Analysis," to include battle damage assessment and repair requirements.

APPENDIX A

TESTABILITY INDICATORS OF SELECTED ARMY EQUIPMENT

Lack of testability is a serious problem in the Army today. It is one of the root causes of ineffective and inefficient maintenance. With the increasing electronics content of new weapon systems, and the increasing cost of spare components, the problem is becoming more and more critical. This appendix illustrates the extent of testability shortfalls on the basis of selected examples: the new systems we examined in the course of this study and some of the current systems or equipment they are replacing. Where detailed information was available, we also explore the reasons for such shortfalls.

Consider first, shortfalls in fault detection capability as measured in terms of the fraction of faults detected (FFD). Examples of currently fielded equipment include the following:

- VRC-12 Series Combat Net Radio: About 80% to 90% of these radios are out of alignment, causing lack of communication capability. First fielded in the mid-1960's, this problem finally surfaced in the mid-1970's. Improved electronic test equipment (ETE) and checkout procedures were developed to correct the problem, but fielding and implementation of this improved diagnostic capability has been slow. In 1981, during the OT II of the infantry fighting vehicle, 90% of the time the IFVs and M60 tanks participating in the test could not even communicate over distances of only 100 meters.

- M65 Airborne TOW Missile System (TMS): Due to built-in test (BIT) shortcomings, the fault detection rate is only 85%. That is, for the 15% of the time that the BIT indicates no system failure, the system is actually out of tolerance, causing inability to shoot the missile or lack of control over the missile in flight. A more complete checkout procedure is available using ETE (actually, a breakout box), but that procedure is too time consuming (16 hours for two technicians) to be used other than for isolation of detected failures and in-phase inspections. Though the AH-1S Modernized COBRA will remain in the inventory through the 1980's, there are no plans to improve the fault detection capability of the M65 TMS. (The Improved TOW missile program does not include improvements to the M65 TMS diagnostics.)

- M60A3 Tank Gun Fire Control System: The BIT addresses only 80% of the electronic components, some of the tests have inherent limitations, and mechanical/hydraulics interfaces are not addressed. As a result, for the 15% to 20% of the time that the BIT indicator on the gunner's control unit shows a green light ("BIT OK"), the system is out of tolerance. This reduces the first-round hit probability when the gun is fired in precision engagement mode to a value identical to that of the M60A1. The M60A3 was, of course, bought primarily for its precision engagement capability. The reported fully mission capable rate for M60A3 tanks in USAREUR is relatively high because the readiness criteria do not require investigation of the status of the fire control system beyond that indicated by BIT. More detailed checkout procedures using ETE are applied in quarterly inspections or in corrective maintenance. Most of the tanks in USAREUR are so inspected before they are sent by train to the shooting range in Grafenwöhr, so the BIT deficiency does not normally surface in peacetime. The contractor has recommended a breakout box to improve failure diagnostics (both fault detection and isolation), but the Army has no plans to procure it.

The Army's new weapons systems, insofar as field data are available, exhibit better fault detection characteristics than the systems they replace. For example, the FFD for the M1 tank has been estimated at 90%. Contract specifications for the new systems included fault detection requirements in the range of 90% to 95% FFD. Indications are that they are achieving close to the levels specified.

The problem of false alarms is serious for some systems but difficult to analyze because of a lack of event documentation and because the consequences (false removals) may be attributable to lack of fault isolation capability (at least in those systems not possessing distributed BIT). Examples include:

- Helicopter Engines, Transmissions, Gearboxes: Chip indicators are the only built-in test equipment (BITE) (besides standard instrumentation such as temperature and revolutions per minute gages) available to monitor the status of oil-wetted components in the propulsion system of current Army helicopters. This diagnostic hardware comprises magnetic chip-detector plugs mounted in the turboshaft engine, the transmission and the tailrotor gearboxes, and cockpit-mounted chip warning lights wired to the chip detectors. When oil debris accumulates on the chip detector, the chip-indicator light comes on; by peacetime standard operating procedures, the pilot should then abort his mission ("precautionary landing"). The design of this BITE, however, does not provide adequate discrimination between the type of debris indicative of an impending mechanical failure and the debris associated with normal wear and tear or fuzz. As a result, only 12%

of the chip light illuminations for the AH-1/UH-1 fleet are significant, meaning they result in component removals; 77% are due to fuzz or normal debris; 21% are caused by faulty wiring. The off-line diagnostics, consisting of ferrographic and spectometric analysis of oil samples (taken at 25 operating hours intervals on all aircraft or after chip light illuminations) performed by the Army Oil Analysis Program (AOAP) laboratories, also have a poor validity. For the T53 engines (installed on the AH-1/UH-1 and since 1980 authorized on-condition maintenance), 50% of impending failures which AOAP should detect are undetected, while 8% of the engines removed and sent to depot based on AOAP test results show no evidence of failure (NEOF). For the T55 engines (installed on the CH-47 and still on time between overhaul limits), these figures are 61% and 4%, respectively. The overall shortfall in fault detection capability is evidenced by the following unnecessary removals and returns to depot (fleetwide averages): 23% for engines, 38% for transmissions, and 46% for gearboxes. Improved BITE technology is available, as demonstrated by the Army's Applied Technology Laboratory in 1980. This technology, using flow-through, burn-off chip detectors in combination with finer filtration, would elminate nuisance chip light indications. Improved BITE would also permit eliminating AOAP test results as a cause for component removals (as the Air Force and Navy have done).

- Complex Digital Systems: Complex digital systems with BIT have a notorious false alarm problem. For example, modern avionics show an average false alarm rate ranging from 10% to 90% depending on the type of system involved (both in commercial and military use). This type of equipment is just beginning to enter the Army. One example is the lightweight Doppler navigation system (AN/ASN-128) installed on the BLACKHAWK and planned for modernization of other helicopters. This system consists of only three line replaceable units (LRUs): radar receiver-transmitter antenna, signal data converter, and computer display unit. Nevertheless, early field data show a 27% NEOF rate for the LRUs returned to the contractor. The system is under a four-year reliability improvement warranty (RIW) so that the only field maintenance currently consists of replacing LRUs deemed to be faulty on the basis of BIT (no other test, measurement and diagnostic equipment (TMDE) is used). While no specific false alarm data are available, the NEOF rate would seem too high to be just attributable to fault isolation problems. (It is noteworthy that the RIW contract includes a penalty clause of $200 per LRU tested NEOF by the contractor in excess of 25% or two per month.)

With respect to shortfalls in fault isolation capability, measured in terms of fraction of faults isolated (FFI) or fault isolation resolution (FIR), examples of currently fielded systems include the following:

- Improved HAWK (IHAWK): The testability shortfalls of the IHAWK air defense missile system and their repercussions on maintenance and support are documented in a previous LMI study (ML904). Briefly, the 1970 improvement from Basic HAWK to IHAWK included BIT with a contractual requirement of 90% FFI. Government acceptance tests confirmed this requirement was met, but in the actual field environment BIT is performing at the 60% FFI level. This gap in diagnostic capability was never corrected: both training and maintenance manuals assume BIT to perform as specified. The result is guesswork by mechanics in isolating faults; that translates into a high NEOF rate (about 40%). Thus, testability shortfalls are compensated by the supply system, but this demands unusual supply support programs in USAREUR with little wartime sustainability.

- M65 TMS: Compared to IHAWK this is a simple system (nine LRUs vs. several hundred), but its lack of testability causes a similar level of maintenance complexity measured in terms of NEOF rates. An engineering analysis shows that the BIT performance measured in terms of fault isolation resolution is as follows:

L	1	2	3	4	5	6	7	8	9
FIR(L)	3%	8%	17%	27%	39%	51%	66%	82%	100%

L = number of LRUs in ambiguity group

FIR(L) = probability of fault isolation resolution to ambiguity group of L or less LRUs.

For example, 27% of the system failures occurring in the field (i.e., failure frequency weighted failure modes) are isolated by BIT to four or less LRUs, including 10% isolated to exactly four. Thus, virtually all failures can be fault isolated only with the aid of ETE. The ETE fielded with the M65 TMS is the test set guided missile system (TSGMS), a "breakout box" with over 200 switch settings and meter readings, requiring 16 hours for two maintainers to perform the checkout procedures documented in 21 tables in the technical manual. The TSGMS was originally planned only for the intermediate maintenance level (AVIM), but was recently authorized also at the organizational level (AVUM) (at least in USAREUR) because 97% of system failures had to be referred to AVIM. The test set, while man-portable, is not transportable by truck without getting out of calibration. The reliability of the test set is poor and repairs of the TSGMS frequently entail a turnaround time of 120 days. It is not surprising that fault isolation is performed poorly, resulting in a NEOF rate of 45% (weighted average of the nine LRUs). Due to limited operating hours in peacetime, the supply system is capable of supporting this excess burden (the Pirmasens Missile Repair Activity in-theater provides backup intermediate and depot level support). In wartime, the situation would, of course, be different. The potential of a new type of diagnostic aid (stand-alone, interactive micro-computer with diagnostic software based on "fault tree" representation of the M65 TMS) to bridge the gap in diagnostics capability was demonstrated in 1980 and 1981. This aid (not test equipment) would permit elimination of the TSGMS, fault isolation resolution in excess of 90%

for single LRU, reduction of skill levels and maintenance/supply burdens, but the Army has no plans to field this type of aid.

- Ground Combat Vehicles: We have been unable to collect accurate measures of fault isolation shortfalls for currently fielded combat vehicles. Instead, proxy measures such as the percentage of troubleshooting tasks not performed by organizational maintenance personnel have been collected by means of interviews of a small sample of USAREUR units. Based on this data, the Improved TOW vehicle has a serious fault isolation shortfall: all on-equipment troubleshooting is performed by DS technical inspectors (normally, E-6 pay grade), not by organizational mechanics. For the M60A3 tank, the situation is less severe: by standard operating procedure, DS technical inspectors verify fault isolation performed by mechanics prior to component removal, they only need to assist in fault isolation in about 30% of turret failures.

The Army's new weapon systems indicate little improvement in fault isolation capability, suggesting that the increased emphasis on testability was insufficient to compensate for increased system complexity; but, at least, the need to compensate for these shortfalls is better recognized now than in the past.

- PATRIOT: Probably the most complex system the Army will be fielding in the 1980's, this air defense missile system has a design goal of 99% fault isolation and repair through LRU replacement at the organizational (battery) level. This was to be accomplished by the operator using BIT (75% FFI) and organizational maintenance personnel using diagnostic software (remaining 24% FFI). Assistance to isolate the remaining 1% failures would be available on-site from the in-theater contractor facility (PATRIOT Field Army Support Center), whose normal workload would be checkout and repair of LRUs. No organic intermediate maintenance (DS or GS) was planned (the originally planned GS capability for LRU repair was eliminated by program manager decision in 1978). Operational testing in 1979 demonstrated the need for a maintenance enhancement program to correct testability shortfalls. The current prognosis of this program is that BIT may attain 60% to 70% FFI and supplementary diagnostic software (including display aided maintenance procedures) another 20% to 25%, for a total fault isolation capability at the battery of about 85% to 90%. To reduce or eliminate the need for on-site contractor support, the Army is now planning an intermediate PATRIOT support unit to provide contact team assistance in troubleshooting the remaining 10% to 15% system failures. The revised USAREUR Materiel Fielding Plan shows that three of such "forward support elements" are planned (consisting of 1 warrant officer and 9 E-7 level technicians), one per air defense artillery group and each supporting 3 PATRIOT battalions. The PATRIOT Field Army Support Center (located at Miesau, which is in the COMMZ) includes a contingent of PATRIOT technicians (1 warrant officer and 15 enlisted) available as backup but primarily planned for component repairs. Battalion level PATRIOT operators (MOS 16T) and maintainers (MOS 24T) have grown from 32 to 46 (including 7 warrant officers). The shortfall in testability, then, is compensated by an increase in maintenance skills, rather than an increased demand on the supply system, as is the case for IHAWK.

- AN/TSQ-73 MISSILE MINDER: This air defense command and control system was fielded in 1979 with the high and medium air defense battalions and higher headquarters, a total of 16 systems theater-wide under the 32nd Army Air Defense Command in USAREUR. The original design required a two-level maintenance concept: fault isolation by the operator/ maintainer to a single module (printed circuit board (PCB) in this case) and PCB repair at depot (or, in USAREUR, the Pirmasens Communications Electronics Maintenance Center, which is a host nation support activity providing both GS and depot level support). The contract required that BIT and diagnostic software would isolate at least 90% of the system failures to an ambiguity group of ten or less boards (FIR(10) = 90%). It also specified a mean time to repair (MTTR) of 35 minutes or less (based on availability requirements computations). The contractor's attempts to meet these requirements have been unsuccessful as demonstrated by operational data. The fault isolation capability achieved, by best estimate, is FIR(15) = 75%, and due to this diagnostic shortfall, the MTTR (demonstrated) increased to 90 minutes. (Sample data collection shows the actual MTTR for a battalion-configured system is 1.70 hours). The diagnostics tools available to the operator/maintainer include:

  -- BIT to detect a system failure and to localize it to the proper subsystem. But the FFD is only 90% and localization is not always accurate. Resources were never spent to correct known shortcomings nor to update BIT for engineering changes which were frequent in the system's early years.

  -- Eight fault isolation routines, one of which the operator must load when BIT indicates a fault is detected. But due to physical computer memory size limitations (late 1960's design with maximum shelter dimensions given), the depth of fault isolation is limited to an average ambiguity group of 10-15 cards, with some groups extending to 300 cards (e.g., central processor unit).

  -- Fault catalog which specifies, for each fault stop code, the suspect boards to be tested by the operator. However, some fault stop codes generated by the fault isolation routines are not contained in the catalog; and the ambiguity group listed for some codes is incomplete, leaving out boards which were found in service use to be the actual cause of the system failure. Again, resources were not spent to correct known shortcomings or to reflect engineering changes.

  -- Module Test Set (MTS), which is a card edge tester to test each of the digital cards in the ambiguity group specified. But, this ETE, advertised as a fully automated, go/no-go card tester in the operator/maintainer training course, requires considerable skill because at least 12 different failure modes can cause the same indication on the front panel; i.e., a fault indication often does not mean that the card module under test is faulty.

-- Fault isolation modules, which are extra analog boards used to isolate failures through swapping and to verify that a fault has been isolated to the proper board. The shelter stocks one of each type (there are 187 different boards with a total count of 4,000 boards in the system) distinct from prescribed load list stockage. However, there is no management system in place to ensure that these modules are actually good.

The consequence of these diagnostic problems is a higher skill level requirement than originally planned. A contractor technician is required to isolate failures in certain subsystems (e.g., the remote interface equipment which resembles prototype engineering); a warrant officer for other subsystems; and at least three years hands-on experience for enlisted personnel to make themselves useful. Nevertheless, the boards returned to the Pirmasens Communications Electronics Maintenance Center for repair on the AN/USM-410 automated test equipment (ATE) show an NEOF rate of 25%. While system reliability is good (equipment mean time between failures (MTBF) = 145 hours, mission MTBF = 277 hours, both for battalion-configuration), mean downtime (MDT) is excessive (MDT = 296 hours), resulting in a poor availability (A_o = 0.48). The reported readiness is higher even though present readiness criteria include two non-peculiar systems (AN/GSS-1 acquisition radar with a notorious availability problem due to its obsolescence and AN/TPX-46 IFF (identification friend or foe) which has much lower reliability than TSQ-73 peculiar hardware). Thus, as in other examples, reported *readiness does not reflect the* extent of maintenance support problems caused by testability shortfalls. Some product improvements have been planned but, to our knowledge, do not address the system's lack of testability. Because the density of the sytem will be reduced to four in USAREUR with the fielding of PATRIOT, the need for on-site contractor support may be a less serious issue than it would seem at first glance.

- M1 ABRAMS Tank: Testability problems of the M1 tanks are documented in a recent LMI report (ML101) comparing the maintenance complexity of the M1 to that of the M60 series tanks. Briefly, testability requirements in the materiel need statement, and contractual systems specifications were limited to a FFD of 90%. Fault isolation capability requirements were not specified explicitly, but implied by a MTTR requirement of 1.4 manhours for the 90% faults detected and repaired at the organizational level. Repair time limits were further specified as 4 clockhours (8 manhours) for 90% of organizational repairs, and 12 clockhours (48 manhours, later reduced to 22 manhours) for 90% of DS repairs. Stringent design to unit price cost goals and accelerated development schedule contributed to limiting the testability design effort. This was revealed at OT II (conducted in 1978) which showed BIT/BITE performence at the 69% FFD level. Fault isolation capability was by design levied on ETE (not built-in), but the contractor developed test sets (a total of 8 peculiar test sets in various stages of development) were found unacceptable. Needed reliability, availability, maintainability-durability improvements of the tank were developed subsequently and evaluated in DT/OT III, conducted in 1981. In the intervening two-year period, the ETE was redesigned into the simplified test equipment (STE)-M1, combining the intended test capabilities of the six original, organizational level test set prototypes with a derivative of the existing STE-ICE (internal combustion engine) into a single test set. (The remaining two DS level test set prototypes were developed into the electrical system test set (DSESTS) and thermal system test set to fault isolate assemblies removed from the tank.) The external test points on the tank for hookup of the ETE were designed to minimize potential for error so that a unique adaptor is required for each test point. As a result, the STE-M1 is bulky; it is configured in seven man-portable cases containing test equipment (2 cases) as well as 140 adaptors and hook-up cables (5 cases). The STE-M1 (like the STE-ICE) is an ATE, using diagnostic software to fault isolate a subsystem failure to a removable assembly. But it represents a limited level of automation: the mechanic must still determine where and how to hook up the test equipment to the tank (the fault symptom list in the technical manual is his main aid) and direct what test routines are to be executed (following test procedures in the technical manual).

Given this background of testability shortfalls only identified by end of full-scale engineering development and the resulting late but accelerated development of test equipment, it is clear that OT III data on maintainability must be interpreted with caution. The diagnostics software was incomplete; test procedures for using STE-M1 (including fault symptom list) had numerous shortcomings; and alternative troubleshooting procedures to compensate for shortcomings in the diagnostic capability provided by BIT/BITE and STE-M1 had not been documented and validated. The prognosis is that the current BIT/BITE is capable of achieving a 90% FFD level; that the false alarm problem noted in OT II (primarily in fuel controls), but much improved in OT III, can be alleviated; but that fault isolation shortfalls will cause on-equipment repair times to exceed the orginally specified limits for more than 10% of detected failures. The consensus estimate of fault isolation resolution potential by STE-M1 and mature diagnostic software (without redesign of the present test points on the tank) is FIR(1) = 50% up to FIR(3) = 95%, indicating the need for skilled mechanics using manual TMDE to fault isolate 50% of the detected failures to a single assembly. OT III data indicated 24% of system failures to require a repair time in excess of four clock hours, 11% in excess of six clock hours active maintenance time (without delay times for obtaining parts or assistance or contact team travel to the site). Even after planned improvements in manuals, software and training have been implemented, a portion of M1 reliability failures will clearly entail a repair time in excess of the fix-forward time limit for the battalion trains area. The key issue is that the repair time cannot be estimated when a failure is detected: it may be one hour or less active maintenance time (P = 0.30) or five hours or more (P = 0.16) (probabilities based on OT III data).

- M2 BRADLEY Infantry Fighting Vehicle: As in the case of the M1, testability was not addressed quantitatively in the original system specifications for the M2. Instead, the following repair time limits were specified: 95% of organizational repairs in less than 4 hours, and 90% of DS and GS repairs in less than 12 hours (limits on preventive maintenance requirements and maintenance ratio were also specified). Fault detection requirements included BIT for TOW missile guidance electronics and BITE indicator panels for mobility components (fuel filter, engine air cleaner, oil pressure, coolant level and temperature, transmission oil temperature) and stabilization system. Fault isolation specifications were limited to requiring provision of necessary test points to hook up TMDE or ETE; test points were required for the electrical system, intake manifold, fuel system, cooling system, crankcase ventilation system, engine timing, transmission, vehicle kits, and one test connector each for the turret drive system, TOW system and gun control unit. The intent to simplify maintenance was articulated by directing that the vehicle design be such that maintenance tasks would not exceed skill level 10 at any maintenance echelon. The full-scale engineering development contract specified that the vehicle be designed with diagnostic connector assemblies to interface with the STE-ICE for fault isolation of all vehicle replaceable assemblies, but testability shortfalls were identified in the physical teardown maintenance evaluation of the full-scale engineering development prototypes in early 1979. This deficiency revealed the need for an enhanced derivative of the STE-ICE, the STE-FVS (fighting vehicle systems) to enable mechanics to fault isolate turret failures. The diagnostic approach, then, is similar to that for the M1 tank: fault isolation is totally dependent on ETE, but the test equipment is so bulky and time consuming that a portion of system failures cannot be repaired in the company or battalion area within the given time limits. Based on engineering estimates, about 80% of reliability failures are in the turret, not the hull. Complexity of the M2 is comparable to that of the M60: it has about 303 test points (270 in turret, 33 in the hull) compared to the M60's 397 (the more complex M1 has 1,075 test points). A total of 99 test routines have been developed for the STE-FVS. Additional diagnostic requirements may be identified when the technical manuals are verified and validated in 1982. At the DS level, the same test set (DSESTS) supporting the M1 (12 LRUs) supports the M2 (13 LRUs). One test set (the TOW subsystem test set) is peculiar to the M2/M3. Two of the seven cases constituting the STE-FVS are common to the STE-M1, the rest contain M2/M3 peculiar adapters and cables. The plan is to develop a less awkward configuration in the future (STE-X).

