Evaluating the Combat Payoff of Alternative Logistics Structures for High-Technology Subsystems

Morton B. Berman, Douglas W. McIver,
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40 Years
1948-1988

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PREFACE

This report describes research that identifies and evaluates alternative logistics structures for *high-technology subsystems* used by major U.S. Army weapon systems, using a new methodology to examine combat logistics structures. The primary goal of this research is to demonstrate the influence of alternative logistics structures on the warfighting capabilities of combat units. A secondary goal is to provide a model analysis employing new techniques that might guide U.S. Army analysts in similar future evaluations. Ultimately, the research goal is not only to support future weapon systems but to inform logistics policy and technical decisions being considered by the Army.

The topic of research was suggested to the Army by the Arroyo Center when it seemed likely that the introduction of sophisticated electronic systems in Army armor and aviation weapon systems might complicate logistics support the same way it has complicated Air Force logistics support. The concepts, tools, and techniques developed by RAND's Project AIR FORCE over the past decade might therefore prove very useful to the U.S. Army. This research provided the vehicle to test these concepts, tools, and techniques in an Army setting.

This research project, entitled "Improving Combat Capability through Alternative Support Structures," was sponsored jointly by Headquarters, Department of the Army, Office of the Deputy Chief of Staff for Logistics, and the Training and Doctrine Command Logistics Center. Drafts of this report have been circulating within the Army since March 1987 and comments received indicate that the research should be of interest throughout the Army logistics community. This research is being performed as part of the Readiness and Sustainability Program of the Arroyo Center.

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Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee, which is co-chaired by the Vice Chief of Staff and by the Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-86-C-0059.

The Arroyo Center is housed in RAND's Army Research Division. The RAND Corporation is a private, nonprofit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

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SUMMARY

THE CHALLENGE

The U.S. Army needs to reexamine the adequacy of its combat logistics structures and to consider alternatives, because its new high-technology subsystems have components that are extremely expensive and hard to maintain, and have wartime demand rates that are difficult to forecast. The Army's current logistics structure evolved to cope with the very different problems posed by earlier generations of simpler weapon systems, for example, repair of engines, transmissions, suspensions, and so forth, involving primarily mechanical parts.

APPROACH TO THE CHALLENGE

To deal with these new high-technology subsystems, this research project identifies alternative logistics structures and employs a new methodology to evaluate them. Several of these alternative logistics structures achieve much greater responsiveness to changing wartime demands by using resources—like transportation and repair—that are much more flexible than stocks of spare parts.

This research focuses exclusively on technologically sophisticated subsystems and uses data on the armament and propulsion subsystems of the M-1 Abrams tank. This focus was chosen on the assumption that the current logistics structure treats less sophisticated equipment problems adequately (e.g., starter failures, clogged filters, and broken torsion bars).

High-technology systems have unpredictable removal rates—a characteristic that will be compounded by the uncertainties of wartime. The current logistics structure encounters serious difficulties and expenses when it tries to provide every maneuver brigade or battalion with operational test equipment, the "right" amount of repair parts, and trained diagnosticians to repair and maintain technologically sophisticated subsystems.

ASSESSMENT OF ALTERNATIVE LOGISTICS STRUCTURES

This research begins with a base case in which one set of M-1 tank test equipment is located—as such sets currently are—in each Forward Support Battalion (FSB). An FSB is located in each of the nine brigades of a U.S. armored corps and is supported by the current distribution system. RAND's Dyna-METRIC model is used to assess the costs and benefits of alternative logistics structures relative to this base case.

The alternatives were selected to examine the influence of different structural characteristics:

- Consolidating test equipment and associated personnel at higher echelons—Main Support Battalion and Theater Repair Facilities—to increase responsiveness to variations in demand at lower echelons.
- Decentralizing test equipment and associated personnel to maneuver battalions to increase battalion unity of command.
- Varying the amounts of test equipment and associated personnel to examine the effect on repair queues that form during wartime scenarios.
- Increasing the spare parts distribution system's responsiveness.

Each alternative is judged on how much it improves combat capability, measured in tank availability, compared to its costs.

FINDINGS

The Army must either increase the responsiveness of its logistics structures or invest inordinate amounts in inventories to prevent losses in combat capability. At a minimum, consolidating test equipment at the Main Support Battalion:

- Improves the availability of test equipment for items that most affect combat availability
- Permits assessing repair priorities across three brigades, thus increasing tank combat availability.

Improving distribution systems and management of repair facilities can also increase the combat availability of tanks if the Army can develop command and control systems that achieve the prerequisite visibility over repair resources and stockage.

A three-pronged program of additional research will help the Army attain the potential payoff shown by this initial analysis:

1. Identify and evaluate (in greater detail) additional alternatives for improving the transportation and distribution system.
2. Develop ways to integrate existing and emerging logistics and operations management information systems to achieve the greater degrees of command and control needed to manage effectively and efficiently a much more flexible support structure.
3. Identify management improvements to make General Support and depot repair/recycle times both shorter and, especially, more sensitive to immediate combat needs.