- AH-64 APACHE: The Army's advanced attack helicopter (AAH) program had the tightest testability requirements specification of the seven weapon systems examined. The Phase 2 engineering development (post-source selection) specifications included a distributed BIT with 95% of failures detected per LRU and a false alarm rate of less than 3%. The development contract, however, did not require a formal demonstration that this requirement was achieved. For OT II (completed September 1981), evaluation of BIT performance was waived because the diagnostic software was incomplete. The contractor did provide an analysis showing that the design met the requirement of 95% FFD by LRU. An alternative assessment of BIT performance was reported in a recent LMI report (ML213-1, November 1982). The Army's Operational Test and Evaluation Agency interprets the OT II data as follows: FFD = 73%, FFI = 77%, and FAR = 11%. By consensus, the mature goal for fault isolation capability to a single LRU was set at 65% (Decision Coordinating Paper for production decision). This weapon system has a relative high complexity: about 120 black boxes and major components are monitored by the fault detection/location system; 20 of these are potted items and discarded at failure, the rest is composed of about 600 shop replaceable units, primarily PCBs. An AAH peculiar configuration of the Army's standard ATE (AN/USM-410) is used for fault isolating these LRUs. The plan is to perform LRU repair at the divisional AVIM: this is farther forward than the USM-410 was originally conceived to be used, but the cost savings (parts stockage) of moving the ATE from corps or COMMZ to division were shown to be substantial. (The USM-410 was RCA equipment designed for fixed plant use; though ruggedized for Army use, the system was never militarized and represents interim ATE until a better solution is found.) In the absence of data on the production versions of the most complex subsystems of the AH-64 (not assessed at OT II), the above assessment of testability is uncertain. OT II results include a system MTTR of 1.7 hours (goal is 0.9 hours) but 49% of the maintenance actions were performed with contractor assistance and two major subsystems were not representative of production configuration: The T701 engine planned differs substantially from the T700 engine used in the test, and the target acquisition designation sight planned will incorporate a different laser rangefinder/designator than the one tested. Test officials judged AH-64 maintainability as marginal.

- UH-60A BLACKHAWK: As a utility helicopter without weaponization the complexity of this system is relatively low. Maintainability of the advanced T700 engine received a great deal of emphasis. Nevertheless, based on a currently observed NEOF rate of 15% for the electronic control unit, there are troubleshooting problems. A new test set is being fielded to overcome this problem. Similarly, some of the new avionics (which were government furnished equipment items for the Utility Tactical Transport Aircraft System program) exhibit troubleshooting problems. For example, the AN/ASN-128 lightweight Doppler radar system has BIT to fault isolate to one of the three LRUs, but the LRUs returned to the contractor show a 27% NEOF rate. This radar is under a four-year contractor RIW program which may be a factor, but the RIW contract includes a $200 penalty per LRU for NEOF returns in excess of 25% or 2 per month. The only test available to the mechanic when the ASN-128 has a failure, is the BIT; there are no documented troubleshooting procedures using TMDE.

- AN/GSG-10(V) TACFIRE: This artillery fire direction system is a command control system first fielded in 1979, comprising the following end items:

    -- fire direction centers (FDC) located at division artillery (DIVARTY) headquarters, higher echelons (group and corps) and field artillery battalions; the DIVARTY FDC is housed in two S280 shelters containing digital computers and display devices, each battalion FDC is housed in one shelter.

-- battery display units (BDU) located one each per firing battery providing one way communication (printer) from the battalion.

-- variable format message entry devices (VFMED) located at divisional Tactical Operations Centers (TOCs) and fire support elements at brigade and battalion, providing two-way digital communication.

-- digital message devices which are hand-held devices for forward observers to transmit and receive digital messages.

The BDU (and possibly the VFMED in the long term) will be replaced by the more advanced battery computer system under a modular TACFIRE improvement program currently in progress.

Testability for the FDC was planned to provide a 90% FFI capability, permitting most repairs to be performed by the operator/maintainer in the shelter. The design approach was similar to that described for the AN/TSQ-73 which has a comparable hardware configuration (two major differences are that the TSQ-73 shelter has two central processing units (CPUs) in contrast to TACFIRE's one CPU, and the TACFIRE hardware is dismountable from the shelter while the TSQ-73 hardware is not, resulting in less interconnecting cables for the latter): BIT for fault detection in a particular component of end-item (CEI); loading of a CEI-peculiar diagnostic routine to fault isolate to an ambiguity group specified in a fault catalog and identified by a fault stop code; use of the MTS to fault isolate to a single board (if digital) or using fault isolation modules to find the faulty board (if analog). In actuality, the BIT and maintenance diagnostics are performing at only 60% FFI level. (One major reason for this testability shortfall is that the contractor's original assumption that virtually all failures would occur within circuit boards rather than in wiring harnesses turned out to be wrong.) In addition to this testability shortfall, a number of additional factors cause a further reduction of the percentage of system failures repaired by the operator/maintainer: the system can be operated in degraded mode permitting repairs to be deferred; proper use of the MTS requires higher skills than possessed by a skill level 10 operator; and firing missions pre-empt running diagnostic routines. The operator thus has a strong incentive to delay repairs until the system totally shuts down due to multiple failures at which point there is little he can do. The limited field data available to date confirm that the operator does less than 60% of repairs: in garrison (no time constraints) he does 50%, on exercises only 20%. The testability shortfall and peculiar operational factors indicated above result in excessive reliance on DS contact team support. By Modified TOE (MTOE), a two-man TACFIRE dedicated contact team (MOS 34Y, ex-34G) normally colocated with (but not part of) the forward support company, DS, in each brigade support area provides on-site support to the FDC. To minimize system downtime, this normally entails replacing an entire CEI (not PCB), transporting it to the division rear area where the rest of TACFIRE DS maintenance (two men) is located (part of the headquarters and light maintenance company). This section has a hot mock-up (AN/USM-141 maintenance van) where the CEI is checked and repaired through board replacement (or, evacuated to depot), and boards are checked prior to evacuation to depot or GS to minimize unnecessary (NEOF) returns. Wartime sustainability of the TACFIRE FDCs, then, depends on on-site contact team assistance at each battalion (but MOS 34Y is critically short with only three of the eight MTOE billets filled per division for TACFIRE support), sufficient stockage of CEIs (but only limited floats currently authorized) and circuit boards (current prescribed load list/ authorized stockage list based on 48 hours turnaround time from GS).

APPENDIX B

ASSESSMENT OF MAINTENANCE SUPPORT PROBLEMS

This appendix summarizes information on maintenance support problems in Army aviation and tracked combat vehicles. Tables B-1 and B-2 are based on the "USAREUR Aviation Command Review and Analysis Special Task Force," Final Report (Draft, April 1981). Tables B-3 and B-4 are based on a study conducted by The RAND Corporation: "Problems in Army Vehicle Maintenance: Results of a Questionnaire Survey," C. R. Harz, RAND Report R-2487-ARPA, June 1981. This study used a comprehensive (over 200 items) questionnaire which was pre-tested at several Army bases, distributed to FORSCOM, TRADOC, and USAREUR activities, and responded to by senior maintenance specialists at Maintenance Assistance and Inspection Team (MAIT), G4, and Director of Industrial Operations (DIO) organizations with an average military maintenance experience of 20.6 years. The response rate was 70% (95 out of 135 questionnaires sent out); the average time to complete the questionnaire was 3 to 8 hours.

Key factors, identified by the questionnaires as causing maintenance performance shortfalls, are the following (in priority order):

- Personnel (both operator and maintainer) training and motivation
- Management and supervision
- Skilled personnel shortages and turnover
- Organization, policy, and procedures
- Supply (repair parts and petroleum, oil and lubricants)
- Tools and test equipment
- Facilities
- Documentation and forms
- Vehicle storage
- Vehicle design characteristics.

The fact that vehicle design characteristics are currently deemed to represent the least important factor contributing to current maintenance performance shortfalls is cause for great concern about future maintenance capabilities, given the increase in maintenance task difficulty at the organizational and DS levels for the systems fielded in the 1980's. (See: LMI Task ML101, "An Approach to Evaluating Maintenance Difficulty," Working Note, July 1982.) If maintenance capabilities for relatively simple systems are as weak as indicated, extraordinary efforts will be required to improve support capabilities for more complex systems, let alone to fix-forward.

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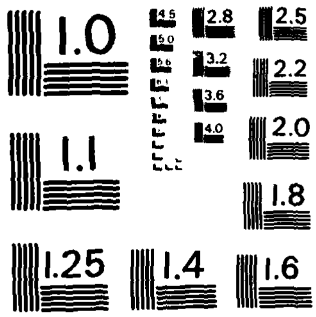

MICROCOPY RESOLUTION TEST CHART
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TABLE B-1. SUMMARY FINDINGS USAREUR AVIATION SPECIAL TASK FORCE

Conclusion: Lack of Capability to Reach or Sustain Realistic Readiness Goals (FMC Rate of 75 percent) for Aircraft Materiel

	Findings	Contributing Factors
(1)	Scheduled maintenance requires too much calendar time: PMI A/C · Avg. Days · Range UH-1H · 29 · (7-44) OH-58 · 42 · (9-61) AH-1S · 46 · (28-61) CH-47 · 52 · (25-70)	Excessive diversions from productive work: low productivity, lack of maintenance skills, poor supply support, cumbersome TMDE, inadequate facilities.
(2)	MTOEs are austere.	Aviation maintenance personnel must also maintain vehicles and generators. The CAB has 3 times the wheeled vehicles/power equipment of an armor bn, but only 1.5 times the operators and mechanics. Parity would require adding 66 personnel.
(3)	MOS diversion reduce productive hours to 20 hours/week for aircraft maintenance.	Diversions include mandatory training, motor pool, security and troop diversions. USAF maintenance personnel devote 35 hours of a 42-hour duty week to aircraft maintenance.
(4)	Maintenance personnel are inadequately trained.	TRADOC objective is to train individuals to 30 percent of MOS critical tasks but AIT graduates can only perform 10 percent of those tasks effectively. Lateral entrants into mid-level supervisor billets from other career fields get only entry-level training.
(5)	Facilities are as inadequate as in most other commodity areas but this has a greater adverse impact on aircraft readiness due to complexity and frequency of aircraft maintenance.	Electrical power in most hangars inadequate to support current aircraft ground test equipment and unacceptable for AH-1S(FM) and UH-60. Lighting is inadequate in 50 percent of the hangars. Heating is inadequate, reducing productivity in winter time. Many hangars lack overhead hoist.
(6)	TMDE repair support remains intolerable, although calibration support has improved since DARCOM takeover.	Obsolete TMDE: inadequate quantities of TMDE; inadequate staffing of USATESAE; lack of TMDE repair parts; lack of command emphasis in units.
(7)	Lack of a backup maintenance capability in-theater will limit wartime surge and sustainment capabilities.	Organic AVIM capability in USAREUR lacks depth and has no quick access to depots. This is evidenced by record levels of "hangar queens" (A/C down for 90 days or longer). This situation will get worse with the projected non-availability from CONUS of new/rebuilt Lycoming engines due to M-1 priority and quality control problems at the plant.
(8)	Aviation material management is inadequate from battalion through theater level.	Management resources at echelons above company are practically non-existent. The CAB and DMMC have one E-7 each authorized. Corps MMC are totally understaffed. HQ USAREUR, ODCSLOG, has only 1 major part time for this function.

TABLE B-2. SUMMARY RECOMMENDATIONS USAREUR AVIATION SPECIAL TASK FORCE

Problems Area/Finding

- AIT graduates perform 10 percent of MOS critical tasks.

- First reenlistment entries from other CMFs into CMF 67 are high, yet receive only skill level 10 training (in FY79 50 percent of personnel in year group 4 came from other CMFs).

- Self-paced training approach is ineffective for sophisticated equipment.

- Training evaluation through SQT is misleading by requiring mechanics to memorize technical manual content which is in conflict with SOP (90 percent failed CMF 67 SQT overall, but 90 percent passed hands-on component).

- AVIM units have a lower MTOE fill in MOS 67N (UH-1 repairman) and 67Y (AH-1S repairman) than do AVUM units. (MOS 67N: AVIM has 79 percent vs. AVUM 98 percent; MOS 67Y: AVIM has 77 percent vs. AVUM 93 percent).

- 68 series MOS is low density in AVUM units by MTOE authorization: average density is two in grades E4/below for 68B,D,F and H (A/C power plant, power train, electrician and pneudraulics repairer, respectively), with no E5/above authorized. The 68K supervisor billet was either not filled or filled by an individual unqualified to provide OJT. As a result, most of the work involved, though AVUM level, is done by AVIM; this is the main contributor to AVIM work backlog.

- MTOE of the air troops in the ACR does not provide qualified supervisory personnel (WO) for AH-1S armament system (in contrast to the MTOE for CAB).

- Based on programmed flying hours and observed PMI times, 50 percent of the unit maintenance programs cannot support a peacetime FMC rate of 75 percent. Root causes include: MOS diversions: skill deficiencies; and poor execution of the PMI concept which requires continuous inspections to be successful.

- Units achieving the shortest PMI duration or highest FMC rates showed command emphasis on balancing operational requirements vs. maintenance capabilities; sustainment of orderly maintenance flow vice short term FMC objectives; and crew chiefs participating in PMI.

- MTOE authorizations for aviation materiel management are inadequate in all echelons from battalion through HQ USAREUR.

- Maintenance capability at the Corps AVIM units is saturated as evidenced by the following backlog data as of February 1981:
  - 22 hangar queens (=A/C NMC is excess of 90 days) with average days NMC of 172 days.
  - 14 aircraft NMC from 60-80 days, of which 13 awaiting depot level repair or TSARCOM disposition instructions
  - this backlog resulted in spite of backup maintenance support from 70th Trans Bn (7100 manhours in 6 months).

- Management of TOW Missile System (TMS) LRUs is inefficient: unit TAT is 3 to 4 weeks, while actual repair TAT at PIMRA takes 2 to 5 days. This affects DX stockage required at Corps AVIM.

Recommendations

(1) Train all skill level 10 MOS critical tasks in AIT. Require demonstrated proficiency in 100 percent of MOS critical tasks as a condition for MOS award.

(LMI Comment: This could triple the AIT course length if training methodology remained constant).

(2) Modify training program for E-5/above reenlisting from other career fields to prepare individuals for supervisory (skill level 20) duties.

(3) Modify written component requirements of SQT to permit "open book" examination.

(4) Cross level MOSs within the combat Aviation Battalions and the Corps AVIM Battalions.

(5) Rotate personnel in MOS 68B,D,F and H to AVIM units to receive supervised OJT.

(6) Modify the MTOE for the ACR to show a requirement for three 100EE armament warrants per air troop as provided in the CAB MTOE.

(7) Reinstate the aircraft armament officers course directed at COBRA/TOW.

(8) Increase manhours available for aircraft maintenance by reducing competing requirements:
- civilianize those that can be (e.g., security, driver details)
- increase MTOE authorization for motor maintenance
- schedule mandatory training outside normal duty hours.

(9) Require technical inspection of aircraft 25 flight hours prior to scheduled PMI to identify maintenance and parts requirements.

(10) Expand the USAREUR Aviation Orientation Course for commanders and maintenance officers with a block of instruction on effective maintenance management.

(11) Enforce utilization of assigned crew chiefs in PMI.

(12) Develop a more realistic measure of aviation unit readiness based on maintenance flows vice pure FMC rates.

(13) Submit MTOE change requests for divisional CABs and MMCs; 800th MMC (VII Corps) to the level approved for 19th MMC (V Corps); 200th TAMMC; and HQ USAREUR, ODCSLOG.

(14) Develop backup depot-level capability in-theater for airframe and component repairs through contracts with German aircraft manufacturers and U.S. corporations.

(15) Provide the Corps AVIM battalions TDA augmentation with local hire maintenance personnel.

(16) Institute intensive management program for TMS LRUs to reduce nonproductive processing and transportation times, monitor the inventory of LRUs and balance distribution between Corps as needed.

TABLE B-2. SUMMARY RECOMMENDATIONS USAREUR AVIATION SPECIAL TASK FORCE (Cont.)

- TMS troubleshooting problems are evidenced by high NEOF rates of LRUs evacuated to PIMRA (27 percent overall for past 12 months).

- Replacement of ORF aircraft does not keep pace with attrition: theater is currently short 13 UH-1 and 4 OH-58 ORF assets.

- Repair parts availability is a major detractor of readiness but cannot be sustantiated by 2406 or 1352 reports because a total work stoppage must occur before aircraft can be reported NMCS. OST for NORS requisitions is 28-35 days but seldom causes total work stoppage given PMI duration. Extensive cannibalization and parts borrowing between units, mask supply problems. PLL clerks are inexperienced and supply management is weak. Due to cost of aviation parts, a greater portion of aviation requisitions are kicked out by DLOGS and SAILS for manual processing. The number of items selected for AIMI is increasing (* in short supply) but a high percentage cannot be ordered until aircraft is NORS.

- Facilities are deficient and impact adversely on readiness. Hangars have been diverted to other purposes. Most airfields do not have sufficient hardstand parking. 70 percent of facilities have inadequate electrical power for current aircraft, while an additional 17 percent will become inadequate with fielding of AH-1S (MC) and UH-60. As a result, tactical generators must be used causing additional maintenance. Over 50 percent of hangars have inadequate lighting, requiring use of portable floodlights powered by tactical generators. Over 50 percent of hangars have inadequate heating. 40 percent of hangars have no overhead hoist, with an additional 20 percent having inoperative hoists so that lift requirements must be met by borrowing a wrecker.

- AR 95-33 is ambiguous with respect to whether aircraft is FMC or PMC.

- AR 220-1 includes the UH-1 as an equipment pacing item in the attack troop of the ACR (MTOE 17-387). Due to its low density (the unit is authorized 21 AH-1S, 12 OH-58 and 3 UH-1), the impact of the UH-1 on readiness computation is disproportionate to its impact on the unit's primary mission.

- USAREUR has no inspection program to systematically evaluate unit aviation maintenance and supply management in contrast to other commodity areas which periodically receive logistics inspections (MAIT, CLAIT).

- Inadequate TMDE and maintenance support for TMDE adversely affects readiness. Majority of aviation TMDE is 1950s era so that repair parts are difficult to get. The October 1979 DARCOM TMDE support mission was grossly under resourced resulting in excessive turnaround for TMDE repair.

(17) PIMRA provide NEOF feedback data to AVIMs and DARCOM LAOs to identify troubleshooting problems and corrective action requirements.

(18) Establish stringent USAREUR policy for management and utilization of ORF.

(19) Articulate to HQDA need to fill ORF shortages to maintain ORF assets at 10 percent of TOE authorizations.

(20) Coordinate with TSARCOM more timely procedures for retrograde/repair of damaged aircraft.

(21) Improve training of PLL clerks and maintenance supervisors.

(22) Require DMMCs to conduct quarterly supply management reviews with supported units.

(23) Require COSCOM MMCs to conduct quarterly reviews with supported DMMCs.

(24) Submit change recommendation for AR 95-33 to identify statistically cannibalization actions with reduced supply responsiveness.

(25) Consider changing the DLOGS and SAILS criteria for aviation Class IX manual management procedures.

(26) Articulate to HQDA the need to reduce the number of items under AIMI management constraints.

(27) Develop theater capability to monitor Class IX stocks among ASL and GSSB stocks; develop procedures to move parts between ASLs and GSSBs.

(28) Use MCA funds to build non-aviation facilities to release the converted facilities back to aircraft maintenance.

(29) Construct needed helicopter parking pads.

(30) Initiate actions to upgrade power supplies in all aircraft maintenance facilities.