ACKNOWLEDGMENTS

This work required considerable data manipulation. We have relied heavily on the data base management and analysis skills of Richard M. Holland, Jr., and Frederick W. Finnegan. Karen E. Isaacson and Patricia M. Boren were extremely helpful in making changes to and suggestions about Dyna-METRIC modeling in the Army context. We also acknowledge Sidney G. Liddle for help in running the Dyna-METRIC model.

This report benefited from detailed and most helpful critiques by our RAND colleagues Craig Moore and Gordon Crawford. Performing this study required data and advice from literally dozens of Army personnel in the Army Materiel, Training and Doctrine, and Forces Commands. We are indebted to them all.

We thank Jean Thomas, Susan Baugh, and Dolly Hardy for cheerfully and efficiently producing the many drafts and formats required to reach this final product.

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GLOSSARY

AMC	Army Materiel Command
AMCCOM	Armament Munitions and Chemical Command
AMSAA	Army Materiel Systems Analysis Activity
ASL	Authorized Stockage List
CCSS	Commodity Command Standard System
CONUS	Continental United States
CRAF	Civil Reserve Air Fleet
DESCOM	Depot Systems Command
DRIVE	Depot Repair Induction in Variable Environments
DSESTS	Direct Support Electrical System Test Set
FEBA	Forward Edge of the Battle Area
FEDC	Field Exercise Data Collection
FSB	Forward Support Battalion
GS	General Support
IFTE	Intermediate Forward Test Equipment
LIF	Logistics Intelligence File
LRU	Line Replaceable Unit
MAC	Military Airlift Command
MARC	Manpower Requirements Criteria
MILES	Multiple Integrated Laser Engagement System
MOS	Military Occupational Specialty
MSB	Main Support Battalion
NEOF	No Evidence of Failure
NTC	National Training Center
PCB	Printed Circuit Board
PPBES	Planning, Programming, Budgeting, and Execution System
R&M	Reliability and Maintainability
SDC	Sample Data Collection
SPARC	Sustainability Predictions for Army Spare Components Requirements for Combat
SRU	Shop Replaceable Unit
TACOM	Tank and Automotive Command
TIS	Thermal Imaging System
TMDE	Test Measurement and Diagnostic Equipment
TOE	Table of Organization and Equipment
TRF	Theater Repair Facility
TSTS	Thermal System Test Set
UPT	Undergraduate Pilot Training

USAREUR	U.S. Army Europe
US^3	USAREUR Support Structure Study
VTMR	Variance-to-Mean Ratio

I. INTRODUCTION

THE CHALLENGE

The U.S. Army's combat logistics structure has evolved over many years. Why, then, is there a need to evaluate alternatives? What has changed, and what will change in the future?

Simply put, the answers to these questions are threefold. The Army has begun to use, and will continue to use, increasing numbers of technically sophisticated subsystems with components that are extremely expensive and hard to maintain, and that have wartime demand rates that are difficult to forecast. The Army's current combat logistics structure evolved to cope with the very different types of problems posed by earlier generations of simpler weapon systems. These primarily contained mechanical, hydraulic, and electric subsystems (e.g., trucks, personnel carriers, and earlier tanks) where problems were easy to diagnose, test equipment was simple, and repair parts were relatively cheap.

Hard-To-Maintain Items

The Army is currently introducing more than 300 new systems, many with sophisticated and highly integrated subsystems that use computers and other complex electronic and electro-optical equipment.[1]

Complex subsystem faults cannot be diagnosed or repaired by technicians alone. They also require sophisticated test and diagnostic equipment, which in turn complicates the logistics process and increases the associated capital expenditures. Compared to repair of simpler, more mechanical systems, repair of these complex subsystems has decreased maintenance flexibility (i.e., no alternative tools, test equipment, or parts) and has increased the potential for misdiagnosed faults. Particularly difficult to accommodate are major weapon systems like the M-1 Abrams tank, the M-2/3 Bradley infantry fighting vehicle, and the AH-64 Apache helicopter. All such new systems have multiple electronic components, and some have highly sophisticated turbine engines. Similar high-technology components in Air Force systems have been found to require an integrated, responsive maintenance and supply system.

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[1] A recent Army Materiel Command (AMC) survey showed that 131 systems have embedded computers, and this trend is growing (see Ref. 1).

It is not clear that current Army logistics structures can fully accommodate these technologically sophisticated weapon systems. Indeed, the Army's large investments in these weapon systems may be undermined if logistics structures cannot ensure their battlefield availability.

Expensive Component Cost

Potential inadequacies in the repair process are further complicated by the high costs of individual components in these sophisticated weapon systems. If broken components (LRUs—Line Replaceable Units) and their subcomponents (PCBs or SRUs—Printed Circuit Boards or Shop Replaceable Units) were relatively inexpensive (as are components for more traditional tracked vehicles), then the Army could buy enough spare components and subcomponents to overcome temporary shortfalls in repair capability. However, sophisticated components are usually more expensive, often by orders of magnitude. Table 1.1 compares the costs of some M-1 tank low-technology and high-technology components currently exhibiting high removal rates.