(31) Upgrade facilities to improve lighting, heating and lift capabilities as needed.

(32) Develop specific USAREUR criteria for definition of FMC and PMC by type aircraft/primary mission and submit these criteria for next revision of AR 95-33.

(33) Develop change recommendation to AR-220-1 deleting the UH-1 as an equipment pacing item in MTOE 17-387.

(34) Restructure the Aviation Operational Readiness and Safety Evaluation (AORSE) system to focus more on aviation materiel management issues/problems affecting unit readiness.

(35) Units must appoint and educate TMDE calibration/repair coordinators.

(36) A new test set (AN/GRM114) being fielded for ground FM radios could replace six pieces of TMDE most frequently used in avionics maintenance and should also be authorized to aviation maintenance units.

(37) USATESAE to consider increasing the use of mobile calibration/repair teams instead of the current fixed base operations.

(38) Articulate to HQDA the necessity to expedite the electronic TMDE modernization program.

TABLE B-3. RAND SURVEY OF TRACKED VEHICLE MAINTENANCE PROBLEMS

Cat[1]	Problem Area	Reponse Rate[2]	Weight[3]	Impact on Maintenance Performance
1	Equipment is abused by operators. Causes: poor supervision; poor training and testing; lack of responsibility.	95%	4.6	Excess breakdown: 60-75% of component replacements are due to improper operation or lack of PM.
	Operators do not perform pre- and post-op checks in accordance with TM. Causes: lack of command emphasis; poor supervision; poor training; lack of motivation or responsibility; poor discipline/attitude.	99%	4.6	Late detection of needed repairs; accidents; minor failures become major ones; excess rework.
	Operators do not receive adequate training either in operation or preventive maintenance (PM).	90%	4.6	Inadequate PM; late detection of needed repairs; operator-induced failures; operator does not report or describe failure symptoms to mechanics.
2	There is a shortage of qualified maintenance personnel; MTOE slots are unfilled or filled by less experienced (lower grade) personnel.	95%	4.4	Inadequate PM; poor diagnosis; deferred corrective maintenance (CM); poor supervision; poor OJT.
	There is a high turnover of maintenance personnel, either due to ETS/PCS or grade structure (up or out policy).	89%	3.7	Low productivity; poor attitude; lack of responsibility; limited development of experience.
	Formal MOS training is inadequate: insufficient training in diagnosis, use of TMDE, use of TMs, fundamentals, and hands-on. About 30% of mechanics are not school trained in MOS (range 10-80%).	72%	3.6	Poor diagnosis; low productivity; maintenance-induced failures; high evacuation rate.

TABLE B-3. RAND SURVEY OF TRACKED VEHICLE MAINTENANCE PROBLEMS (Cont.)

Cat[1]	Problem Area	Response Rate[2]	Weight[3]	Impact on Maintenance Performance
2	OJT is inadequate; no supervised, structured program; lack of qualified supervisors; inadequate time available; many MOS divisions.	91%	4.0	Poor diagnosis, inadequate PM; low productivity.
	Available TMDE is not used. Causes: lack of training (85%); diagnosis by replacement easier (90%); TMDE difficult to hook-up and use (44%); fear of damage to TMDE (35%); lack of TMs or TMs hard to understand (47%); TMDE not available (out of calibration or due to repair) (22%); lack of critical items (30%); or lack of skilled supervision (20%).	92%	4.3	Late detection of needed repairs; poor diagnosis; low productivity; replacement of serviceable components; excess rework.
3	Command emphasis on maintenance is lacking: officers are seldom seen in shops.	86%	4.1	Inadequate PM; low productivity; deferral of maintenance.
	Periodic maintenance is not supervised. Causes: supervisors do paperwork, not motor pool; lack of command emphasis; supervisors are untrained and have poor attitude.	87%	4.6	Inadequate PM; operator apathy; poor procedures; late detection of needed repairs; poor diagnosis; low productivity
	Performance of PM in accordance with TM is not enforced. Causes: lack of supervision, time, and motivation.	93%	4.4	Inadequate PM; late detection of needed repairs; poor diagnosis; excessive downtime; minor failures leading to major ones; increased workload at support maintenance levels.

TABLE B-3. RAND SURVEY OF TRACKED VEHICLE MAINTENANCE PROBLEMS (Cont.)

Cat[1]	Problem Area	Response Rate[2]	Weight[3]	Impact on Maintenance Performance
3	Performance of troubleshooting in accordance with TM is not enforced. Causes: insufficient training (78%); poor supervision (70%); TMs not available or difficult to understand (54%); lack of serviceable TMDE (15%); changing parts is easier.	94%	4.3	Poor diagnosis; late detection of needed repairs; maintenance-induced failures; excess rework; unnecessary parts replacement; no development of troubleshooting skills.
	Maintenance forms are filled out incorrectly; some forms are intentionally falsified: DA Form 314 (88%); 2406 (70%); 2404 (50%); 2408-1 (42%). Causes: lack of emphasis/supervision; documentation is time consuming; clerks are inadequately trained.	94%	3.9	Forms cannot be used for their intended purpose as a management tool. Readiness reports give a totally inaccurate picture. Unit commander cannot get accurate maintenance status from consolidated forms.
	Maintenance personnel are used for many non-maintenance duties.	N/A	N/A	Limited productive use of maintenance personnel (about 2 hours per day); low productivity; inhibits OJT; poor attitude and responsibility.
	There is no effective incentive program to improve maintenance performance.	86%	3.3	Inadequate PM; low productivity; lack of interest and motivation; no interest in self-improvement.

[1]Key: 1 = Operators, 2 = Mechanics, 3 = Management/Supervision

[2]Response rate is percent of respondees (N = 95) identifying stated issue as a problem.

[3]Average weight computed from individual respondee's assessments of importance of problem on a six-point, Likert-type scale:

5 = very important
0 = unimportant

SOURCE: "Problems in Army Vehicle Maintenance: Results of a Questionnaire Survey," C. R. Harz, RAND Report R-2487-ARPA, June 1981.

APPENDIX C

LEVEL OF REPAIR ANALYSES

Level of repair analysis (LORA) is part of the logistic support analysis and determines where an item is repaired. The parameters which influence or should influence these decisions are listed in Table C-1. This table is adopted from the Army Materiel Command (AMC) study referenced in the table. Because of the huge effort involved to do LORA manually, automation of the LORA process was begun in the late 1960's. The earliest models used by the Army included the following:

- Generalized Electronics Maintenance Model (GEMM), developed and used by the Communications-Electronics Command.
- Replacement Unit Repair Level Analysis Model (RURLAM), developed by the Army Management Engineering Training Agency and later renamed the Integrated Logistics Support Analysis Model.
- Cost Analysis of Maintenance Policies (COAMP) model, developed by RCA and used by the Armament and Missile Commands.

A comparison of these models was conducted by the AMC in 1973. This comparison is summarized in Table C-2, which is adopted from the AMC study referenced in the table. The table shows which parameters are accommodated in each model and how well.

Various other models have evolved over the last ten years. One of the most comprehensive models is the Logistics Analysis Model (LOGAM), which was developed in the late 1970's by the Missile Command. LOGAM is actually the most recent version of the Logistic Cost Analysis Model (LOCAM), five versions of which were developed in the 1970's. LOCAM I, in turn, was an adaptation of the COAMP model previously mentioned. LOGAM is an operating and support cost model with huge input data requirements. The model generates the life cycle operating and support cost for any one of the 20 maintenance concepts listed in Table C-3 and illustrated in Figure C-1.

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSIS

I. SUPPORT PARAMETERS.

A. Support Equipment (tools, TMDE, facilities, etc.).

1. Uses - What support equipment is required for each of the various maintenance tasks? Can different support equipment perform the same function?

2. Costs - What are the costs to purchase and maintain each type of support equipment? If support equipment is to be developed, what are the R&D costs?

3. Availability - How often will the support equipment be available and in usable condition? What is the maintenance downtime, calibration requirements, etc.?

4. Efficiency - How long does it take for each support equipment to perform its function? What percentage of the functions are performed correctly?

B. Manpower Parameters.

1. Skills/capability - What skills (MOS types) are capable of performing the different maintenance actions? How many men are required? Is there substitutability of MOS types?

2. Support Costs - What are the average costs for clothing, food, salary, fringe benefits, retirement benefits, medical, etc., necessary for each MOS type required for the maintenance actions? Consider both the current manpower support costs and the increases projected for the life of the equipment.

3. Training Cost - What training is required to learn to operate support equipment and perform maintenance on the system? What is the cost for each MOS type?

4. Availability - What amount of the time will each MOS type be available to work on the system? Consider the maintenance workload on other systems, leave, special duty, etc.

5. Turnover - How often will new men have to be trained to perform the maintenance functions?

SOURCE: "Evaluation of Maintenance Support Optimization Models," Willard F. Stratten, et al; Maintenance Support Center, Army Materiel Command, 20 April 1973 (AD #761-112).

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSIS
(Cont.)

6. Efficiency - A measure of how well each MOS type performs his work. Are there maintenance induced failures--is the repair performed correctly, etc.? Also, where more than one MOS type can perform the maintenance, what is their relative speed and quality? Does a learning curve apply?

C. Available Support Structure - Is the system to be maintained by a dedicated support structure (i.e., serving only one type of system), or is the system to be one of many different types of equipment supported by a common maintenance structure? If the system is supported by a dedicated structure, the repair level decisions are dependent exclusively on the characteristics of the system. However, in a support structure common to several different types of systems, the systems may have common components; the same maintenance personnel and support equipment may be used in support of many of the different types of systems. In this circumstance, level of repair decisions must consider the interrelationships and requirements of all different systems.

D. Publication Requirements and Costs - How many pages of documentation are required to proceed to each succeeding equipment indenture level for repair, and what is the average cost per page? (It requires less documentation to describe a remove-replace action than it does to describe a remove-repair-replace action, hence this information is useful in making a repair vs discard decision).

II. MISSION PARAMETERS.

A. Mission Profile - What is the average length of each mission, the frequency of missions, types of missions, utilization, etc.?

B. Readiness Requirements - The readiness goal (availability, operational readiness, etc.) which the system must meet. This depends upon the equipment and the responsiveness of the support structure.

C. Mobility Requirements - Requirements for certain levels of support to be capable of moving within a specified period of time (e.g., it may not be feasible to locate bulky test equipment at lower support levels because of a requirement for these levels to be highly mobile).

D. Vulnerability - The probability of destruction by hostile acts (e.g., expensive support equipment may be positioned only at higher levels of support because of a high probability they would be destroyed if they were positioned at the lower levels).

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSIS (Cont.)

III. DEPLOYMENT PARAMETERS.

A. Representative Force Structure - What are the distances between the levels of support? How many organizational units are allocated to each DSU, DSU to each GSU, etc.? (If the force structure varies with deployment area, a representative force structure should be considered).

B. End Item Density - The force structure, on an average, will support how many different end-item types, and what quantity of each type?

C. Contact Team Feasibility - Instead of evacuating the equipment to the maintenance facility, is it possible to take the maintenance capability to the equipment? Weigh the costs and responsiveness associated with the alternatives.

D. Waiting Times/Turnaround Times - What is the averate time a reparable must wait at the different maintenance levels before action is taken to repair the item? What is the elapsed time from the receipt of a failed item until the item is repaired and ready for reissue?

E. Transportation Times and Cost - What are the transportation times required to transport an item from one level to another? What costs are involved (i.e., apportion transport vehicle cost and driver cost, and include any packing and container costs)?

F. Operating Hours of Maintenance Facilities - What is the work schedule? How many hours per day and how many days per week are the maintenance facilities in operation?

G. Deployment Environment - How does the environment of each deployment area affect the maintenance operations/equipment performance?

IV. EQUIPMENT PARAMETERS.

A. Structure - How is the equipment constructed? What actions can be taken to repair a specific failure? (For example, a part failure could be corrected by: (1) Directly replacing the failed part, (2) Replacing the assembly containing the part - then repair or replace the part, (3) Removing the component containing the assembly with failed part, etc.).

B. Costs - What are the purchase prices of the end-item, its different components, modules, and parts?

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSIS (Cont.)

C. Essentiality - Which failures would cause an end-item to abort its mission?

D. Overhaul Times and Costs - What is the time between overhauls? What is the time required to evacuate, overhaul, and return an item? What are the associated costs? What items are overhauled?

E. Failure Rate and Its Characteristics - What are the failure rates (or preferably the maintenance factors) of the parts, components, and assemblies? In each case, is the item's failure rate decreasing (item experiences break-in failures), constant (item experiences random failures), or increasing (item experiences wear out failures)? Changes in the failure rates should be considered for a time period equal to the remaining life of the equipment.

F. Remaining Life - The period of time from the present until the date the equipment is to be retired. On a new item, this is equivalent to the economic life.

G. Repair/Replace Times - Depending on how failures can be corrected (see para IV - A), what is the average maintenance time required to perform each maintenance action?

H. Float - Is float authorized? If so, what quantities are authorized?

I. Weights and Volumes - What are the shipping weights and volumes of the different components, modules, and parts?

J. Preventive Maintenance Requirements - What preventive maintenance actions are required? What is the frequency of PM actions? How long do they take? What resources (men, tools, test equipment, etc.) are required?

V. SUPPLY PARAMETERS.

A. Inventory Management Cost - Cost of storage facilities, of handling items in storage, of obsolescence, of clerical work associated with keeping an item in inventory, of packaging materials and containers, etc. This cost is frequently stated as a percentage of the item's acquisition cost.

B. Protection Level (Safety Factor, Confidence Level) - The probability that a repair part will be available when one is required.

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSIS (Cont.)

C. Requirements Objective Period - That duration of time for which initial support is being provisioned (usually expressed in months).

D. Order and Shipping Times - The time elapsing between the initiation of stock replenishment action for a specific activity and the receipt by that activity of the materiel resulting from such action.

E. Stockage Objective - The number of days of supply which a maintenance or supply point is authorized to have in stock at any given time.

F. Replacement Rate (or Factor) - The estimated percentage of equipment of repair parts in use that will require replacement during a given period due to wearing out beyond repair, enemy action, abandonment, pilferage, etc.

VI. ECONOMIC CONSIDERATIONS.

A. Sunk Costs - Cost resulting or incurred from past decisions which are irrelevant to the present considerations of alternative course of action. For example, an exotic test set was purchased to repair a certain component. Now, after these test sets have been purchased and used, the component is being reevaluated for possible throw away. The purchase price of the exotic test set is irrelevant in costing the repair-discard alternatives. This is because the test set was previously purchased and the money remains spent regardless of whether the repair or discard alternative is selected.

B. Fixed Costs and Incremental Costs - Fixed costs are those costs which are not affected by changes (e.g., changes in the maintenance support structure and policy), while incremental costs are those which are affected by change. In evaluating alternatives, incremental costs are the only costs that need to be considered.

C. Present Value (Present Worth) - In costing alternatives, the sequence of disbursements may differ among the alternatives. Considering the time value of money, it is necessary to discount those disbursements to present values before a valid comparison of the cost of the alternatives is possible.

D. Inflation - Increases in dollar prices for given units of value, such as parts, equipment, and labor, can affect the economic decisions in LOR analyses. Inflation can be incorporated into present value calculations by combining the discount rate (dr) and the inflation rate (ir) as follows: $(1 + dr) \times (1 - ir) - 1 = dr'$ to form a new discount rate (dr') for use in present value calculations of future expenditures.

TABLE C-1. PARAMETERS FOR LEVEL OF REPAIR ANALYSES (Cont.)

E. Salvage Value - The expected value of facilities or equipment at the end of its useful life.
F. Concepts of Time Perspective - In evaluating alternatives, both the short- and long-run effects of the alternatives should be considered. For example, the MOS cost for repairing certain components of a new system at DS may be a sunk cost in the short run if an existing MOS supporting a previously fielded system can be used. But when the latter system is phased out, the MOS cost is no longer a sunk cost. As a result, the decision to repair the component at DS may, in the long run, not be the least cost alternative. The repeated introduction of new systems into the support structure could tend to perpetuate a situation (the requirement for a certain MOS type at DS) which is not optimal.
G. Cost Constraints - What limits are established on life cycle cost, annual cost, etc.? What limits, if any, are set for support equipment, manpower, inventory costs, etc.?
H. Risk and Uncertainty - Methods of handling the elements of risk and uncertainty must be incorporated into the decision process.

TABLE C-2. COMPARISON OF LEVEL OF REPAIR ANALYSIS METHODOLOGIES

PARAMETERS	PRE-1970 MAC	RURLAM	COAMP	GEMM
I. Support Parameters				
A. Support Equipment (tools, TMDE, facilities, etc.)				
1. Uses			X2	X3
2. Costs			X3	X3
3. Availability	X		X1	
4. Efficiency				
B. Manpower Parameters				
1. Skills/Capability	X		X1	X3
2. Support Costs		X3	X3	X3
3. Training Costs			X3	X3
4. Availability	X			
5. Turnover				X3
6. Efficiency				
C. Available Support Structure	X			
D. Publication Requirements and Costs			X2	X3
II. Mission Parameters				
A. Mission Profile		X3	X3	X3
B. Readiness Requirements		X2	X2	X2
C. Mobility Requirements				
D. Vulnerability				
III. Deployment Parameters				
A. Representative Force Structure		X3	X2	X2
B. End Item Density		X3	X3	X3
C. Contact Team Feasibility			X1	
D. Waiting Times/Turnaround Times			X3	X3
E. Transportation Times and Costs		X3	X3	X3
F. Operating Hours of Maintenance Facilities		X2	X2	X3
G. Deployment Environment				

SOURCE: "Evaluation of Maintenance Support Optimization Models," Willard F. Stratten, et al; Maintenance Support Center, Army Materiel Command, 20 April 1973 (AD #761-112).

TABLE C-2. COMPARISON OF LEVEL OF REPAIR ANALYSIS METHODOLOGIES (Cont.)

PARAMETERS	PRE-1970 MAC	RURLAM	COAMP	GEMM
IV. Equipment Parameters				
A. Structure		X2	X2	X2
B. Costs		X3	X3	X3
C. Essentiality		X1	X1	X1
D. Overhaul Times and Costs				X2
E. Failure Rate and Its Characteristics		X1	X1	X1
F. Remaining Life				
G. Repair/Replace Times		X3	X3	X3
H. Float				X1
I. Weights and Volumes		X3	X2	X2
J. Preventive Maintenance Requirements				
V. Supply Parameters				
A. Inventory Management Cost		X3	X3	X3
B. Protection Level		X3	X3	X3
C. Requirements Objective Period				X3
D. Order and Shipping Times		X3		X3
E. Stockage Objective		X3	X3	X3
F. Replacement Rate			X3	X3
VI. Economic Considerations				
A. Sunk Costs			X3	
B. Fixed Costs and Incremental Costs		X3		X3
C. Present Value			X3	
D. Inflation				
E. Salvage Value			X2	
F. Concepts of Time Perspective				
G. Cost Constraints		X2	X2	X2
H. Risk and Uncertainty		X1	X1	X2

KEY: X denotes parameter is considered in level of repair analysis; the number following the X refers to how well the model accommodates the parameter; i.e., 3 = very good, 2 = good, 1 = fair, no number = undetermined.

TABLE C-3. LISTING OF MAINTENANCE CONCEPTS ACCOMMODATED IN LOGAM

GA = Specifies a policy of discard at failure. There are no maintenance support activities. All failure, false no-go indications, and attrition rate inputs result in LRU discard. Only LRUs are stocked in the supply system. There is no demand for modules or parts.

GB = Similar to GA but here is a provision to detect false no-go's at direct support and only failed and attrited LRUs are discarded. There is no demand for module or part stock. There is a demand for checkout service at direct support and the model uses Type I test equipment input data for this.

GC = Specifies LRU repair at equipment level by removing and replacing a defective module. The defective module is discarded.

GD = Specifies LRU repair at direct support by removing and replacing a defective module. The defective module is discarded.

GE = Specifies LRU repair at general support by removing and replacing a defective module. The defective module is discarded.

GF = Specifies LRU repair at general support with checkout performed at direct support to remove false no-go LRUs before sending the work to general support. LRU repair is by removal and replacement of a defective module and the defective module is discarded.

GG = Specifies LRU repair at depot. Defective modules are discarded.

GH = Specifies LRU repair at depot preceded by a checkout at direct support to screen false no-go's.

GI = Specifies LRU repair at equipment level and module repair at direct support.

GJ = Specifies LRU repair at equipment level and module repair at general support.

GK = Specifies LRU repair at equipment level and module repair at the depot.

GL = Specifies LRU and module repair at direct support.

GM = Specifies LRU repair at direct support and module repair at general support.

GN = Specifies LRU repair at direct support and module repair at depot.

GO = Specifies checkout to catch false no-go's at direct support followed by LRU and module repair at general support.

GP = Specifies checkout to catch false no-go's at direct support followed by LRU repair at general support and module repair at depot.

GQ = Specifies LRU checkout to catch false no-go's at direct support followed by LRU and module repair at depot.

GR = Specifies LRU and module repair at General Support.

GS = Specifies LRU repair at general support and module repair at depot.

GT = Specifies LRU and module repair at depot.

NOTE: The concepts are illustrated in Figure C-1. The factors GA through GT are input specified and must sum to one so that all maintenance work is accounted for.

FIGURE C-I LOGAM MAINTENANCE CONCEPT MATRIX

FOR THE MAINTENANCE POLICY DESIGNATED BY

TEST EQUIPMENT WILL BE LOCATED AT	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	*	TEST EQUIPMENT CAN ISOLATE FAULTS TO THIS LEVEL
EQUIPMENT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	TRC	LRU
			X						X	X	X										TE TER	MODULE
DIRECT SUPPORT		X		X		X		X	X			X	X	X	X	X	X				TC	LRU
				X					X			X	X	X							TF TFR	MODULE
									X			X									TMO TMOR	PART
GENERAL SUPPORT					X	X				X			X		X	X		X	X		TC	LRU
					X	X				X			X		X	X		X	X		TI TIR	MODULE
										X			X		X			X			TMI TMIR	PART
DEPOT							X	X			X			X		X	X		X	X	TC	LRU
							X	X			X			X		X	X		X	X	TD TDR	MODULE
											X			X		X	X		X	X	TMD TMDR	PART

LRU (GA–GB) MODULE (GC–GH) PART (GI–GT)

REPAIR WILL BE ACCOMPLISHED BY DISCARDING AND REPLACING THE FAILED.

* LOGAM MNEMONIC

SOURCE: LOGAM USERS MANUAL, U.S. ARMY MISSILE COMMAND, AUGUST 1982.

APPENDIX D

MANAGEMENT AND SUPPORT OF COMMON TEST EQUIPMENT

INTRODUCTION

The Army's management and support (calibration and repair) of test, measurement, and diagnostic equipment (TMDE) has traditionally been weak for a variety of reasons. Test equipment is not managed as a separate commodity. Until very recently, acquisition had no centralized control; different support practices are followed by the major commands; and no reporting systems are in place to provide top-level visibility of the extent of unavailability of test equipment in maintenance units and the resulting impacts on maintenance performance. (AR 220-1 limits unit readiness reporting requirements to specific pacing items, the unit's primary combat systems; maintenance units have no pacing items and do not report materiel readiness.)

Shortcomings of test equipment support have not been a serious issue in previous wars this country has been involved in. Prior to the Vietnam era, weapon system maintenance was less dependent on test equipment than it is today as a result of weapon system complexity. The Vietnam conflict did not test organic support capabilities either. Test equipment repair and Level C calibration facilities were stable so that both missions could be and were accomplished by civilian contractors. Level A calibration was provided by mobile teams airlifted on an exchange basis from area calibration laboratories located in Okinawa. This type of support concept would seem unfeasible in a future conventional war.

The Army has recognized the increasing criticality of test equipment for effective weapon system support and has recently taken some major steps to improve management of acquisition and support of test equipment. The effects of inadequate management in the past, however, cannot be corrected overnight. Resource shortages have limited the extent of improvements achieved to date, so test equipment inadequacies and weak support may continue to plague the Army throughout the 1980's. This appendix reviews some of the problems as well as the steps the Army has taken to improve management and support of common test equipment.

BACKGROUND

With the Army reorganization of the Technical Services and formation of the Army Materiel Command (AMC) in December 1962, the U.S. Army Metrology and Calibration Center (USAMCC) was created to assume technical direction of an Army-wide calibration system. The lack of such a system had been identified by the Army Maintenance Board as one of the factors contributing to maintenance problems encountered in the Korean war. The system, first established in August 1963 and virtually unchanged until 1979, had the following key characteristics (see Figure D-1):

- Materiel Development and Readiness Command (DARCOM) responsibility for Level A calibration (calibration accomplished by Army Standards Laboratory, Area Calibration Laboratories, or Area Calibration Teams using calibrated measurement standards to calibrate other standards or TMDE)
- Field Army (USAREUR, Eighth U.S. Army) responsibility for Level C calibration and repair of its own TMDE (Level C is calibration accomplished by maintenance units using their calibrated TMDE to calibrate other TMDE).

Shortcomings in the implementation of the TMDE calibration and repair "system" and the life cycle management of TMDE have been the subject of numerous studies in the past. Some brief excerpts from selected studies may be useful to indicate that the problems plaguing the Army today (1) are not new but were identified as long as 15 years ago, and (2) seem to defy practical solutions as long as support equipment is accorded lower priority than the supported weapon systems.

FIGURE D-1. ARMY CALIBRATION SYSTEM (PRE-1979)

ARMY STANDARDS LABORATORY

Mission: Provide cyclic and on-request metrology and calibration services to all Army Calibration Laboratories.

Calibration Equipment: Primary Reference Standard

↓

ARMY AREA CALIBRATION LABORATORY

Mission: Provide calibration of measurement standards and TMDE used by Army units within specified geographic area beyond capability of Army Calibration Teams

Calibration Equipment: Calibration Standards Set - Secondary Reference

Operation: Fixed facility environmentally controlled

↓

ARMY AREA CALIBRATION TEAM

Mission: Provide Level A calibration service for Army activities within a specific area.

Calibration Equipment: Calibration Standards Set - Secondary Transfer

Operation: Most mobile teams, some operated as fixed facilities

↓

ARMY MAINTENANCE CALIBRATION. FACILITY

Mission: Provide Level C calibration service to supported maintenance or tactical units

Calibration Equipment: Calibrated TMDE (AN/GSM-256 recently fielded)

Operation: Organizational element of a MACOM's installation maintenance activity or a field army's designated GS maintenance unit.

In 1965, the Department of the Army (DA) Board of Inquiry of the Army Logistics System (known as the Brown Board) was established to review the entire logistics system. With regard to test equipment management and support, the Board found that management was diffused among commodity commands, lacked central coordination, and was out of contact with user needs; that much-needed replacements of obsolete equipments did not receive attention, while at the same time duplicate efforts were applied to developing automated test equipment; that training in the use, calibration and repair of test equipment was inadequate; and that test equipment manuals were inadequate. The Brown Board concluded that inadequate test equipment, inadequate training, inadequate supervision, and an ineffective MOS structure were the chief causes of weapon system malfunction diagnosis problems; that the incidence of faulty malfunction diagnosis by maintenance personnel in the Army was unacceptably high; and that effective management of common test equipment was seriously lacking. The Brown Board recommended that the Army's acquisition system should make specific provisions for the analysis of prime equipment diagnostic requirements and timely development of new test equipment; and that a central activity should be established within the AMC to oversee test equipment development and management.

In response to the Brown Board inquiry findings, the AMC conducted its own examinations of test equipment management and support. One study, conducted by an AMC working group created November 1967 to examine test equipment management, recommended that a centralized management system for all test equipment (general purpose as well as special purpose) be developed, with coordination offices established at all commodity commands, project management offices, and headquarters elements. A second study, conducted jointly with the Combat Development Command and Continental Army Command, examined the Army calibration system. This was the first detailed examination of the Army calibration system since its 1963 inception. The study concluded that personnel and equipment were inadequate for accomplishment of the Level C calibration program workload and that management control of Level C calibration was poor to non-existent. ("Joint U.S. Army Calibration Study," July 1968). The first study was followed by additional AMC studies of organizational issues associated with a centralized management system for test equipment. These studies ultimately resulted in establishment of a DA Central TMDE Activity (CTA) at Lexington Blue Grass Army Depot, effective July 1973. The second study ultimately resulted in development of a set of calibration equipment designed to support Level C calibration. This set (AN/GSM-256) was partially fielded in the mid-1970's.

Establishment of the CTA did not solve the Army's TMDE management problem due to lack of authority and resources. Shortcomings in TMDE management continued to be a target of studies and critical audit reports. In 1979, a study directed by DARCOM summarized these studies, identified the basic management problem as one of diffused decision making without centralized control, and noticed the fundamental similarity to management problems associated with all elements of integrated logistics support (ILS): "The current DoD/Army management structure leads to a significant imbalance in priorities, resulting in weapon systems which invariably fail to meet their hardware potential because of lesser priorities given to ILS." ("Assessment of DA/DARCOM TMDE Program," Joseph M. Heiser, Jr. LTG, USA(Ret), 29 September 1979). The organizational recommendations of this study were considered by the DA TMDE Action Team study conducted December 1981 through

March 1982. This review resulted in the present reorganization for TMDE management, effective May 1982:

- Commanding General (CG), DARCOM, as executive agent for TMDE
- Deputy CG, DARCOM, as executive director for TMDE supported by an Office for TMDE Management at HQ, DARCOM
- CG, Communications-Electronics Materiel Command, as operating agent for TMDE
- PM, TMDE to manage the TMDE Technology Lab, Automatic Test Support System (ATSS), and TMDE Modernization offices
- USAMCC functions reorganized into the TMDE Support Group, reporting to the executive director as a HQ, DARCOM activity
- CTA continued as a HQ, DARCOM activity reporting to the executive director for TMDE.

During the 1970's, field army calibration and repair of test equipment showed little or no improvement from the weaknesses first identified and documented by the Brown Board in 1966/1967 and confirmed by the "Joint U.S. Army Calibration Study" in 1968. (See: DA Study, "Review of OCONUS Calibration Facilities," 1 October 1975; there are also various Inspector General, Army Audit Agency, and GAO reports on the same topic.) In view of these conditions and advances in TMDE technology, DA, Deputy Chief of Staff for Logistics (DCSLOG) directed DARCOM to develop an improved concept for test equipment calibration which would be: responsive to the Army's needs, standard worldwide, compatible with the other Services, cost effective, and adaptable to both peacetime and wartime circumstances with minimum disruption during transition. Specific guidance provided by DCSLOG for this study included the following requirements for the improved concept:

- DARCOM will administer the worldwide program, operate all secondary reference laboratories and selected secondary transfer teams, administer technical management and proficiency inspections, and submit annual report by Major Command (MACOM) reflecting the status of worldwide calibration services.

- The improved concept must provide the Army in the field with calibration/repair capability commensurate with their readiness, workload density and mobility requirements.

- Forward area calibration facilities and teams will accomplish TMDE repair (incidental to calibration) to the maximum extent possible. TMDE red-tagged, where repair is not possbile, will not be returned to DARCOM reference labs but repaired by existing rear-area repair facilities. Calibration standards will continue to be processed for repair through calibration facility channels (DA, DCSLOG Message, 24 February 1976).

The study, conducted from March 1976 through March 1978 (followed by implementation planning in 1978/1979) under the lead of the USAMCC, was a thorough and very comprehensive piece of work. The first phase of the study reviewed the existing system, confirmed the known weaknesses of the system, and identified the following major deficiencies:

- The Standard Army Calibration System has been independently implemented by major commands in a manner which is not in the best interest of the Army as a whole.

- The Army Calibration System differs from that of other Military Departments primarily in the degree to which repair and calibration of TMDE are combined.

- Current procedures for controlled acquisition of TMDE are inadequate to correct past proliferation and associated support problems.

- Effective automation of calibration processes is limited by the wide variety, low-density and dispersed location of Army TMDE, and the lack of enforced scheduling systems.

- The readiness of test measuring and diagnostic equipment and efficiency of operations is diminished by the separation of repair and calibration functions.

- Maintenance unit TOEs generally do not contain a specific mission for Level C calibration, nor do they specifically authorize equipment for it's accomplishment.

- Equipment used for Level C calibration is authorized for other purposes and is generally old and in need of replacement.

- The current two levels of calibration (Level A and Level C) complicate TMDE support channels from the users' standpoint.

- Excessive delays in obtaining required repair parts for TMDE in overseas theaters are due mostly to past proliferation of TMDE, complexity of supply regulations and the lack of trained supply personnel in maintenance units.

- A lack of standardization exists in job description, classification and wage scale among civilian TMDE repairmen and calibrators.

- Deployable capability for TMDE repair or Level C calibration is inadequate within CONUS.

- The current USAMCC program for TMDE repair and calibration parallels that of overseas host commands to the point of duplication.

- Calibration recall systems are not completely in effect in USAREUR and the 5th Signal Command in Europe. Level C calibration workload is therefore unknown and can only be estimated.

- No standard system for quality assurance for TMDE repair and calibration is in effect.

- A general lack of awareness of the need for and the benefit derived from calibration is prevalent throughout the Army.

- No organized refresher training program exists for civilians who repair and perform Level C calibration of TMDE.

- Improvements are needed in the program of on-the-job training for MOS 35H (Calibration Specialist) personnel.

- Elements of the training provided MOS 35B (Electronic Instrument Repairman) and MOS 35H personnel are considered to be inadequate by many OCONUS maintenance officers and shop supervisors.

- The cost of TMDE repair and calibration cannot currently be identified in a meaningful manner.

  ("DA Concept Study for Improved Army-Wide TMDE Calibration and Repair Operations, Volume I - Executive Summary," March 1977).

The second phase of the study involved a comparative evaluation of four alternative concepts (illustrated in Figure D-2):

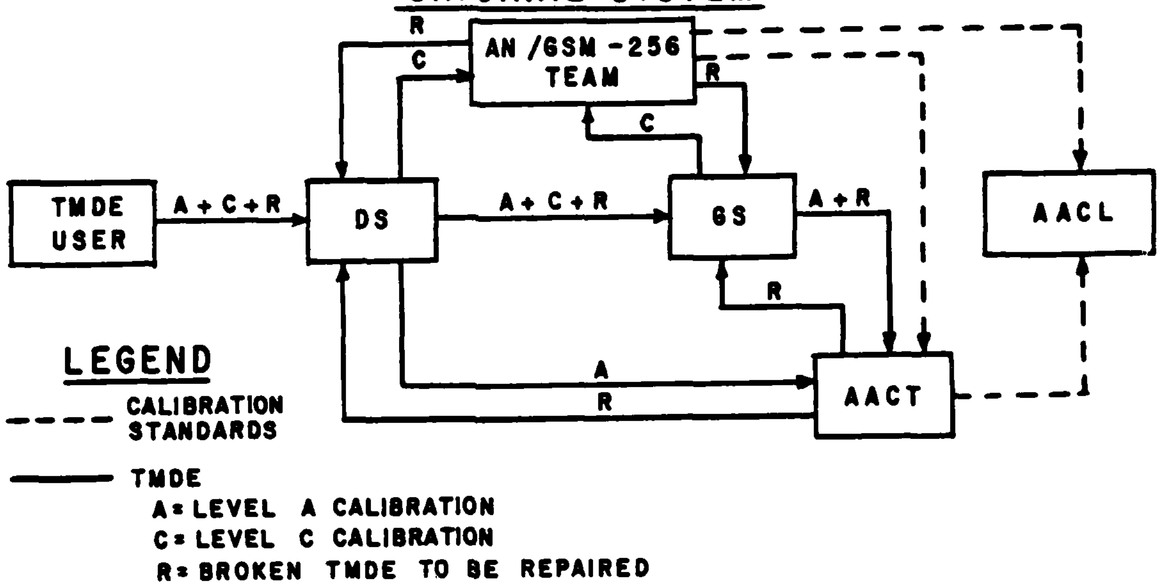
- Concept A: Improvements to the existing system but no change in management control of repair and calibration resources. Two key changes are: (1) the organization responsible for calibration assumes responsibility for repair, and (2) the AN/GSM-256 is made available in accordance with basis of issue plan in order to provide a deployable capability for repair and Level C calibration.

- Concept B: Area support concept to provide total TMDE calibration and repair support from a single source with DARCOM management and control of all TMDE calibration and repair support service. Support of special purpose TMDE, however, remains unchanged.

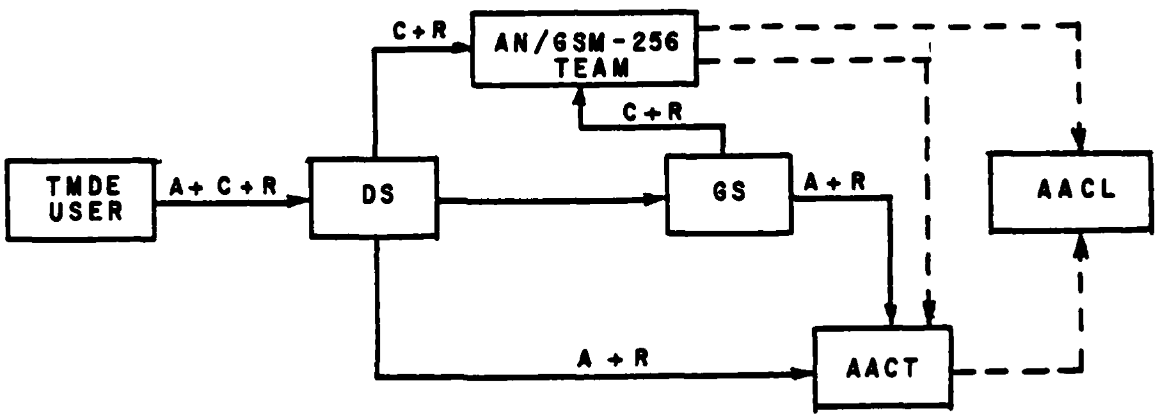
- Concept C: Similar to B except that DARCOM control is limited to the Army Area Calibration Laboratories (AACLs) (secondary reference labs), with TMDE calibration/repair below AACL level under MACOM command and control.

FIGURE D-2 ALTERNATIVE TMDE SUPPORT CONCEPTS EVALUATED BY USAMCC

ORIGINAL SYSTEM



ORGANIC LEVEL C CALIBRATION/REPAIR (CONCEPT A)



CONSOLIDATION OF CALIBRATION AND REPAIR (CONCEPTS B, C, and D)

- Concept D: Similar to B and C in that repair and calibration support for general purpose TMDE are consolidated on an area support basis. However, command and control of secondary reference labs and consolidated calibration and repair centers are exercised by the host command or predominant user vice single-command control by DARCOM.

The evaluation was based on nineteen effectiveness criteria. The results of the analysis conducted by USAMCC for Concepts A and B are shown in Table D-1. Concept B was found to be the most favorable alternative in all but four of the nineteen criteria. A separate cost analysis was conducted, showing that the ten-year discounted cost for Concepts B, C, and D was similar but approximately $52 million less than Concept A. On the basis of these analytic results, Concept B was recommended by the study team and subsequently approved by DA. Implementation of the revised concept was planned in phases, with USAREUR first. In October 1979, DARCOM assumed command and control of all calibration and repair in USAREUR. All MOS 35B personnel were removed from maintenance units and reassigned to DARCOM Calibration and Repair Centers (CRC). The CRC is the new term for the organization providing single-source total calibration and repair support for general purpose TMDE (and calibration support for special purpose TMDE). The CRC may operate both mobile and fixed Area TMDE Support Teams (ATSTs) and an AACL. MOS 35B personnel were converted into MOS 35H, the single MOS responsible for both calibration and repair of common TMDE (35B training still continues for reserve personnel).

TEST EQUIPMENT SUPPORT CAPABILITY (USAREUR)

DARCOM assumption of the TMDE support role in Europe created the U.S. Army Test Equipment Support Activity Europe (USATESAE). The organization includes a headquarters located at Zweibruecken, collocated with the 200th Theater Army Materiel Management Center; and three CRCs, one each located in the three USAREUR support areas: Schwanheim (V Corps), Augsburg (VII Corps), and Pirmasens (21st SUPCOM). The CRCs have a number of ATSTs, both mobile and fixed, and base facilities including an AACL.