The M-1's high costs move the Army in a new direction compared to previous weapon systems. The top 20 LRU maintenance drivers of the M60A3 tank averaged 3.2 removals per 100 hours, with a mean LRU cost of \$19,600. The M-1's top drivers average 7.8 removals per 100 hours, with each LRU costing an average \$53,500.[2]

Table 1.1

COSTS OF LOW-TECHNOLOGY AND HIGH-TECHNOLOGY COMPONENTS ON THE M-1 TANK

Low-Technology Components	Cost ($)	High-Technology Components	Cost ($)
Track shoe assembly	119	Power control unit	23,254
Instrument panel	7,590	Thermal imaging system, thermal receiver unit	101,593
Centrifugal pump	4,630	MI laser rangefinder	32,477
Storage battery	75	Thermal electronic unit	16,272
Starter motor	1,173	Body assembly, gunner's primary sight	45,809

SOURCES: Refs. 2 and 3.

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[2] See Refs. 4 and 5.

High costs such as these make "buying our way" out of the problem difficult—even more difficult when coupled with already high investment costs of the Test Measurement and Diagnostic Equipment (TMDE) required at all echelons and of the highly skilled personnel required to repair LRUs and PCBs. Thus in terms of total costs, buying repair components to support the current logistics structures is many times more expensive than it would be for more traditional and less technologically sophisticated components.

Forecasting Demands

One might be tempted, nevertheless, to pay these high costs as long as they could guarantee the combat availability of the weapon systems and as long as no other logistics structure was more cost effective. Unfortunately, we cannot forecast resource needs with sufficient accuracy to ensure that larger inventories would cover wartime demands.

In part, the inability to forecast resource needs results from the macroresource diversity of the logistics structures. Figure 1.1 is a macro-characterization of the current logistics structure for the supply and

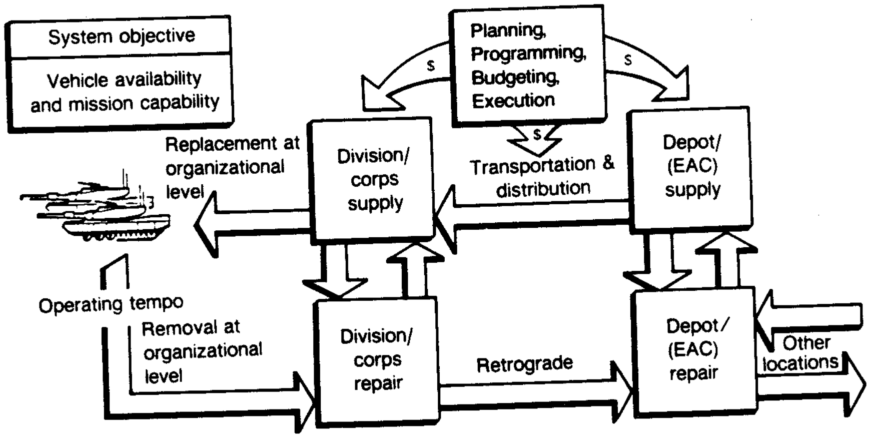

Fig. 1.1—The current logistics structure for recoverable repair parts (Class IX)

repair of recoverable repair parts (Class IX).[3] The support system for major weapon systems contains many thousands of personnel. Since no single person or agency can direct such a large collection of activities, it is divided into several functions (e.g., maintenance, supply, and transportation) and into echelons within these functions (e.g., supply is divided into retail and wholesale, and maintenance is divided into several echelons from the unit to the depot).[4]

If we examine tanks in particular, we see—and intuition suggests—that as the operating tempo increases, removals of failed (or apparently failed) LRUs also increase. These removals could be conducted by organizational-level personnel. However, the forward support battalion support teams often perform this task. These personnel replace the removed LRU, if a spare one is available, from the Prescribed Load List (PLL) or Authorized Stockage List (ASL). The LRU is then transported to the brigade/division support area to be checked using the appropriate TMDE. When the fault is located, maintenance personnel replace the appropriate PCB and return the LRU to serviceable status. PCBs and some LRUs can be repaired only at the corps level or at echelons above corps (EAC)—such as theater facilities, AMC depots, or contractor facilities.

Movement of serviceable and reparable components among these echelons requires a transportation and distribution system. To maintain the tank's availability, each function and echelon needs to have the proper resources in terms of LRUs, PCBs, TMDE, management, and transportation to ensure the availability of serviceable components each time a removal occurs.

Currently the Army attempts to place sufficient wartime resources in each function at all echelons, which implies the ability to forecast wartime demand rates. Unfortunately, accurate forecasts are impossible for three major reasons:[5]

1. Resource demands fluctuate erratically, thwarting forecasting even in peacetime. Figure 1.2 shows three years quarterly

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[3] Repair parts (Class IX) can be classified as "recoverable" or "not recoverable." This report focuses on recoverable repair parts, which normally cost more than nonrecoverable ones.