TABLE D-1. EVALUATION OF TMDE SUPPORT ALTERNATIVES[1]

Effectiveness Criterion	Weight	Concept A	Concept B
1. Deployment capability and personnel proficiency	11.2	85.4	91.0
2. Calibration/repair support commensurate with customer requirements	10.7	72.0	92.5
3. TMDE readiness	9.4	74.0	88.5
4. Management control to assure proper utilization of calibration/repair service	7.7	72.4	88.4
5. Maximum use of DARCOM management and technical expertise	7.4	73.9	98.5
6. Use of standard Army supply system but capable of capturing demand data for low density TMDE	6.3	67.6	88.6
7. Availability of required administrative/logistic support	5.9	74.4	85.1
8. Extent of compatibility with other US Forces and US Allies	5.6	72.0	91.0
9. Adequate utilization of calibration standards/equipment	5.1	68.6	94.1
10. AACL capability/redundancy to meet peacetime and wartime requirements	4.5	87.5	79.4
11. Variety of geographic assignments with adequate rotation base	4.4	90.0	90.8
12. Standardization of calibration/repair funding procedures	4.3	67.5	84.3
13. Uniformity in job classifications and wage grades	3.6	66.9	91.8
14. Extent to which concept has been tested in operational practice	2.9	88.8	79.1
15. Minimum impact on union contracts and existing agreements with foreign governments	2.9	93.1	76.5
16. Opportunities for job advancement/career development	2.6	75.0	89.1
17. Consistency with emerging Army doctrine (EAD-X, RGS)	2.4	76.3	82.9
18. Adaptability to automation	1.6	69.5	91.0
19. Adaptability to contractor support	1.5	77.5	89.6
Overall Operational Effectiveness		76.0	89.1
Ten Year Discounted Cost ($ million)		$ 261.7	$ 210.0

[1]The weight associated with each criterion was based on the study group's perception of the criterion's relative importance to overall mission accomplishment. The effectiveness score of each concept in terms of each criterion was based on the study group's judgment or quantitative data using a 100 point grading system:

100 = perfect satisfaction of criterion
90-100 = excellent
80- 90 = good
70- 80 = fair
60- 70 = poor
< 60 = unacceptable.

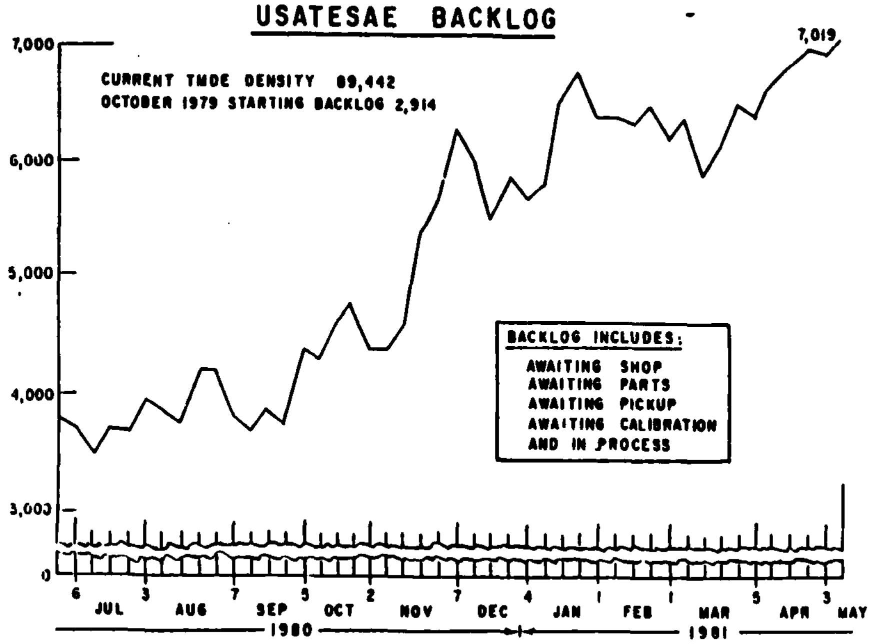
SOURCE: "DA Concept Study for Improved Army-Wide TMDE Calibration and Repair Operations, Volume II - Discussion, Analysis, Conclusions," March 1977.

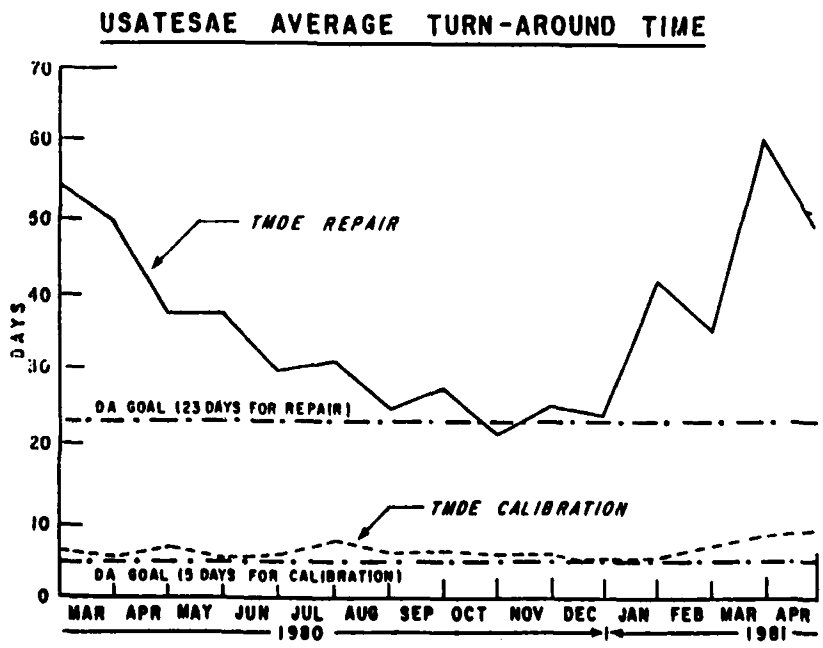
The TMDE supported by USATESAE amounts to a density of about 90,000 items in theater, comprising 10,017 different line items (data as of May 1981). The flow of TMDE requiring calibration and/or repair varies between 2,000 and 3,000 items a week. Since October 1979, when the reorganization became effective in USAREUR, the TMDE backlog has increased from 2,914 (1 October 1979) to 7,019 (10 May 1981). The average turnaround times for calibration and repair are above DA standard or goal (see Figure D-3). (Note: More recent data may or may not show improvements in these trends. Our data collection in USAREUR terminated in May 1981 with no opportunity to obtain more recent data.)

Excessive turnaround time for repair translates into unavailability of test equipment for the user, because there are virtually no operational readiness floats (ORF) for test equipment in theater. The records of USATESAE show a total of 60 line items of ORF (only 11 of which are identified as critical TMDE) with a density of 3,240 items, but most are radiac equipment (3,066 items). (Radiac test equipment is a special category; most of this equipment is small and returned by mail to CONUS for calibration or repair. It has possibly higher top-level visibility than conventional, non-nuclear test equipment.) Thus, in mid-1981, the entire inventory of conventional floats (i.e., above MTOE authorizations) in USAREUR was 174 items (53 lines) authorized with 203 actually on hand. USATESAE sees the need for reconstituting ORF to compensate for long turnaround times of critical TMDE but, as a DARCOM activity, it is not their responsibility; rather it is up to USAREUR as the owner of ORF. If an item is not listed in SB710-1-1 (ORF Factors), ORF is not authorized.

The weak TMDE support capability of USATESAE, in spite of the predicted increase in operational effectiveness as a result of the reorganization, may be attributed to two main factors: supply support (TMDE repair parts) problems

FIGURE D-3. TEST EQUIPMENT SUPPORT INDICATORS (USAREUR)





and shortage of skilled TMDE calibration/repair personnel. The first problem is caused by past proliferation of TMDE resulting in low density for most line items, associated low-demand data to which the Army's standard supply system is not responsive, and obsolescence of much of the equipment, causing unavailability of repair parts in the commercial market. The Army has taken steps to correct this problem so that it will become less serious in the future (see next section on Test Equipment Modernization). The second problem is a generic problem faced by the Army in many technical MOSs -- a problem for which there are no easy answers.

The personnel situation in USATESAE is shown in Table D-2. Part A of the table shows the requirements as determined by USAMCC based on actual workload (numbers of calibration and repair jobs per year), measured productivity, and ATST skill level composition required for proficient job performance. USAMCC assumed, however, that the consolidation of calibration and repair would result in a 20% gain in productivity. Thus, the stated requirement for direct worker billets is optimistic, if anything. Nevertheless, authorized direct billets show a significant decrease in skill level mix as a result of personnel policies. The second table shows a further reduction in skill level mix on-board, with only 50% of E-5 billets filled. The overfill of E-4 billets cannot possibly compensate in numbers for lack of experience and proficiency. If anything, they reduce the productive throughput capacity by requiring on-the-job training supervision from the limited E-5's available.

The need for on-the-job training of entry-level training graduates has become more pronounced than in the past due to reductions in training course lengths and limited hands-on training, while the job task requirements doubled as a result of the MOS 35B/35H merger. USATESAE supervisors estimated that the production could be increased by 30% if the people they had on-board were skilled: quality assurance workload could be reduced by 20%, and 25% of non-commissioned officer time now spent on monitoring or assisting apprentices could be utilized productively instead. Reportedly, MOS 35H training is undergoing review.

TABLE D-2. USATESAE CALIBRATION AND REPAIR PERSONNEL

A. Production Personnel Requirements and Authorizations

Grade	Requirements[1]	Authorized[2]
E-7	68	39
E-6	128	115
E-5	120	104
E-4/below	0	54
Total	316	312

B. TDA Authorization and Fill (MOS 35H and 35B)[3]

	HQ Det		Augsburg		Pirmasens		Schwanheim		Bn Total	
Grade	Auth	O/H	Auth	O/H	Auth	O/H	Auth	O/H	Auth	O/H
E-8	1	1	5	0	5	1	5	1	16	3
E-7	7	2	12	14	15	13	12	12	46	41
E-6			28	38	48	45	39	37	115	120
E-5			37	24	34	17	33	12	104	53
E-4			14	42	7	22	8	38	29	102
E-3			12	0	5	4	8	9	25	13
TOTAL	8	3	108	118	114	102	105	109	335	332

[1]Source: "DA Concept Study for Improved Army-Wide TMDE Calibration and Repair Operations, Volume VII - Update of Resource/Requirements Data," March 1978.

[2]See Table B minus indirect personnel.

[3]Authorization and on-hand (O/H) data as of March 1981. Numbers exclude administrative and support personnel (e.g., truck drivers).

TEST EQUIPMENT MODERNIZATION

Test equipment development, procurement, and support costs are easily underestimated because it is support equipment, not managed as a separate commodity so that specific data are lacking and costs are invisible. Nevertheless, these costs are comparable to ones associated with a major weapon system acquisition program. Tri-Service/industry estimates are that each of the Services has an inventory of $10 billion (procurement cost) and spends $1 billion a year to maintain this test equipment. In the case of the Army, this estimate may be too high; other sources estimate its inventory of test equipment at half that much. Table D-3 provides some statistics on Army test equipment showing the effects of past proliferation due to lack of management. With close to 9,000 different makes and models of test equipment in the present inventory (excluding special purpose test equipment), some experts estimate that standardization and control of common test equipment procurement could reduce this to 600.

The benefits of standardization lie especially in test equipment support. Important characteristics of the current inventory are that about 90% of the equipment is common test equipment, 10% weapon system peculiar or special purpose test equipment, and the distribution of test equipment density is extremely skewed. TMDE line items (make/model) with quantities of 20 or less in the Army-wide inventory constitute more than 90% of the total inventory. Conversely, makes/models with quantities of 100 or more represent only 2% of the inventory but nearly 60% of the total Army calibration workload. (Source: DA Concept Study for Improved Army-Wide TMDE Calibration and Repair Operations, Volume II, March 1977). Due to the low density of most TMDE, it was impossible in the past to accrue sufficient demand data to be able to stock required repair parts under the standard Army supply system. Even with

TABLE D-3. ARMY TEST EQUIPMENT STATISTICS

All Test Equipment	Inventory (1977)	Estimated Requirement
Number of line items (different makes and models)	8,800[a]	600[b]
Density (number of items)	730,000[c]	415,000[d]
Investment Cost	$5 billion[e]	$1.7 billion[f]

Notes:

(a) Number listed in calibration requirements bulletin, TB43-180.

(b)(c)(d) Source for estimates: "Assessment of DA/DARCOM TMDE Program," J. M. Heiser, Jr., LTG, USA (Ret.), September 1979.

(e) Average estimate includes $2.4 billion Army-owned test equipment installed at industry. Source as above.

(f) Projected requirement (RDT&E, PA, and OMA funds) for FY78-82. Source as above.

the consolidation of calibration and repair under the CRCs, it may be difficult to generate sufficient demand data to qualify for stockage of parts. Proliferation automatically translates into excessive repair turnaround time.

In view of these facts and the obsolescence of the 1950's era test equipment, the Army has programmed a TMDE modernization program designed to replace obsolete makes and models by a much smaller variety of modern test equipment. Originally planned as a five-year program, reduced funding is stretching this program out over a ten-year time frame at about $30 million a year starting with FY81. The impact this program will have on reducing current proliferation is illustrated by Table D-4, showing that the FY82 program will replace 650 makes/models by only ten new line items.

TABLE D-4. TMDE MODERNIZATION - FY82 PROGRAM

Item	Employed At	Number of Makes/Models Replaced
Digital Multimeter (3½ digits,20Hz-5KHz)	ORG-Depot	54
Ditigal Multimeter (4½ digits,20Hz-50KHz,RF probe)	DS-Depot	81
Oscilloscope (DC-100MHz)	DS-Depot	177
Oscilloscope (DC-200MHz)	DS-Depot	14
Signal Generator (450KHz-2.4GHz)	DS-Depot	84
Signal Generator (2.0-18GHZ)	DS-Depot	28
Signal Generator (Function, 0.1Hz-10MHz)	DS-Depot	81
Signal Generator (Pulse)	DS-Depot	41
Signal Generator (Sweep, 100KHz-40GHz)	DS-Depot	59
Transmission Test Set (Telephone)	ORG-Depot	30

APPENDIX E

WARTIME SUPPORT OPTIONS

INTRODUCTION

The purpose of this appendix is to illustrate the overriding influence of weapon system characteristics, not doctrinal notions, in wartime maintenance support. Two weapon systems are used as case examples: TACFIRE and the M1 ABRAMS tank. Both exhibit serious testability problems which would limit operational availability in wartime under current maintenance concepts and resources. The options to improve wartime support lead in opposite directions. In the case of TACFIRE, operational availability would be improved by moving maintenance skills further forward than the current support concept provides. In the case of the M1, the same objective would be achieved by moving a portion of organizational level skills back to the brigade support area. Either option assumes that the fix-forward repair time limits are real; i.e., system downtime beyond six hours results in evacuation to the brigade support area.

Advocating these changes is not our intent; the best way of solving a serious testability problem is to improve testability, not to work around it. Assuming that this is not done, however, our intent is to show the logical implications of the testability shortfall.

TACFIRE

Operational and Organizational Concept

The TACFIRE system is a network of computer centers and remote communication devices designed to automate command and control functions of field artillery (FA). Effective utilization of FA assets is very dependent on communications between and among FA elements and supported maneuver elements. FA is employed both as division artillery (DIVARTY) and non-divisional artillery (FA battalion, brigade, or group). The DIVARTY organizational structure consists of a headquarters, three DS battalions, one per maneuver brigade, and are one GS battalion. Each DS or GS battalion has three firing batteries. Non-divisional artillery units are attached to or reinforce a division and organized the same way as DIVARTY. Information on targets or friendly unit locations is provided by fire support teams (FIST) and forward observers organic to each DS or GS battalion, the target acquisition battery (for counter fire) organic to DIVARTY HQ, and aerial observers organic to reinforcing FA brigades. The maneuver elements, at each echelon, have a fire support officer or fire support elements (battalion/brigade fire support coordination center, division tactical operations center) responsible for coordination of fire support. The FA operations centers (DS or GS Battalion Operations Center, DIVARTY tactical operations center) are responsible for command and control of all fire support for maneuver forces, counterfire, and allocation of artillery resources, with the mission to provide dedicated, responsive, effective, and efficient FA fires.

Prior to TACFIRE fielding, the entire command, control, communications and intelligence system was dependent on radio communications and manual processing and compilation of targeting data, fire plans, and fire missions. The only equipment used was a Field Artillery Digital Computer (FADAC) at each battery for ballistic computations. With TACFIRE, the entire process is automated, permitting a significant improvement in mission performance with the same artillery resources. TACFIRE equipment includes the following:

- Fire Direction Center (FDC) installed at FA operations centers at battalion and higher echelons. Each FDC consists of one general purpose computer, data display equipment, and communications devices mounted in one (battalion operations center) or two (DIVARTY TOC) shelters (modified S-280).

- Variable Format Message Entry Device (VFMED) used by fire support elements to submit data to and retrieve data from the central computer. The VFMED is an input/output device, transportable in two transit cases, and mounted in a truck.

- Battery Display Unit (BDU) used by each firing battery. The BDU is an output device (one-way communications with the computer) which displays fire orders and ballistic solutions to the firing battery. The FADAC computer still remains with the battery as a back-up device for ballistic computations. Under an on-going TACFIRE product improvement program, the BDU will be replaced by the battery computer system (BCS), now in full production.

- Digital Message Device (DMD) used by fire support teams/forward observers to feed target data or friendly unit locations into the system. The DMD is a small, hand-held device.

Figure E-1 summarizes the organizational concept of TACFIRE. To get some idea of the communications needs to exploit TACFIRE capabilities, the following quote may be informative (referring to employment of the system in a division):

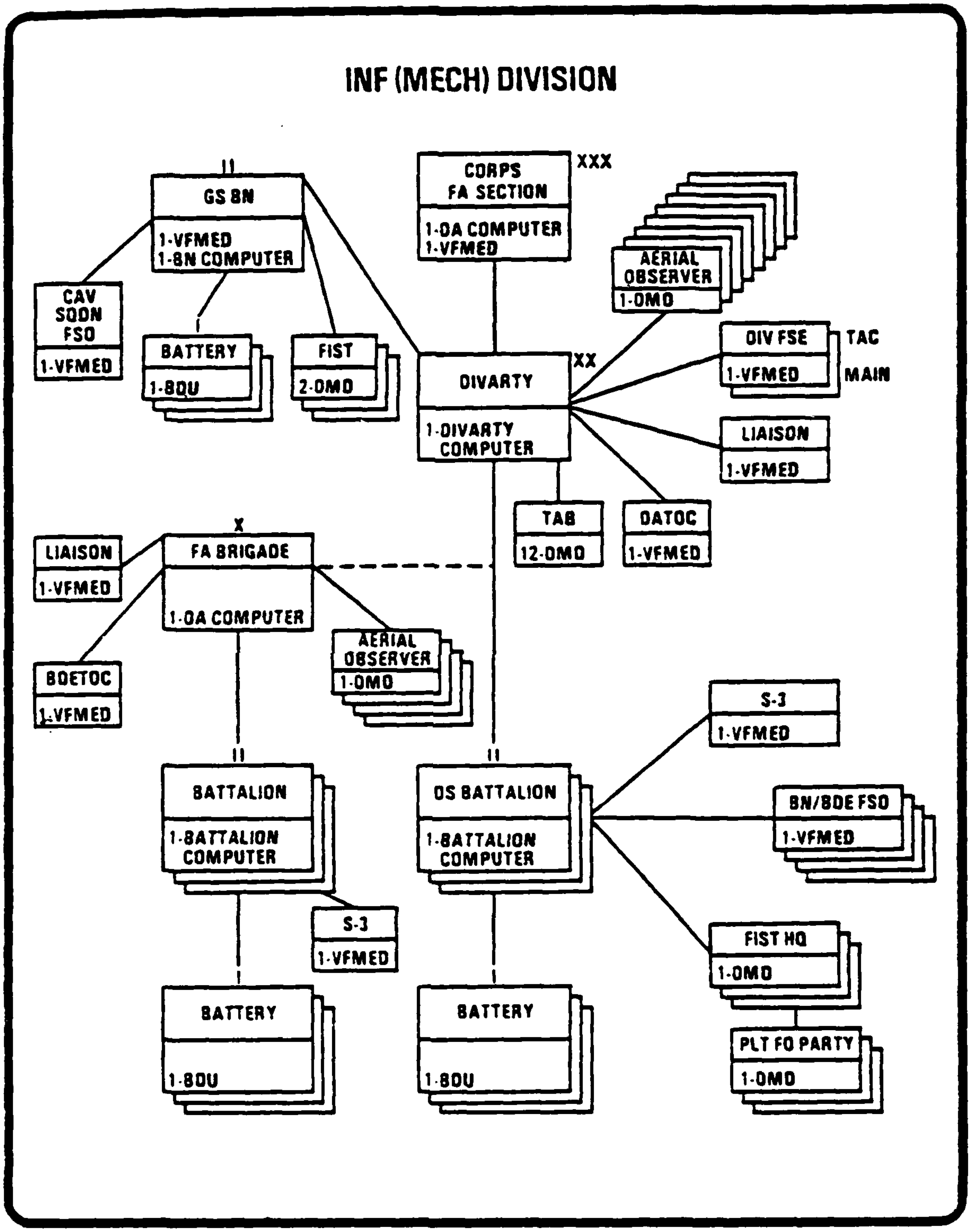
> "TACFIRE is a very demanding system regarding communications. Communications equipment must be properly aligned and well maintained. Maximum use must be made of 292 antennas and radio transmission stations." ("Materiel Fielding Plan," 25 January 1981)

System Description

The AN/GSG-10(V), Fire Direction System, Artillery (TACFIRE) consists of automatic data processing centers, local and remote input/ output devices, and operations facilities for FDC personnel. The major equipments and their employment were identified above. Each has a modular design; the major components are identified in Table E-1. However, software, not hardware, was the pacing item in the TACFIRE acquisition program and was one of the causes for excessive program delays (initial concept to initial fielding took close to 20 years). The software comprises:

- Operating System: The system is responsible for real-time execution of the application and maintenance and diagnostics programs

FIGURE E-1. DISTRIBUTION OF TACFIRE EQUIPMENT



Source: "TACFIRE", TC 6-1, U.S. Army Field Artillery School, July 1977.