[4] The Planning, Programming, Budgeting, and Execution System (PPBES) provides resources that are allocated among the functions and echelons. Unfortunately, there are long time lags and misconnects between the PPBES level and the operating levels' allocation decisions in the Army (and other services), so the resources finally allocated often do not match current needs.

[5] In addition, difficulties of integrating the interdependent functions and echelons magnify forecasting problems. Each function uses performance measures only loosely related to combat availability (e.g., transportation uses ton-miles; the depot uses manhours per unit produced; supply uses fill rate measures).

removals, whether coded as failures, faults, or no evidence of failure, for all the M-1's fire control system components for three battalions from the Sample Data Collection (SDC) system. Disaggregating the data to show monthly or weekly events or removals for individual battalions would reveal even greater variability. No supply system currently provides repair parts in a way that can handle such erratic fluctuations, and for technologically sophisticated subsystems, the implied supply purchase costs would be very high, if appropriate provisioning computations were incorporated. (Section II discusses this variability further.)

2. Wartime demand levels depend upon wartime activity levels (or tempos), and these activity levels can be forecast only by employing planning contingency scenarios. However, it is unlikely that a real contingency will ever match a planned scenario. So resources developed for a particular planned scenario will often not cover peak requirements in an actual

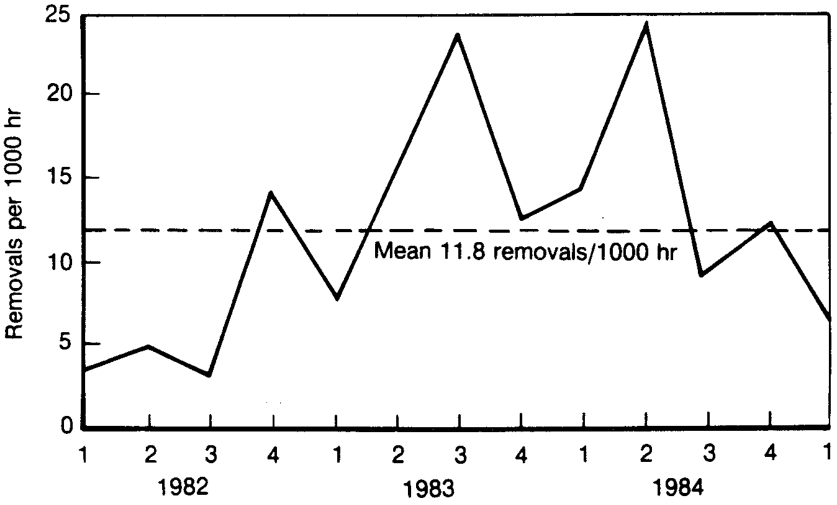

Fig. 1.2—Highly variable demand rates: M-1 fire control system

contingency. This is especially true as the Army plans greater variability in its combat tactics.[6]

3. Growing enemy capabilities create greater and increasingly unpredictable threats to repair, supply, and transportation resources. Thus, even if one could accurately compute and stock the number of repair parts that would be needed, enemy attacks could well destroy portions of these stockpiles and the critical TMDE needed for fault diagnosis.

For these reasons, Army provisioners undertake a frustrating exercise whenever they attempt to forecast the wartime demands of LRUs for technologically sophisticated weapon systems like the M-1 tank. Since they cannot accurately forecast the repair parts they will need, they cannot ensure combat vehicle availability merely by purchasing an apparently adequate amount of spare LRUs.

Although forecasting problems undoubtedly existed with older and less technologically sophisticated subsystems, those subsystems' diagnostic procedures were simpler to perform, their repair systems were naturally more flexible, and their spare parts were cheaper. These subsystems typically depended on people for repair, not on expensive TMDE, and field fabrication of repair parts was often possible. The crew of a World War II tank needed no special equipment to tell them of a problem with their turret drive, and they could often mend the broken subsystem using "make do" tools and repair items.

By contrast, the repairer of the M-1 cannot improvise a transistor the way his World War II counterpart could improvise a mechanical fix. Technologically sophisticated subsystems depend more critically on complex logistics structures, highly trained personnel, and good fault diagnosis equipment—and provision of all of these becomes increasingly difficult to ensure during wartime conditions. Thus if the crew of an M-1 tank has a problem with its laser rangefinder, they must depend only on the maintenance and supply system, with its specially trained personnel, to return the tank to action. And if the crew must resort to use of the manual systems, the M-1's increased firepower—paid for with scarce DoD dollars—is compromised.

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[6] For descriptions of increasing nonlinear operations, see Ref. 6.

RESEARCH APPROACH

How can the Army meet this challenge? We hypothesize that a realistic solution involves developing and evaluating alternative logistics structures whose more fungible resources—like transportation and repair—are made *responsive* to changing wartime demands.

The Army recognizes the problems posed by its technologically sophisticated weapons and is currently considering measures to deal with them. We believe that the challenge the Army faces involves evaluating alternative logistics structures in terms of their responsiveness to unpredictable wartime demands. Thus our work not only investigates alternative logistics structures but also demonstrates the applicability of new tools that the Army can use to evaluate the effectiveness of logistics structures in meeting wartime demands.

Initially using data on the armament and propulsion subsystems of the Abrams M-1 tank, our research hypothesizes alternative logistics structures and assesses their responsiveness—in terms of improvements to combat vehicle availability—under contingency scenarios. We focus exclusively on technologically sophisticated subsystems—not on such problems as starter failures, clogged filters, and broken torsion bars. This focus rests on the assumption that the current logistics structure adequately treats unsophisticated equipment but encounters serious resource allocation difficulties when it tries to provide every maneuver brigade with operational test equipment, an adequate amount of repair parts, and trained diagnosticians to repair and maintain technologically sophisticated subsystems.

This research concludes that high demand variability creates the need to pursue organizational and policy changes that increase the ability of logistics structures to adapt and react quickly. This requires fostering a resource management system that can deal with the inevitability of surprise and that tries to develop sufficient flexibility to respond effectively and maintain combat capability. Such an approach plays down trying to fulfill forecasted resource requirements that are essentially unattainable and too costly. We explore responsive structures in this research, and the results suggest organizational and policy changes to:

- Move the location of component repair,
- Increase the availability of special test equipment, and
- Improve distribution and depot management.

Section II delves more deeply into demand variability, and Sec. III describes the approaches we used to evaluate alternative logistics structures. Section IV describes the conclusions and next steps in our research.

Appendixes A through C describe, respectively, the variability of fire control removal rates, fire control removal rates in the Field Exercise Data Collection (FEDC), and the basis of our cost estimates for alternative logistics structures.

II. ANALYSIS OF DEMAND VARIABILITY IN A HIGH-TECHNOLOGY WEAPON SYSTEM

Since plans for wartime logistics support must be made during peacetime, they must account for a great number of uncertainties. This section investigates how these uncertainties are likely to confound standard logistics solutions for weapon sustainability, especially stock buyouts of spare parts.

FOCUS OF ANALYSIS

Our analysis focuses on components in the M-1 tank that reflect the greatest change in tank technology, cost, and complexity. Out of a total of 205 LRUs on the M-1, we selected 19 in the M-1's fire control and stabilization system and 11 in its powerpack (see Table 2.1). All these LRUs use relatively complex electronics technology; we focus less on optics, microswitches, transmissions, and the like. Although these LRUs constitute but 15 percent of the tank's overall recoverable components, they account for 56 percent of all its maintenance actions. Moreover, these LRUs add the most value to tank performance. If a tank were to lose its laser rangefinder, for example, it would operate with only 63 to 66 percent of its previous combat effectiveness.[1]

In attempting to forecast the need for spares, estimates of mean removal rates and variances about those means are of critical concern. In particular, one needs to estimate the level of demand for spares, the uncertainty surrounding that estimate, and the rate at which the mean demand for spares varies over time, from unit to unit, and the like. The mean values are typically believed to be related to activity rates—that is, hours of operation, rounds fired, and miles driven.

Characterizing the variance in removals, our description focuses on the M-1's fire control and stabilization system. (Results for the powerpack system are similar and thus will not be presented here.) Our data come from a single data collection, the M-1 SDC, administered by the Army's Tank and Automotive Command (TACOM). This data base covers the 11-month period from October 1984 to August 1985 and contains both removal and operational activity information for approx-

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[1] Personal communication from Walter Clifford, Division Chief, Air Warfare Division, AMSAA. For a comparison of M60 and M-1 effectiveness, see Ref. 7.

Table 2.1

HIGH-TECHNOLOGY LRUS IN THE M-1 TANK

LRUs in the Fire Control and Stabilization System	LRUs in the Engine System
Turret network box	Turbine engine
Crosswind sensor	Fuel nozzle
Computer	Electrical fuel pump
TIS power control unit	Electronic control
Gunner body assembly	Electromechanical-fuel
TIS image control unit	Fuel control
TIS thermal receiver	Distribution manifold
Laser rangefinder	Forward engine module
Turret drive electronics assembly	Rear engine module
Thermal imaging system electronic unit	Combustion liner
Servomechanism assembly	Accessory gearbox
Servomechanism traverse	
Line of sight electronic assembly	
Panel assembly—upper	
Slip ring assembly	
Panel assembly—lower	
Gyro assembly rate	
Head assembly	
Computer control panel	

imately 170 tanks (three battalions) at three locations (Ft. Hood, Texas; Schweinfurt and Bamberg, Germany).

We measure removal rates in terms of operating hours of the tank rather than in terms of rounds fired. There are several reasons for this choice. Most important, analysis of what factors explain or predict a fire control and stabilization system removal shows that tank operating hours and rounds fired are about equally good; in the logit model discussed below, both factors were of roughly equal significance and of equal size. This should not be surprising; the M-1 fire control system's electronics tend to operate whenever the tank itself is operating. Furthermore, it is not obvious that the act of shooting a round itself places more stress on the system (and causes more failures) than keeping the electronics hot.