TABLE E-1. TACFIRE COMPONENTS OF END-ITEM

Component[1]	FDC DA	FDC BN	VFMED	BDU	DMD	Units Per Division Slice[2]
	2	8	32	22	129	
Central Processing Unit (CPU)	1	1	-	-	-	10
Input Output Unit (IOU)	1	1	-	-	-	10
Mass Core Memory Unit (MCMU)	4	3	-	-	-	32
Magnetic Tape Unit (MTU)	2	1	-	-	-	12
Digital Data Terminal (DDT)	7	6	-	-	-	62
Communications Control Unit (CCU)	1	1	-	-	-	10
Power Converter Group (PCG)	2	1	-	-	-	12
Alphanumeric Keyboard (KYBD)	1	1	1	-	-	42
Display Editor (DE)	2	2	1	-	-	52
Switch Panel Assy (SPA)	1	1	-	-	-	10
Display Plotting Unit (DPU)	1	1	-	-	-	10
Display Control Unit (DCU)	1	1	-	-	-	10
Electronic Tactical Display (ETD)	1	-	-	-	-	2
Electronic Line Printer (ELP)	2	1	1	1	-	66
Remote Communications Monitor Unit (RCMU)	3	2	-	-	-	22
Remote Data Terminal (RDT)	-	-	1	1	-	54
Digital Message Device (DMD)	-	-	-	-	1	129
Packaging	2 shelters each	1 shelter each	2 transit cases each	2 transit cases each	hand-held device	TOTAL CEIs; 545

[1]Excludes miscellaneous items: interconnection kits, fixtures, terminal boxes, patch panels, power entry panel, tool kits, MTS and COMSEC.

[2]Includes equipment fielded with corps elements attached to division and to be maintained by same TACFIRE personnel.

in response to input messages from the various TACFIRE devices. It also formulates and distributes the necessary output to the appropriate addressees.

- Application Programs: These programs maintain current status information in various data files and perform computations required for artillery survey, target analysis, and fire planning.

- Maintenance and Diagnostic Programs: The maintenance and diagnostics software (MDS) is divided into routines which are continuously executed to check system status and a set of routines which must be initiated by the operator (when a system failure is detected) for the purpose of isolating a failure to a small group of circuit cards within the faulty device.

An informative description of the software development can be found elsewhere (see: Alan B. Salisbury, "TACFIRE: A Case History of a Weapon System Software Development," Journal of Systems and Software, Volume 2, pp. 155-175, 1980). The system is designed to permit "graceful degradation," so that mission processing can continue and repairs be deferred until the tactical situation permits. In the event an FDC is totally down (which would occur, for example, if the computer is down), lateral back-up capability exists by switching to an adjacent FDC, which can immediately assume the mission of the failed FDC but at the expense of throughput capacity.

Evolution of Maintenance Concept

The TACFIRE Quantitative Materiel Requirement (QMR) approved by DA in January 1966, included the following maintenance-related specifications for the FDC:

- 90% of system failures to be repaired by organizational level
- reliability: MTBF = 150 operating hours
- maintainability: MTTR = 30 minutes (system level repairs).

Requests for proposal for the contract definition phase were released in July 1966. Competitive contracts were awarded in February 1967 to three contractors for a 20-week level of effort to develop system specifications based on the given functional system design requirements. The source selection evaluation board made its recommendation in September. A total package procurement contract was awarded to Litton in December 1967. The program suffered serious delays due to hardware and software problems, and was later, in 1973, converted to a cost-plus-fixed-fee contract. The first production unit was fielded in 1979.

The original maintenance concept proposed by Litton was strongly influenced by the QMR and the policy of maximizing maintenance on-site to achieve required operational availability. The concept was as follows:

- Organizational: The operator/maintainer (proposed MOS 31B) repairs 90% of system failures through replacement of cards or modules using diagnostic aids: built-in test providing fault detection; maintenance diagnostics sofware providing fault localization to a group of cards (ambiguity group) identified by a fault code; fault catalog listing the suspect cards in the ambiguity group in order of probability of failure; special test equipment (AN/GSM-208) known as the Module Test Set (MTS) to check digital cards; and "fault isolation modules" (one spare card of each type in the system mounted in drawers within the shelter and known to be good) to assist in fault isolating analog cards and verifying fault isolation.

- Direct Support: Provides no maintenance, just supply support.

- General Support: Contact maintenance team provides on-site maintenance support as far forward as the battalion FDCs. The team (comprising two computer repairmen, MOS 34G, and a Communications-Electronics Materiel Command (civilian) field maintenance technician) carries maintenance floats (major component of end-item (CEIs), Table E-1) to replace the items which the operator/maintainer is unable to troubleshoot and performs troubleshooting and repair of those items in the mobile test facility, a complete hot mock-up of the FDC mounted on a tractor-trailer.

- Special Repair Activity/Depot: Performs card repair using automated test equipment (ATE) and overhaul of components.

This concept was deemed unacceptable by TRADOC in view of the limited operational suitability of the mobile test facility in forward echelons. Also, maintenance policies at the time discouraged the use of hot mock-ups as test equipment in the field (AR 750-43).

The revised concept, tested in OT II (1974) and OT III (1977), eliminated the hot mock-up but was intended to provide responsive on-site support. The changes were as follows:

- Organizational: No change, except for a change in MOS (MOS 13E vice MOS 31B).

- Direct Support: A contact maintenance team (two MOS 34G repairers for the entire division) provides on-site support for those failures the operator/maintainers are unable to repair. If the contact team cannot repair the failure on-site, it replaces the faulty CEI(s) with maintenance floats carried by truck. The team returns faulty items to the division support area (Headquarters & Light Maintenance Company of the divisional maintenance battalion) electronics shop; if repair is beyond DS capability, the item is evacuated to GS or depot. The contact team has test equipment not authorized at the organizational level (common TMDE including oscilloscope, ohm meter, multimeter; and special test equipment including a "passive maintenance device" to troubleshoot wiring problems and the MTS), but relies primarily on the same diagnostic aids available to the operator/ maintainer. A civilian field maintenance technician is available at the divisional maintenance battalion to assist in troubleshooting, especially with regard to software problems.

- General Support: Provides backup to DS but has no specific skills or test equipment beyond those available at DS for CEI repairs. GS is authorized repair of selected cards (based on level of repair analyses (LORA)) using ATE for fault isolation.

- Special Repair Activity/Depot: Repairs those cards not authorized at GS, provides backup to GS, and overhauls end-items.

OT II was focused upon TACFIRE operations, not maintenance; the test surfaced significant shortcomings in operator training (and other problems not germane to the present discussion). During OT III serious maintenance deficiencies were identified which necessitated a change in maintenance concept. The key problems were as follows:

- Inability of the operator/maintainer to fault isolate more than approximately 70% of system failures (OT III report assessed this parameter at 77%; a subsequent Logistics Evaluation Agency study estimated this at 60%).

- Inadequacy of DS manpower to provide responsive on-site assistance in support of TACFIRE wartime operations.

- Conflict between system readiness requirements and the need to take the system "down" to fault isolate system failures to the module (circuit card) level. Mission requirements and the ability to operate the system in degraded mode combine to present a strong incentive to continue operation deferring corrective maintenance until the system is totally degraded and multiple failures necessitate extensive technical assistance and system downtime.

The revised maintenance concept, evaluated during the "subsequent maintenance assessment" in 1978, resolved this conflict, in part, by moving difficult fault isolation tasks away from the tactical equipment, using DS on-site assistance to replace suspect CEIs, not boards within the CEI, and using a hot mock-up, not the tactical equipment, to fault isolate suspect CEIs. The specific changes were as follows:

- Organizational: No change, except that the expected fault isolation capability was reduced from 90% to 70%. Also, the operator received more TACFIRE training resulting in a new MOS (MOS 13C: TACFIRE operations specialist) vice the old MOS (MOS 13E: cannon fire direction specialist, with an additional skill identifier for TACFIRE operations). A TACFIRE warrant officer was added to DIVARTY to improve management of TACFIRE support and establish repair priorities.

- Direct Support: One contact team (two computer repairmen) per artillery battalion provides direct support and is colocated with the forward support company (DS) in each brigade support area. The support consists primarily of providing maintenance floats, replacing faulty CEIs, and returning them to the division support area where the TACFIRE maintenance support facility (MSF) is located. (In peacetime, or if the system has no firing mission, the contact team attempts to fault isolate to the circuit board level and replaces boards, not CEIs.) The MSF consists of a complete hot mock-up of the FDC in battalion configuration (AN/USM-141) and two computer repairmen. (Due to the increasingly large number of different equipments supported by MOS 34G, this MOS was split into several MOSs in 1980. One of these is MOS 34Y, field artillery computer repairer.)

- General Support and Depot: No change.

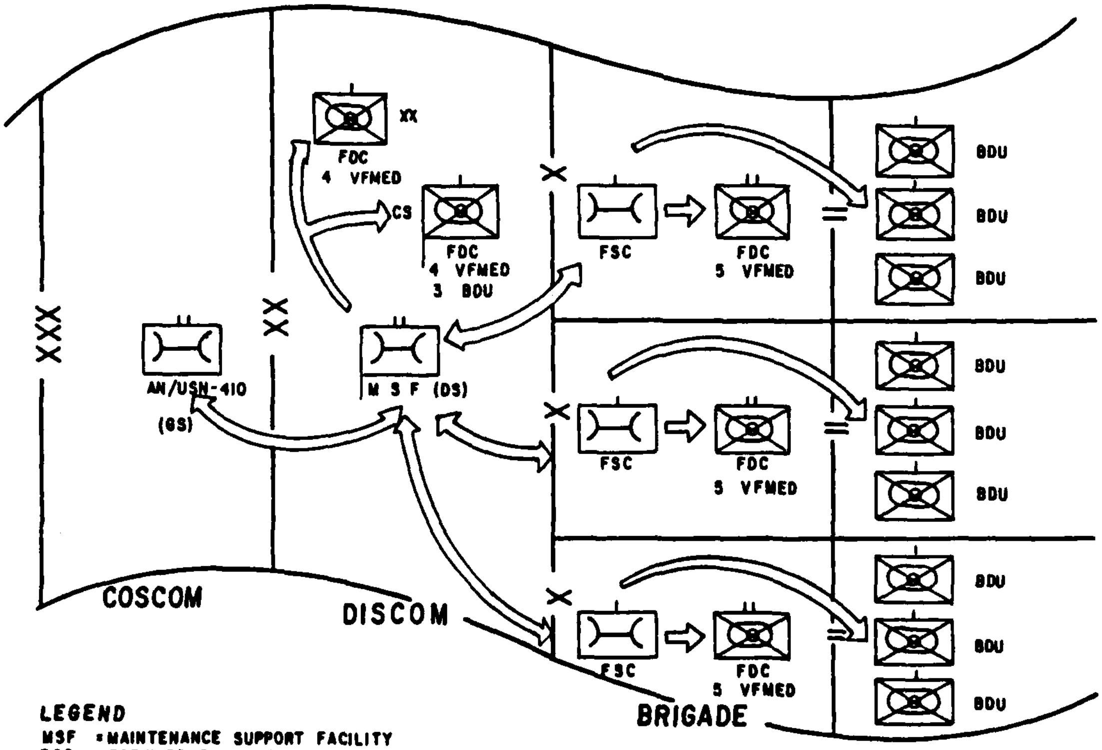
This final revision of the maintenance concept was evaluated in 1978 during a 100-hour command post exercise ("subsequent maintenance assessment") and found acceptable. No further changes in concept have occurred in the early years of TACFIRE fielding (see Figure E-2). The above discussion has focused on the FDC because it is the most important part of TACFIRE. The same maintenance personnel supporting the FDC also support the remote devices:

- VFMED: This equipment, normally mounted in tracked vehicle, has BIT which performs poorly (about 40% to 50% of faults are isolated). The DS contact team either fault isolates to the faulty circuit board using common TMDE or replaces the faulty CEI.

- BDU/BCS: The BDU had no BIT and due to its limited capabilities is being replaced by the BCS, now in full production. The BCS is composed of nine modules and is designed with BIT which, reportedly, is performing well.

- DMD: This equipment is direct exchanged (floats are stocked at the forward support company) and repaired in the TACFIRE MSF or evacuated to depot.

FIGURE E-2. TACFIRE MAINTENANCE CONCEPT



LEGEND
MSF = MAINTENANCE SUPPORT FACILITY
FSC = FORWARD SUPPORT COMPANY
FDC = FIRE DIRECTION CENTER (TACFIRE END ITEM)
BDU = BATTERY DISPLAY UNIT (TACFIRE END ITEM)
VFMED = VARIABLE FORMAT MESSAGE ENTRY DEVICE (TACFIRE END ITEM)

Maintenance Performance

Data generated by the subsequent maintenance assessment (SMA) test are shown in Table E-2. The following observations are worthy of note:

- Actual failures were about five times what would be expected on the basis of demonstrated reliability. For example, the MTBF for the FDC was 104 hours based on DT/OT III, but during the SMA the FDCs had a failure every 21 operating hours.

- About 25% of system failures required DS contact team assistance. Overall, 7 of the 17 malfunctions restored by contact teams were actually organizational level tasks according to the Maintenance Allocation Chart (MAC); 3 of the 6 FDC failures repaired by contact team were organizational level tasks.

- In spite of the ideal circumstances of this test (no electronic warfare was played so that communications were unhindered; players were familiar with the terrain so that contact teams did not get lost), it took over one and a half hours to process a request for contact team assistance, and about one hour for the contact team to arrive on-site from the time it received the request (after correction for distance and travel speed in a Scenario-Oriented Recurring Evaluation System (SCORES) II wartime scenario). That the administrative and logistics delay time (ALDT) was relatively low (seven hours for FDC parts during the total SMA period) was due to adequate stockage and the fact that the contact team often was already on its way to on-site when assistance was required; for example, for FDC failures the ALDT was 70 minutes per failure repaired by contact team instead of the 150 minutes otherwise required.

- Heavy reliance on contact team assistance implies a high work load for these teams (which are not manned for 24-hour operation), yet their producitve maintenance hours are low due to travel time. For example, with wartime divisional TACFIRE operation around the clock (i.e., the 100 SMA test hours compressed in five days including two moves), the available contact team manhours (three teams of two MOS 34Y technicians each) in a five-day period would be 205 manhours by manpower authorization criteria standard. Though their productive maintenance manhours would be 36.5 (hands-on maintenance 2,189 man minutes per Table E-2), they would actually be extremely busy. Eliminating the multiple calls for assistance for one VFMED and one call deferring an FDC maintenance action, they would receive, on the average, 34 calls for assistance, with about 20 while back at the forward support company and the remaining 14 while underway. The SMA test data indicate that they could spend about 300 manhours getting ready and in transit, well above the manhours available. The implication is that productive utilization of these contact teams is low; a result which is aggravated by the critical shortages in MOS 34Y due to poor retention.

TABLE E-2. TACFIRE MAINTENANCE DATA

A. CORRECTIVE MAINTENANCE (All Times in Minutes)

END ITEM	TEST TIME	NUMBER OF FAILURES	DOWNTIME		A_o[1] (%)	OPERATOR/MAINTAINER			DS CONTACT TEAM		
			CM	ALDT		Failures Corrected	MMH	MTTR	Failures Corrected	MMH	MTTR
FDC	30,000	24	812	417	95.5	18	403	14.0	6	1110	93.3
VFMED	96,000	21	1489	6254	91.6	12	1805	74.3	9	1062	66.4
BDU	78,000	26	340	682	98.2	24	551	13.8	2	17	5.0
TOTAL	6,000/Item	71	2641	7353	85.9	54	2759	27.3	17	2189	68.7

[1]Includes downtime of 876 minutes caused by GFE outage (generators, air conditioners, radios, etc.).

B. DS CONTACT TEAM ASSISTANCE (All Times in Minutes)

END ITEM	NUMBER OF[2] OPERATOR REQUESTS FOR ASSISTANCE	DELAY TIME FROM FAILURE TO OPERATOR REQUEST	AVERAGE TIME TO PROCESS REQUEST	GET READY TIME FOR DS CONTACT TEAM	AVERAGE DS TRAVEL TIME (ONE WAY)	COMPARABLE TRAVEL TIME IN SCORES-IIA SCENARIO (17km/Hour)
FDC	8	8	87	37	22	61
VFMED	21	7	110	26	23	64
BDU	2	1	103	20	53	67
DMD	11	20	74	7	30	73
TOTAL	42	9	94	23	26	66

[2]Includes four FDC problems and four VFMED problems repaired by operator prior to arrival of contact team; eight calls for the same VFMED problem before it was finally repaired by DS.

KEY:
- CM = Corrective Maintenance
- ALDT = Administrative and Logistics Delay Time
- MMH = Maintenance Manhours (in minutes)
- MTTR = Mean Time To Repair (in minutes)

SOURCE: "TAFIRE Subsequent Maintenance Assessment," TCATA Rest Report 1089, TRADOC Combined Arms Test Activity, Fort Hood, November 1978.

Operational maintenance data on TACFIRE is scarce due to limited operating hours to date. Data collected by Communications Research and Development Command (CORADCOM) in 1979 and 1980 suggest the following:

- Most system failures are corrected by DS contact team. The reported percentage of repairs accomplished by the operator/ maintainer ranges from 20% (while on field exercise) to 50% (in garrison).

- System reliability shows an upward trend; e.g., the DIVARTY FDC exhibits a MTBF of 123 hours (CORADCOM assessment, 1980).

- Utilization of the hot mock-up permits screening suspect boards before they are evacuated to GS or depot. The NEOF rate experienced in TACFIRE circuit boards at Tobyhanna Army Depot is about 35%.

- Fire direction officers tend to assign higher priority to mission requirements or readiness than to corrective maintenance requirements. Much of the equipment is operated in degraded mode for many months until major repairs are absolutely necessary.

Root Causes of Maintenance Shortfalls

Causes of the poor maintainability of the system may be summarized as follows:

- Shortfalls in Automated Diagnostics: About 60% to 70% of system failures are isolated by BIT and MDS programs to functional areas (ambiguity groups) vice the 90% expected. One reason for this shortfall is that design engineers assumed that close to 100% of failures would occur in circuit boards; actually, failures occur all through the system, particularly in the interconnections, which the automated diagnostics are not designed to fault isolate. When the system ages in the future, this gap in automated fault isolation capability is bound to get worse. (In contrast to the TSQ-73, also designed by Litton, the TACFIRE FDC is designed to be dismountable from the van. This Army-specified design requirement magnifies the interconnection problem.)

- Shortfalls in Semi-Automated Diagnostics: The MTS is designed to provide a rapid, automated means by which the operator can find the faulty circuit card within an ambiguity group of digital cards. It is a card edge tester hooked up to a display which is supposed to show whether or not the card under test is faulty. Using this test equipment is, however, not as easy as advertised. There are at least 12 different failure modes which may cause a card to fail the MTS check, 11 of which do not entail a failed element on the card tested:

  -- poor seating (resistive contacts on the card module under test/unit under test interface)

-- poor seating on the MTS probe/card module under test interface

-- open circuit in the unit under test wiring affecting the card module under test

-- defective element in the circuitry on a card module driving the card module under test

-- poor seating on the driving car module/unit under test interface

-- power deficiency in the unit under test

-- defective relay in the card module under test

-- defective relay on the driver card

-- defective MTS probe

-- defect in MTS itself.

Many of these failure modes produce apparently identical failure indications on the front panel (display) of the MTS. A great deal of schooling and experience is required before the operator can determine quickly and accurately where a failure is located and what is causing it.