Given little to choose between these two explanatory factors on statistical grounds, we focus on operating hours for other reasons. Calculating variance-to-mean ratios (VTMRs) on the basis of rounds fired would be difficult, because no rounds at all were fired during most of our data time period (firing was usually concentrated in one or two periods of the year). Available Army scenarios define tank tempos in terms of operating hours; although that is not crucial to the argument in this section, it improves comparability between the variance analysis and the logistics modeling of Sec. III.

VARIANCE IN REMOVALS DURING PEACETIME

Variance in Removals over Time

Figure 2.1 demonstrates the variability of monthly removal rates in the fire control and stabilization system in 1986. Overall, there was a mean of 11.4 component removals per 1000 operating hours. Traditional provisioning methods assume that the VTMR equals 1; i.e., the variance is the same size as the mean. VTMR is a well-established concept in inventory theory and is used in many military supply models, like the Army's SESAME model. In inventory theory, demands follow a Poisson arrival process, which has a VTMR of 1. The further the actual VTMR is from 1, the poorer the fit of the Poisson model. In practical terms, if one bought spares assuming a VTMR of 1, there would be shortfalls in the highest demand periods, depending, of course, on the responsiveness of the repair system.[2]

Of course, stocks are bought for individual components, not on the basis of aggregate subsystem numbers. Table 2.2 shows VTMRs for the individual components in the fire control and stabilization system. Even though these VTMRs tend to be lower than those found for some other comparable systems[3], almost two-thirds of fire control components have VTMRs greater than 1.00 and thus diverge from assumptions normally made in supply models. Note as well that quite often

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[2] This follows assuming a reasonable repair cycle time for the average LRU, on the order of two weeks. In the worst month (July 1987), 87 removals occurred over about 3000 tank operating hours; with average repair time at about a half month, 41 LRUs would be expected in repair at any one time. This falls outside the range of variance anticipated by standard theory. The latter would expect 17 LRUs in repair at any one time (3000 × 11.4 removals per 1000 hours × 0.5 month to repair), with variance equal to 17, so two standard deviations above that of safety stock would imply that 17 + 8 = 25 spare LRUs are necessary to cover backorders.

[3] For example, a study of the F-16 gives an average VTMR for 156 recoverable items of 3.73 (see Refs. 8 and 9). Note that the average F-16 VTMR covers a multiyear period, whereas the average M-1 fire control VTMR covers only 11 months. Shifts of means over lengthy periods increase VTMRs. See also Ref. 10.

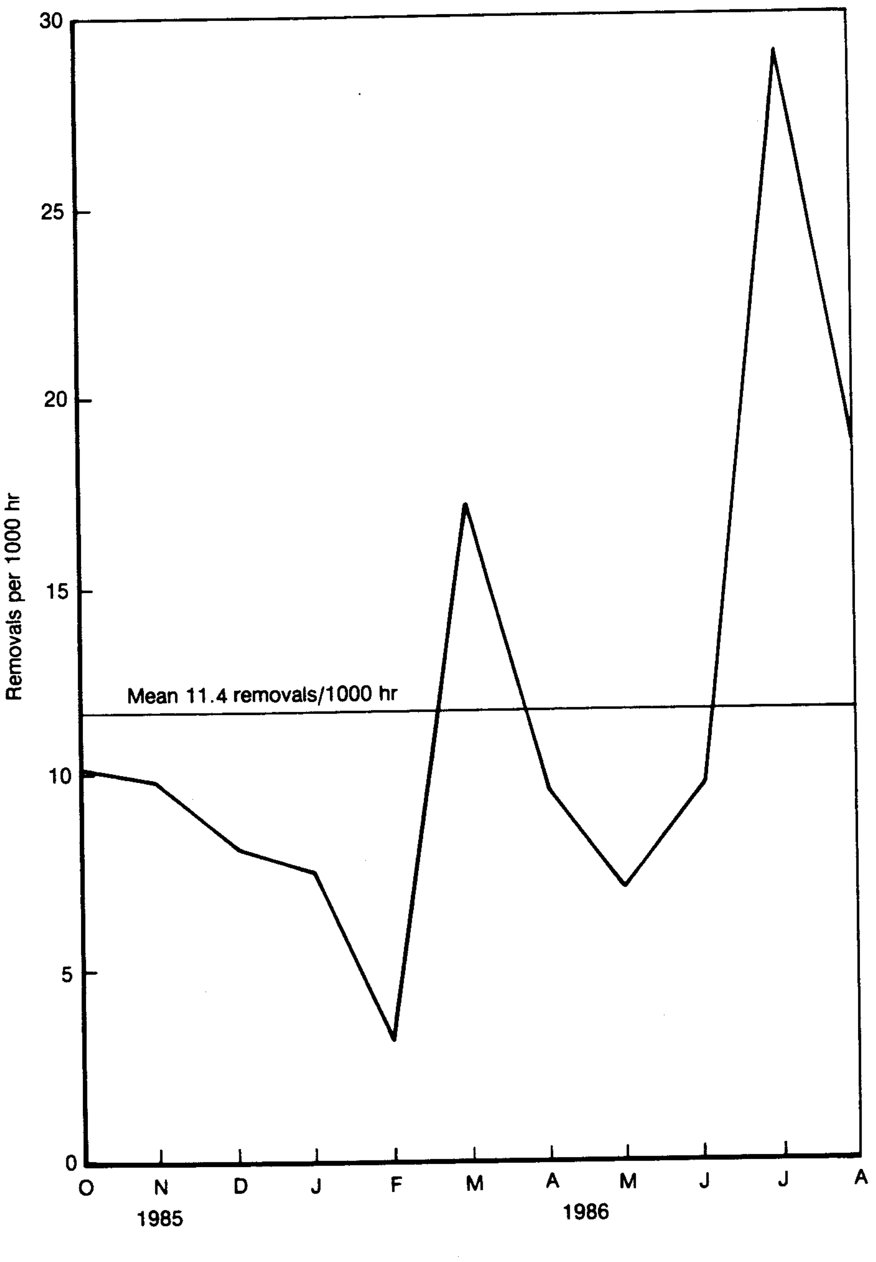

Fig. 2.1—Variability of removals in the fire control and stabilization systems (FY 1986 data)

Table 2.2

VTMRS FOR INDIVIDUAL COMPONENTS IN THE FIRE CONTROL AND STABILIZATION SYSTEM, FY 1985

LRU	Removals per 1000 Hours	VTMR
Turret network box	1.80	2.94
Computer	1.29	0.88
Crosswind sensor	1.27	4.75
TIS power control unit	1.22	3.35
TIS electronic control	0.97	0.93
Gunner body assembly	0.95	0.73
Line of sight electronic assembly	0.82	1.94
TIS image control unit	0.78	0.66
TIS thermal receiver	0.72	1.51
Laser rangefinder	0.62	2.33
Servomechanism traverse	0.53	1.03
Turret drive electronics assembly	0.51	1.19
Servomechanism assembly	0.42	0.72
Panel assembly—upper	0.23	1.24
Gyro assembly rate	0.21	1.65
Panel assembly—lower	0.19	1.09
Slip ring assembly	0.19	1.58
Computer control panel	0.17	0.86
Head assembly	0.08	0.82
Mean		1.55
All fire control LRUs	13.0	5.72

NOTE: The removal rates are often positively correlated so the overall VTMR is higher than if independence is assumed.

the VTMR is below 1; standard provisioning models may tend to overbuy stocks for these items.[4]

In addition, the fluctuations of these VTMRs pose serious problems for the logistics planner who must predict the need for spares. Modifications in some components, or problems cropping up in others, make new VTMRs different from old ones. Consequently, the buyer will find himself with great oversupplies of a suddenly more reliable component, yet missing supplies for a component he had previously thought was adequately covered. (See Appendix A for a comparison of 1985 and 1986 removal rates.)

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[4] Though the VTMR is a standard tool in the field, it is not a perfect measure (for instance, it is not dimensionless). The coefficient of variation may also be usefully employed to understand variance in removal rates.

Variance in Removals over Geographical Locations

Demand rates change over locations as well as over time, as Fig. 2.2 illustrates. Differences arise from a variety of sources including varying maintenance practices, varying toleration of failed components, and the varying punishment that tanks experience whether in garrison or at the range. Such differences should be expected to continue in wartime as units adopt changing combat postures.

PROJECTED VARIANCE IN REMOVALS DURING WARTIME

As we have just seen, there are dramatic variances in removal rates (over time and over geographical location) of high-technology components during peacetime activities. This section investigates how wartime—reflecting greater activity rates and uncertainties concerning combat scenarios and enemy attack—will further increase these variances.

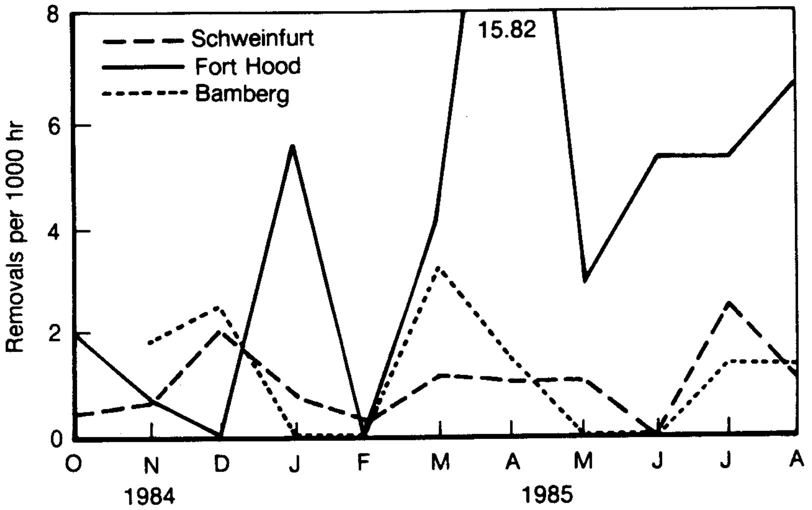

Fig. 2.2—Variability in removals of the turret network box over different geographical locations (FY 1985 data)

Greater Wartime Activity Rates

During peacetime, the Army uses its tanks at a smaller fraction of projected wartime activity than the other services use their weapon systems. In typical airbase or sea operations, aircraft are flown at rates that differ relatively little from anticipated combat rates.