- Shortfall in Training: The above technical limitations in the diagnostics aids provided to the operator, are not compensated by technical training. Instead, the curriculum is based on the presumption that automated diagnostics performs as advertised (90%), and that use of the MTS is a simple task unambiguously identifying the faulty card. Trainees are taught to call contact team support for those "few" failures that they cannot isolate using these automated diagnostics tools.

- Shortfall in Experience: Because of the perceived conflict between mission or readiness requirements and corrective maintenance (requiring to take the system down), operators do not get the opportunity to "grow" their troubleshooting skills in the field environment. Instead, the attitude taught in formal school is reinforced so that there is no interest in using or improving the few maintenance skills they do possess.

Wartime Sustainability

Sustainability of TACFIRE in wartime is clearly limited. To improve wartime support, an increase in organizational level maintenance skills organic to each artillery battalion is essential. There are different ways in which this might be effected. One alternative, providing a TACFIRE maintenance warrant officer at each battalion's FDC, was previously recommended by the user but rejected by DA. (Instead, one warrant officer was authorized at DIVARTY HQ.) A second alternative would be to add a senior non-commissioned officer billet to each FDC with personnel filling those billets receiving extensive technical training after they spend their first enlistment term as TACFIRE operations specialist. A third alternative would be to increase the skill levels of the current TACFIRE operators; for example, institutional skill level 20 and 30 courses could be given and/or the operators might be rotated between the FDC and the TACFIRE MSF to improve troubleshooting skills through hands-on practice.

Any of these alternatives improves maintenance capabilities organic to the artillery battalions so that the dependency on contact team support may be reduced. Under this approach, contact team assistance is primarily to provide parts, not skills. The need for MOS 34Y personnel to perform component repair in the TACFIRE MSF (and as backup capability) remains, of course, unchanged. Thus requirements for MOS 34Y may be reduced by using them more efficiently.

The improvement in TACFIRE mission sustainability by increasing organic maintenance skills is not immediately clear from standard logistics computations of operational availability. For example, Table E-3 compares the current support concept with the alternative option outlined above. The manpower increase resulting from injecting organizational level maintenance personnel is partially offset by a reduction in DS contact team personnel. Using conservative estimates of maintenance requirements (reliability) and task difficulty (repair time distribution, see Figure E-3), the alternative support option would provide only a small increase in operational

TABLE E-3. TACFIRE FORWARD MAINTENANCE SUPPORT OPTIONS

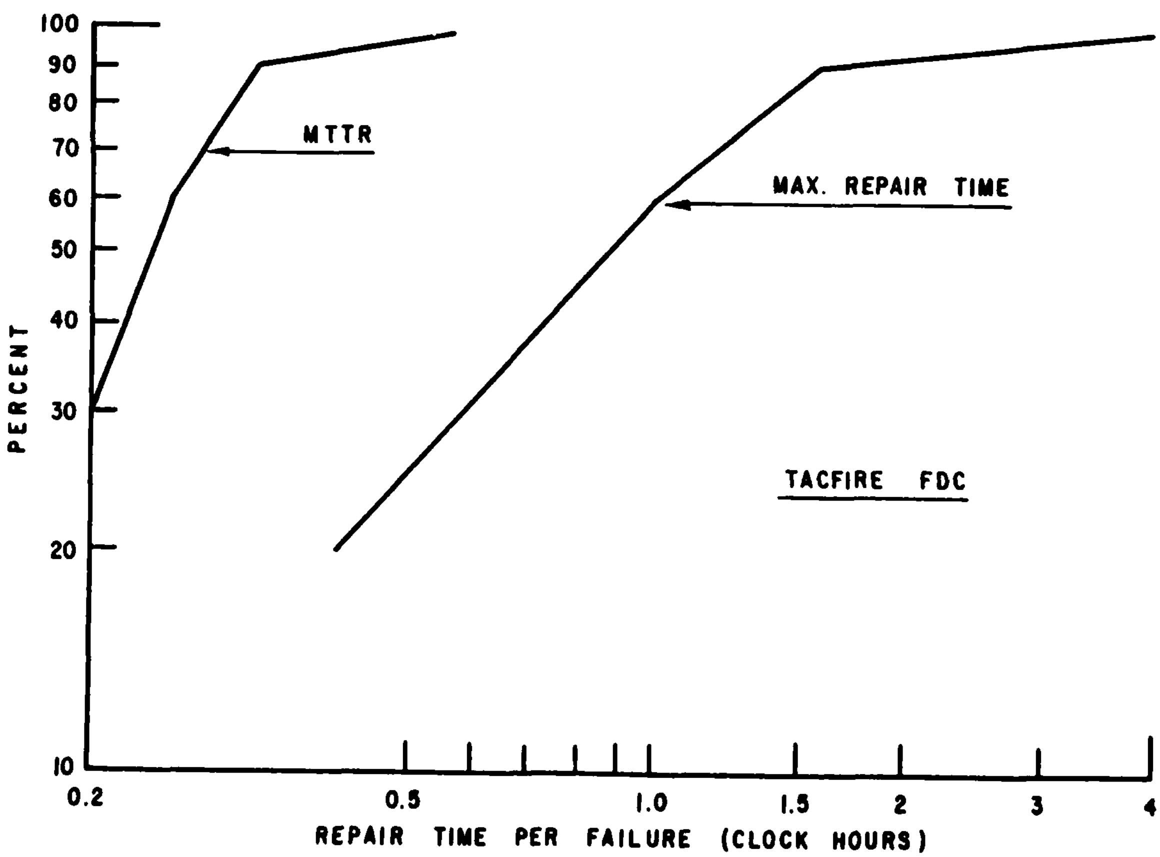
(Estimates Based on SMA and Operational Exercise Data)

ITEM	CURRENT CONCEPT	ALTERNATIVE OPTION
Maintenance Allocation (percent corrective maintenance actions, FDC equipment only)		
- Operator	30%	10%
- Organizational	-	80%
- DS Contact Team	70%	10%
Maintenance Manpower in Division Slice		
- Unit	-	7 MOS 13X (1 each per Bn FDC)
- DS Forward	6 MOS 34Y (attached to Bde Spt Bn)	2 MOS 34Y (attached to DIVARTY)
- TACFIRE MSF	2 MOS 34Y	2 MOS 34Y
Equipment Parameters Based on Best Estimates		
- MTBF (FDC)	30 Hours	
- MTBF (Mission)	120 Hours	
- Repair Time	Figure E-3	
- Support Equipment Availability	85%	
Average Administrative and Logistics Delay Time (including contact team travel)		
- From Bde Area	2.5 Hours	
- In Bn Area	0.5 Hours	
Average Downtime Per System Failure (half of requests for assistance met by contact teams already underway)		
- MTTR	.58 Hrs	.58 Hrs
- MALDT	.35 * 2.5 + .35 x 0.5 = 1.05 Hrs	.8 * .5 + .1 * 2.5 = .65 Hrs
- Mean Down Time	1.63 Hrs	1.23 Hrs
Criterion Measures		
- Operational Availability (FDC non-degraded including support equipment)	$.85 * \frac{30}{31.63} = 80.6\%$	$.85 * \frac{30}{31.23} = 81.7\%$
- Mission Sustainability without DS Assistance	210 Hrs (see Figure E-4)	1850 Hrs (see Figure E-4)

availability. If that were the criterion, this would hardly be worth the effort. A more fundamental criterion, however, is wartime sustainability. One measure for that criterion is the mission duration which could be sustained in the absence of DS contact team assistance: interruptions in the latter are not improbable in wartime. We have not performed the detailed analysis required to assess quantitatively the increased mission sustainability. The numbers shown for the criterion measure in Table E-3 are a rough approximation, indicating more an order of magnitude than a precise estimate. More detailed data, operating scenarios, and a simulation model would be required to compare the alternative concepts in terms of this criterion.

FIGURE E-3. CUMULATIVE DISTRIBUTION OF REPAIR TIME

(Estimate Based on SMA Data)



Our estimate of wartime sustainability is based on the following assumptions:

- Degraded Operation: The true system MTBF for the FDC is assumed to be 120 operating hours in accordance with optimistic estimates using recent operational data. It is assumed that the system can continue mission performance when failures occur without being repaired. After four failures, however, it is assumed the system is down. It is also assumed that the MTBF for such component failures is a constant, regardless of component or failure mode.

- Mission Scenario: Firing missions are assumed to come in bursts lasting 50 to 100 hours, on the average 72 hours. After every mission, operational status of the FDC is interrupted for maintenance and mobility. These lulls have an average duration of 10 hours providing enough time for repairs if the required skills are available. Under the current support concept, operators are able to repair, by removal/replacement, 30% of the failures; under the alternative option, organizational mechanics are able to repair 90%. In either case, repairs are possible only as long as the system is not totally down (i.e., has four unrepaired failures).

- Support Scenario: There is no DS contact team assistance to perform those repairs beyond unit maintenance capability. Parts are assumed to be available as needed, either from combat load list or war reserve materiel through supply channels.

We know these assumptions are not accurate; they are, however, a reasonable approximation of reality for comparison purposes. The result is shown in Figure E-4, based on the following computations. For an exponential failure distribution, the component mean time between failures (m) is computed as follows:

$$\text{Prob}\ \{\text{component failure between o and t}\} = F(t) = 1 - e^{-t/m}$$

$$\text{Prob}\ \{\text{component operational after 120 hours}\}$$

$$= 1 - \text{Prob}\ \{\text{4 component failures in 120 hours}\}$$

$$= 1 - (1 - e^{-120/m})^4 = 0.5 \rightarrow m = 65.28 \text{ hours}$$

For an average mission duration of 72 hours, and lulls between successive missions lasting long enough to make repairs if the skills are available, the probability that the system is operational (though degraded) after k lulls is given by the following expression:

$$1 - (1 - Q)^4,$$

where

$$Q = (1 - P_f + P_f P_r)^k$$

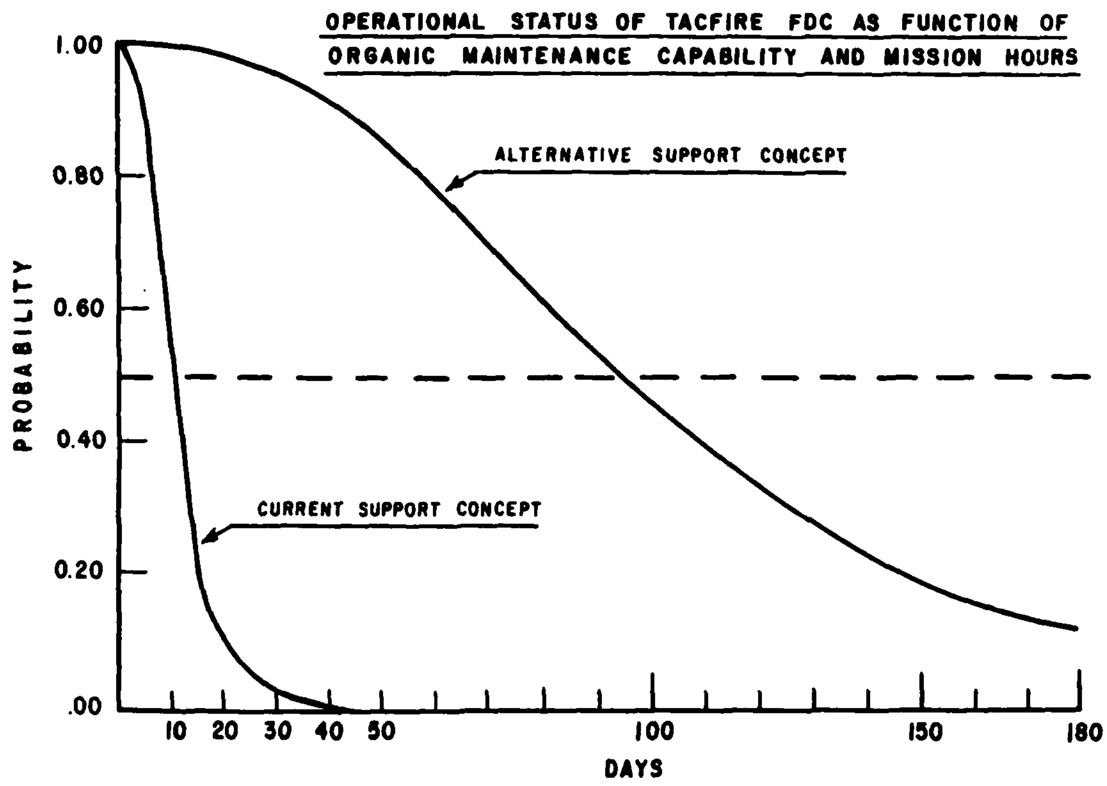
P_f = Prob {component failure in 72 hours, given m = 65.28 hours}

P_r = Probability of repair of component failure

K = Number of lulls between firing missions = number of firing missions = $\frac{\text{Operating Hours}}{72}$

(The probability that the system would be nondegraded is Q^4.)

FIGURE E-4. COMPARISON OF WARTIME MISSION SUSTAINABILITY WITHOUT DS ASSISTANCE



This expression was evaluated on a computer for different values of P_r and k. The result for the support concepts discussed (P_r = 0.3 for current concept, P_r = 0.9 for alternative) is shown in Figure E-4. For a 180-day war scenario, the alternative clearly offers significant advantages which do not surface under standard A_o computations. Without DS assistance, TACFIRE has a 50% probability of being down (unrepairable without DS) after 210 operating hours (approximately ten days) under the current support concept; after 1850 operating hours (approximately 90 days) under the alternative concept.

M1 ABRAMS TANK

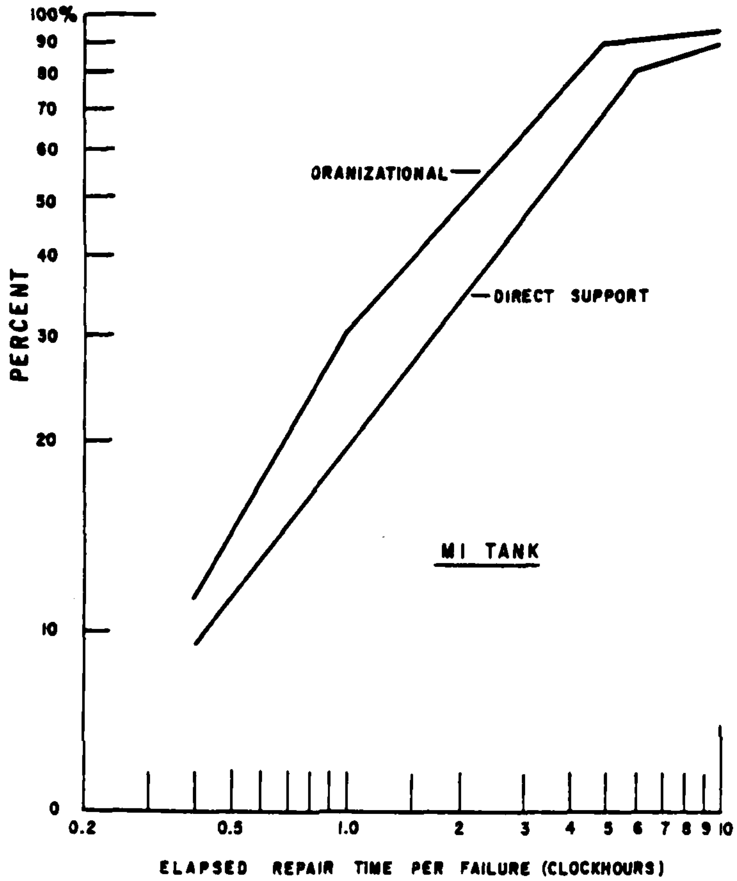
Maintainability

The M1 program and the tank's impressive operational capabilities, despite its disappointing reliability and maintainability characteristics, have been addressed in many reports. The maintenance support problems may be traced back to the lack of timely integrated logistic support planning, program schedule constraints, and design-to-unit production cost ceilings. Whatever the root cause, the tank exhibits poor testability. This results in lengthy on-equipment repair times (primarily for fault isolation), bulky test equipment (STE-M1), and a need for experienced personnel if maintenance is to be effective. These effects tend to limit the extent of fix-forward which could be expected in wartime. The extent of the maintenance problem was described in a recent LMI report: "An Approach to Evaluating Maintenance Difficulty," Working Note ML101, July 1982.

Figure E-5 shows the distribution of hands-on repair times as measured during OT III. Two curves are shown: one for organizational and one for direct support repair tasks. No information is available on the percentage of the latter tasks which were on-vehicle. (Based on MAC data, about 45% to 50% of DS maintenance is on-vehicle -- a percentage, incidentally, which is

FIGURE E-5. CUMULATIVE DISTRIBUTION OF REPAIR TIME

(OT III)



comparable to that for the M60A3.) The OT III data may or may not be representative of what will happen in the operational environment once the support system has matured. For example, the efforts by the diagnostics improvements task force will result in correcting some of the present problems through improvements in technical manuals and test program software, enhancements of alternate troubleshooting procedures and schematics, improved quality control at the manufacturer, and certain hardware engineering changes. On the other hand, bearing in mind the poor maintenance practices encountered for the M60 tank (see Chapter 2), improvements in maintenance performance in the operational environment over OT III test results would seem uncertain. Even with the introduction of skill level 3 technical training courses (as the Army is currently planning), the inherent lack of testability, in our estimation, will limit potential improvements in repair times.

Some of the long repair times are due to fault isolation problems. A consensus estimate is that for the mature system about 50% of failures will require manual troubleshooting procedures to isolate the failure to a single, removable assembly (LRU). Another factor explaining lengthy repair times for some failures is the limited accessibility resulting from the tight packaging of the components within the tank hull/turret. For example, in the case of an engine failure, the engine must first be removed using a crane (authorized at the organizational level), repaired by replacing whatever is wrong (which may be as simple as replacing a solenoid or starter), and then re-installed. The total operation requires about 18 hours, 9 of which are on-vehicle (remove/re-install engine) and 9 off-vehicle. Similarly, a failure in the gunner's primary sight assembly requires removal of the total assembly, again using a crane, repair by replacing the faulty module, such as the laser range finder or thermal integrated sight, and re-installation. The entire operation takes 7 to 8 hours by MAC (12 hours per operational data), partly on-vehicle (3 hours) and partly off-vehicle (4.7 hours). The Army's philosophy, generally, is to authorize those off-vehicle repairs at the organizational level if the repairs are simple (remove/replace of components, no repairs involving disassembly). This policy reduces spares stockage requirements, thus saving costs and improving mobility.

Maintenance Requirements Analysis

The M1 was one of the first Army programs for which a comprehensive analysis of maintenance manpower and logistics support requirements was conducted in accordance with TRADOC Regulation 11-8 (issued February 1981).[1] That regulation requires the system proponent to perform a maintenance manpower and logistics analysis (MMLA), for both peacetime and wartime scenarios, as part of the cost and operational effectiveness analysis prepared/updated for each major program milestone.

The M1 MMLA was done in two parts: a battalion-level study using a stochastic simulation model and a theater-level study using a deterministic model. Neither study included wartime cannibalization nor off-vehicle (LRU) battle damage repair, so the analytic results tend to overstate wartime parts requirements and understate maintenance manpower requirements. The MMLA effort was too comprehensive to summarize here with proper credit to that study. Results, however, insofar as maintenance manpower requirements are concerned, are summarized in Table E-4. While the total maintenance manpower provided by TOEs is sufficient to perform all non-deferrable, essential maintenance (excluding battle damage repairs), it is not available at the right place: only 65% of the organizational requirement is covered and there is no excess at DS; all the excess is at GS. One way of cutting the requirement down is to eliminate all off-vehicle repairs; this would double stockage requirements (from $6 to $12 billion), but eliminate the maintenance manpower shortage. Another approach addressed by the study was a redirection of maintenance workload. The MMLA study recommended that the manpower allocation across maintenance echelons be reviewed.

[1]That regulation and the M1 analysis were the result of guidance from the OASD(MRA&L), one applicable to all Services (Memorandum, "Manpower Analysis Requirement for System Acquisition," 17 August 1978, also known as the "White Memo") and one specifically directed to the M1 program (Memorandum, "XMI Manpower and Logistics Analysis Requirements," 25 July 1979, also known as the "Danzig Memo").

Wartime Support Option

The Army's M1 MMLA study highlighted the forward maintenance capability deficiency, but it did not address how this could best be resolved. It left the solution open, either moving maintenance personnel forward or moving equipment to the rear. The study results, summarized in Table E-4, assume perfect maintenance. No allowances are included for diagnostic problems which may double or triple the estimated repair items, for cannibalization of unrepairable tanks to recapture needed parts, or for battle damage repair. The battalion-level MMLA study, however, showed that the repair of battle damage could be as much as seven times the non-deferrable portion of scheduled and unscheduled maintenance.

TABLE E-4. WARTIME MAINTENANCE MANPOWER REQUIREMENTS (M1 MMLA)[1]

Maintenance Category	Non-Deferrable Maintenance Only		TOE Maintenance Manpower (H-Series TOE)
	Including Repairs Off-Vehicle	Excluding Repairs Off-Vehicle	
Organizational	2,356	610	1,548
Direct Support	1,808	1,000	1,813
General Support	440	61	3,720
Depot	(1,367)	(714)	-
Total Military Manpower	4,604	1,671	7,081

[1]Theater-level, 180-day war scenario; 2,003 tanks; average daily usage: 14 operating hours (including idle time), 7.2 miles travel, and 5 rounds fired.

Based on the data currently available, repair time limits would cause the following allocation of on-equipment repairs:

- Company Area: at most 15% (time limit 2 hours)
- Battalion Trains Area: 60% to 70% (time limit 6 hours)
- Brigade Support Area: 15% to 25% (time limit 24 hours).

This allocation is based on known repair time distributions and an estimated time of one and one-half hours minimally required to call for maintenance assistance, process the request, get ready, and other indirect time such as hook-up time of the STE-M1 (which can be as much as 45 minutes).

What proportions of system reliability failures would actually be repaired at each echelon would depend on battle conditions, mission criticality of failures, and maintenance workload versus capacity. Failures requiring the STE-M1 for fault isolation would most likely not be repaired in the company area because moving this test equipment around in that environment is unrealistic. The unserviceable equipment rally (UER) point in the combat trains area would thus be the foremost location for any system repairs other than simple failures diagnosed visually and repaired further forward. At the UER point, the choice is between recovering the tank further to the rear (the maintenance collection point in the brigade support area), repairing the tank on-site, or cannibalizing the tank for serviceable components needed to repair other tanks. The intent would be to repair as much as possible at this echelon, because the alternative is a combat loss to the battalion commander (the turnaround time for vehicle repairs at the next higher echelon, the brigade support area, would be at least 24 hours). The choice is made more difficult, however, by the fact that the needed repair time often cannot be estimated in advance with certainty; i.e., the failure symptom, due to lack of testability, does not define unambiguously the repair tasks and associated repair times needed. The implication of a wrong decision (starting a tank repair task which turns out to require 12 hours before it is completed) is an increased exposure to enemy action and disruption of repair activities, possibly resulting in loss of the vehicle by enemy capture. The choice, then, between recovery/evacuation and repair, would be determined by battle conditions and the battalion commander's risk assessment. Even ignoring battle damage, it would be necessary to retrograde more tanks than the Army is apparently assuming it can, considering the limited maintenance capability (numbers and skill levels of maintenance personnel) at the brigade support area (see Tables E-5 and E-6). In essence, the wartime support option is to perform a portion of organizational maintenance as far back as the brigade support area, not to move maintenance teams forward as the Army is now planning to do.

This support could be provided by detaching a cadre of mechanics from the battalion maintenance platoon, or adding an organizational maintenance section to the brigade support battalion. In peacetime, this organizational maintenance section could be used for improved hands-on training of apprentice maintenance personnel before they are rotated into tank battalions. In wartime, this section would provide the needed contingency maintenance capability currently lacking in the Division 86 TOEs. Experience also suggests that maintenance efficiency is enhanced by having organizational and DS level personnel working together on the vehicle -- a posture which is planned for the UER point but not for the maintenance collection points to the rear of the UER point. Intuition suggests that an increase in maintenance capability in the brigade support area would be essential for battle damage repair in view of the very limited maintenance capability (numbers of personnel) planned for the GS battle damage assessment teams.

TABLE E-5. TRACKED VEHICLE MAINTENANCE PERSONNEL BY ECHELON: HEAVY DIVISION

UNIT DESCRIPTION	GRADE	DIVISION SUPPORT AREA	BRIGADE SUPPORT AREA	BATTALION TRAINS: TANK BN 45E	45T	63E	63T	MECH INFTY BN 45T	63T	COMPANY AREA: TANK CO 45E	63E	MECH INFTY CO 45T	63T
BATTALION[2] MAINTENANCE PLATOON	E-7					2			2		1		1
	E-6					6			1				
	E-5					2			4	1	1	1	2
	E-4			1		3	1	1	11	1	2	1	2
	E-3				1	3	1	1	1	1	3	1	1
	TOTAL			1	1	16	2	2	19	3	7	3	6
	TOTAL ORGANIZATIONAL MAINTENANCE PERSONNEL IN BATTALION			20				21		40		36	

UNIT DESCRIPTION	GRADE	DIVISION SUPPORT AREA WO	41C	45G	45K	63G	63H	BRIGADE SUPPORT AREA WO	41C	45G	45K	63G	63H	BATTALION TRAINS: TANK BN 45G	45K	63G	63H	MECH INFTY BN 45K	63G	63H	COMPANY AREA
BRIGADE[3] SUPPORT BATTALION	WO							3													
	E-8												1								
	E-7												1		1					1	
	E-6										2		3								
	E-5								1		1		1		2		4	1		2	
	E-4								1	1	1	1	3	1	3	1	5	1	1	3	
	E-3								2		2		6		3		4	1		3	
	TOTAL							3	4	1	6	1	13	1	9	1	13	3	1	9	
MAINTENANCE BATTALION,[4] DIVISION SUPPORT COMMAND, ARMOR DIVISION	WO	3																			
	E-8																				
	E-7				1		3														
	E-6			1	1		4						6								
	E-5		1	3	1	1	2				1		1								
	E-4		1	2	1	2	4				1		12								
	E-3		1	2	2	3	2				1		6								
	TOTAL	3	3	8	6	6	15	-	-	-	3	-	25								
MAINTENANCE[5] SUPPORT BATTALION (RCS)	WO	2					(MST)	1					(BDA)								
	E-8																				
	E-7						2				1		1								
	E-6										1										
	E-5				4		4			1											
	E-4		2		6		6														
	E-3						10														
	TOTAL	2	2	-	10	-	22	1	1	-	2	-	1								
TOTAL DS/GS MAINTENANCE PERSONNEL IN ARMOR DIVISION		5	5	8	16	6	37	10	13	3	23	3	65	6	54	6	78	12	4	36	
TOTAL MAINTENANCE PERSONNEL AVAILABLE FOR FORWARD SUPPORT IN ARMOR DIVISION	978	77 (DS/GS)						117 (DS/GS)						196 (DS/GS) + 204 (ORG)							384 (ORC)

[1]Division organization is based on Division 86 TOE for 6 armored battalions and 4 mechanized infantry battalions. Brigade organization is 2 *armored battalions and 1 mechanized battalion.*

[2]Battalion Maintenance Platoon comprising QC Section and Maintenance Section located in battalion trains area and 4 company maintenance teams forward.

[3]Brigade Support Battalion with maintenance company located in the brigade support area and maintenance support teams (2 for tank battalions, 1 for mechanized infantry battalion) deployed forward. Composition of maintenance support teams shown is for 1 maneuver battalion each.

[4]Maintenance Battalion, Division Support Command, Armor Division with Light and Heavy Maintenance Companies in division support area and 5 maintenance support teams plus 1 calvary support team deployed in brigade support area.

[5]Maintenance Support Battalion (RCS) providing forward support through maintenance support teams (MST) and battle damage assessment (BDA) teams. Figures show 50% of planned TOE billets for these forward teams. 1 RCS battalion being planned per 2 divisions.

NOTE: Data exclude ITV and other equipment maintained by different MOS; recovery section personnel (operators and welders); and maintenance MOS billets which by TOE description do not involve maintenance.

TABLE E-6. MOS/GRADE SUMMARY OF DIVISION MAINTENANCE PERSONNEL

		E-8	E-7	E-6	E-5	E-4	E-3	TOTAL
41C	Fire Control Instrument Repairer				5	6	7	18
45E	M1 Turret Mechanic				24	30	24	78
45G	Fire Control System Repairer			1	3	11	2	17
45K	Tank Turret Repairer		8	8	25	33	31	105
45T	ITV/IFV/CFV Turret Mechanic				16	20	26	62
63E	M1 Tank System Mechanic		36	36	36	66	90	264
63G	Fuel/Electric System Repairer				1	15	3	19
63H	Track Vehile Repairer	3	13	19	42	73	66	216
63T	ITV/IFV/CFV System Mechanic		24	4	18	82	26	184
	Total Enlisted	3	81	68	200	336	275	963
WO	Warrant Officer (various MOS) Total:							15
	Total Maintenance Personnel:							978

APPENDIX F

A CASE EXAMPLE OF THE RELATIONSHIP BETWEEN DESIGN CHARACTERISTICS AND BATTLE DAMAGE RESTORABILITY

A good example to illustrate the potential impact of design characteristics on battle damage restorability and the limited management attention afforded the latter is provided by the AH-1S COBRA, Fully Modernized. Since the mid-1960's when it was first fielded, the AH-1 has gone through many product improvements. The most recent one is currently in progress at the manufacturer's plant with the first "fully modernized" COBRAs fielded in 1982. In view of the steadily increasing payload of successive configurations, space/weight/cost reductions received major emphasis in the improvement programs to ensure that the helicopter would meet minimum performance requirements. Inter alia this weight reduction effort included the wiring systems in the helicopter:

- Higher density of thinner wires in harness assemblies (the resulting increase in kill probability for a given harness hit and the number of wire repairs required in a given area were ignored)

- Reduction in insulation thickness and conductor gauge (the resulting increase in wire breakage rate and difficulty of reading wiring markings without a magnifier, which is not included in the mechanic's toolbox, were ignored)

- Reduction in slack of wires, making all connections as taut as possible (the effect on maintenance difficulty, requiring to connect replacement boxes to the leads prior to installing them in the racks, was ignored; in turn, this maintenance procedure increases wire breakage rate)

- Elimination of drip loops in wiring installations by waiving MIL-W-5088 requirements (the resulting moisture in wiring connections is one of the culprits responsible for false alarms, false BIT indications, and high "no evidence of failure" rates).

While all these weight savings reduced the maintainability of the AH-1S, the single most important design change, from a battle damage restorability viewpoint, was the elimination of the wire harness disconnects in the latest, "fully modernized" COBRA model. All previous configurations had tail boom disconnects and separate tail boom harness segments. For a reported weight savings of 30 pounds, this single design change was responsible for making any forward repair of battle damage in the tail boom impossible. The elapsed maintenance time is over 100 hours vice the 6 hours previously required (U.S. Army Aviation Research and Development Command TR-82-D17, "Wiring Inspection and Repair Techniques," Fort Eustis, Virginia: Applied Technology Laboratory, October 1982, USGO).

Without the disconnects, a repair now involves removal of all boom wiring, repair of harnesses, installation of new boom assembly, installation of repaired harnesses into new boom, and checkout of TOW operational status. In previous models, a new boom assembly, with wire harness segments already incorporated, could be installed as a replacement for the damaged tail boom. It is well to remember that tail boom hits were the most prevalent type of battle damage in Vietnam, responsible for grounding about one-third of the helicopter inventory for the entire theater each year.

In addition to this design shortfall, the ability of aircraft mechanics to make wire repairs meeting minimum standards of quality is minimal. They receive little or no training in wire repair; the formal school training that is given is not for the MOSs who actually would do the repairs. The tools required are not included in the standard tool box. The wiring drawings available do not include internal functions of most of the boxes, which complicates finding wiring failures. Moisture problems are not documented. Electromagnetic inference does not receive much attention, either in training, in technical documentation, on-the-job, or by the contractor when he changes from prototype to production engineering. And due to limitations in quality assurance procedures, wiring problems may be present when helicopters are first delivered from the manufacturer's plant to the Army: 60% to 90% of the tests specified in current military specifications for wiring are either incorrect, invalid, or inapplicable to current materials (First Air Force/Navy/Society of Automotive Engineers A-2 Wire and Connector Conference, 7 May 1980, Orlando, Florida). In sum, wiring problems represent a maintenance nightmare in peacetime, let alone wartime, which the Army has not addressed in the past. Applied Technology Laboratory's helicopter battle-damage repair program is designed to satisfy this void, but the fully modernized COBRA must be redesigned again, if the Army is serious with respect to fix-forward.

APPENDIX G

GLOSSARY OF TERMS

AACL	-	Army Area Calibration Laboratory
AACT	-	Army Area Calibration Team
AAH	-	advanced attack helicopter
A/C	-	aircraft
ACR	-	Armored Calvary Regiment
AIMI	-	aircraft intensive-management item
AIT	-	advanced individual training
ALDT	-	administrative and logistics delay time
AMC	-	Army Materiel Command
A_o	-	operational availability
AOAP	-	Army Oil Analysis Program
AORSE	-	Aviation Operational Readiness and Safety Evaluation
AR	-	Army Regulation
ASD	-	Assistant Secretary of Defense
ASL	-	authorized stockage list
ATC	-	Army Training Center
ATE	-	automated test equipment
ATL	-	Applied Technology Laboratory
ATST	-	Area TMDE Support Team
AVCRAD	-	Aviation Classification Repair Activity Depot
AVIM	-	aviation intermediate maintenance
AVUM	-	aviation unit maintenance
AVRADCOM	-	Aviation Research and Development Command
BCS	-	battery computer system
BDA	-	battle damage assessment
BDU	-	battery display unit
BIT	-	built-in test
BITE	-	built-in test equipment
CAB	-	combat aviation battalion
CEI	-	component of end-item
CG	-	Commanding General

CLAIT	-	Command Logistics Assistance and Inspection Team
CM	-	corrective maintenance
CMF	-	career management field
COAMP	-	cost analysis of maintenance policies
COMMZ	-	communications zone
CONUS	-	continental United States
CORADCOM	-	Communications Research and Development Command
COSCOM	-	corps support command
CPU	-	central processing unit
CRC	-	Calibration and Repair Center
CTA	-	Central TMDE Activity
DA	-	Department of the Army
DARCOM	-	Materiel Development and Readiness Command
DCSLOG	-	Deputy Chief of Staff for Logistics
DIO	-	Director of Industrial Operations
DISCOM	-	Division Support Comamnd
DIVARTY	-	division artillery
DLOGS	-	direct logistics system
DMD	-	digital message device
DMMC	-	Division Materiel Management Center
DoD	-	Department of Defense
DRS	-	Division Restructuring Study
DS	-	direct support
DSESTS	-	DS electrical system test set
DSU	-	direct support unit
DT	-	Development Test
DX	-	direct exchange
EAC	-	echelons above corps
ETE	-	electronic test equipment
FA	-	field artillery
FADAC	-	Field Artillery Digital Computer
FAR	-	false alarm rate
FDC	-	fire direction center
FDLS	-	fault detection/location system
FEBA	-	forward edge of battle area

FFA	-	fraction of false alarms
FFD	-	fraction of faults detected
FFI	-	fraction of faults isolated
FIR	-	fault isolation resolution
FM	-	fully modernized
	-	Field Manual
FMC	-	fully mission capable
FMEA	-	failure modes and effects analysis
FORSCOM	-	U.S. Army Forces Command
FSU	-	forward support unit
FVS	-	fighting vehicle systems
GAO	-	General Accounting Office
GEMM	-	General Electronics Maintenance Model
GFE	-	government furnished equipment
GS	-	general support
GSU	-	general support unit
GSSB	-	general support supply base
HQ	-	Headquarters
HQDA	-	Headquarters, Department of the Army
ICE	-	internal combustion engine
IDF	-	Israeli Defense Force
IFF	-	identification friend or foe
IFV	-	infantry fighting vehicle
IHAWK	-	Improved HAWK
ILS	-	integrated logistic support
LAO	-	Logistics Assistance Office
LMI	-	Logistics Management Institute
LOCAM	-	Logistic Cost Analysis Model
LOGAM	-	Logistics Analysis Model
LORA	-	level of repair analysis
LRU	-	line-replaceable unit
MAC	-	maintenance allocation chart
MACRIT	-	manpower authorization criteria
MACOM	-	Major Command
MAIT	-	Maintenance Assistance and Inspection Team

MALDT	-	mean administrative and logistics delay time
MC	-	mission capable
MCA	-	military construction, Army
MCP	-	maintenance collection point
MDS	-	maintenance and diagnostics software
MDT	-	mean downtime
MIL-STD	-	Military Standard
MMC	-	materiel management center
MMH	-	maintenance manhours
MMLA	-	maintenance manpower and logistics analysis
MOS	-	military occupational specialty
MRA&L	-	Manpower, Reserve Affairs and Logistics
MSF	-	maintenance support facility
MS+	-	Maintenance Support Positive
MST	-	maintenance support team
MT	-	maintenance team
MTBCM	-	mean time between corrective maintenance
MTBF	-	mean time between failures
MTOE	-	modified table of organization and equipment
MTS	-	module test set
MTTR	-	mean time to repair
NEOF	-	no evidence of failure
NMC	-	not mission capable
NMCS	-	not mission capable, supply
NORS	-	not operational ready, supply
OASD	-	Office of the Assistant Secretary of Defense
OCONUS	-	outside the continental United States
ODCSLOG	-	Office of the Deputy Chief of Staff for Logistics
O/H	-	on-hand
OJT	-	on-the-job training
OMA	-	Operations & Maintenance, Army
ORF	-	operational readiness float
ORG	-	organizational maintenance
OSD	-	Office of the Secretary of Defense
OST	-	order-and-ship time

OT	-	Operational Test
PA	-	Procurement, Army
PCB	-	printed circuit board
PCMC	-	Pirmasens Communications-Electronics Maintenance Center
PCS	-	permanent change of station
PFASC	-	PATRIOT Field Army Support Center
PIMRA	-	Pirmasens Missile Repair Activity
PLL	-	prescribed load list
PM	-	preventive maintenance
	-	program/project/product manager
PMC	-	partially mission capable
PMI	-	phased maintenance inspection
QC	-	quality control
QMR	-	quantitative materiel requirement
R&D	-	research and development
RDTE	-	research, development, test and evaluation
RGS	-	restructured general support
RIW	-	reliability improvement warranty
RURLAM	-	Replacement Unit Repair Level Analysis Model
SAILS	-	Standard Army Intermediate Logistics System
SCORES	-	Scenario Oriented Recurring Evaluation System
SDC	-	sample data collection
SMA	-	subsequent maintenance assessment
SMR	-	source, maintenance and recoverability
SOP	-	standard operating procedure
SQT	-	skill qualification test
SRU	-	shop replaceable unit
STE	-	simplified test equipment
SUPCOM	-	Support Command
TADS	-	target acquisition designation sight
TAMMC	-	Theater Army Materiel Management Center
TAT	-	turnaround time
TCATA	-	TRADOC Combined Arms Test Activity
TDA	-	table of distribution and allowances
TFD	-	fault detection time

TM	-	technical manual
TMDE	-	test, measurement and diagnostic equipment
TMS	-	TOW Missile System
TOC	-	Tactical Operations Centers
TOE	-	table of organization and equipment
TOW	-	tube-launched, optically-tracked, wire-guided
TRADOC	-	Training and Doctine Command
TSARCOM	-	Troop Support and Aviation Materiel Readiness Command
TSGMS	-	test set guided missile system
TSTS	-	thermal system test set
TT	-	test thoroughness
UER	-	unserviceable equipment rally
USA	-	U.S. Army
USAF	-	U.S. Air Force
USAMCC	-	U.S. Army Metrology and Calibration Center
USAOCS	-	U.S. Army Ordnance Center and School
USAREUR	-	U.S. Army Europe
USATESAE	-	United States Army Test Equipment Support Activity, Europe
VFMED	-	variable format message entry device
VTM	-	vehicle test meter
WO	-	warrant officer
WWII	-	World War II

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The Army's concept of forward maintenance support is patterned after the methods used by the Israeli Defense Force during the 1973 Middle-East War. The concept emphasizes the performance of repairs on-site or as far forward as possible, rather than retorgrading inoperable weapon systems for repair. Our review of Army maintenance practices, including support of seven new systems, reveals that the Army's capability to "fix-forward" falls far short of its needs.

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To achieve adequate forward maintenance support, the Army must:

(1) Dramatically improve the capabilities of forward-echelon maintenance units, especially organizational-level units, by providing better training, test equipment, and test equipment support.

(2) Establish battle damage assessment and repair capabilities.

(3) Clarify fix-forward maintenance policy, including its implications for task allocation, level of repair analysis, and wartime workload analysis.

(4) Provide intensive management of the key system characteristic influencing fix-forward potential: testability.

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