For the M-1, it is a different matter altogether. One battalion-level scenario projects a wartime activity rate of up to 350 operating hours per tank in a 30-day period.[5] In sharp contrast, we find that the average monthly peacetime activity rate for M-1 tanks is 27 hours—that is, less than one-tenth this projected wartime activity. This makes immediately obvious the relative difficulty of extrapolating M-1 reparable item removal rates to wartime activity levels, especially compared to the Air Force and Navy systems.

Figure 2.3 demonstrates the peacetime activity rates for the M-1 in the SDC. It summarizes the monthly activity of three battalions of approximately 170 M-1 tanks over 11 months. In over half of the roughly 1900 cases, the tanks were used fewer than 20 hours a month. In 90 percent of the cases the tanks were used fewer than 60 hours a month. We focused on the 10 percent of the cases when tanks were used at greater activity levels to infer possible trends that may characterize projected wartime activity rates.

Figure 2.4 demonstrates how variance increases at higher tempos. Here only two extremes of the data set are considered: cases with low activity (20 hours or fewer per tank per month) and cases with high activity (60 hours or more per tank per month). Each dot reflects the average number of fire control removals in a month per tank at that level of activity. (There are fewer months represented on the high side because in some months there were not enough high-activity cases to be meaningful. In addition, to avoid problems of unequal sample sizes, the low-activity cases were sampled so that there would be roughly equal numbers of tanks in each month—around 25—for both activity levels.) Figure 2.4 shows a much greater spread among high-activity tanks than among low-activity ones; in fact, the standard deviation for high-activity tanks is about twice as large as that for low-activity ones.

Figure 2.5 adds evidence on VTMRs. The VTMR is more than twice as great for high-activity tanks than it is for the low-activity ones. Moreover, the VTMR will probably be higher yet during wartime, given that peacetime "high-activity" tanks are used at about one-third the expected wartime rate.

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[5] From a scenario developed by the Armor Center Directorate of Combat Developments.

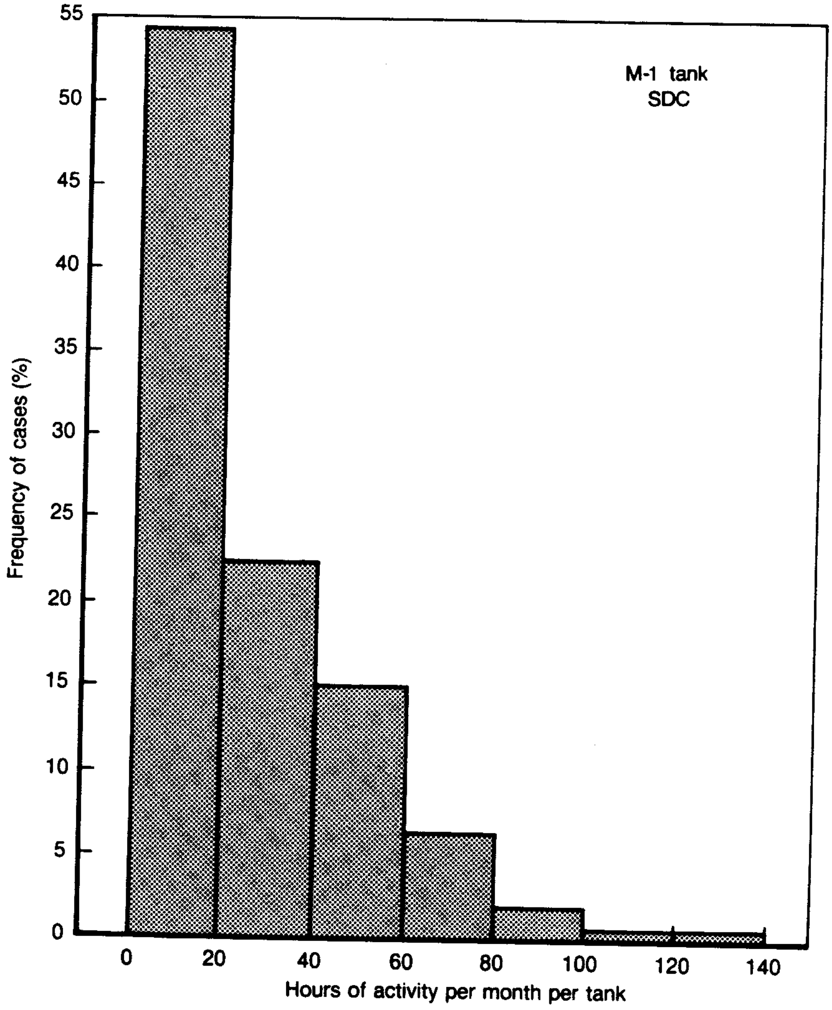

Fig. 2.3—Frequencies of monthly activity rates for M-1 tanks

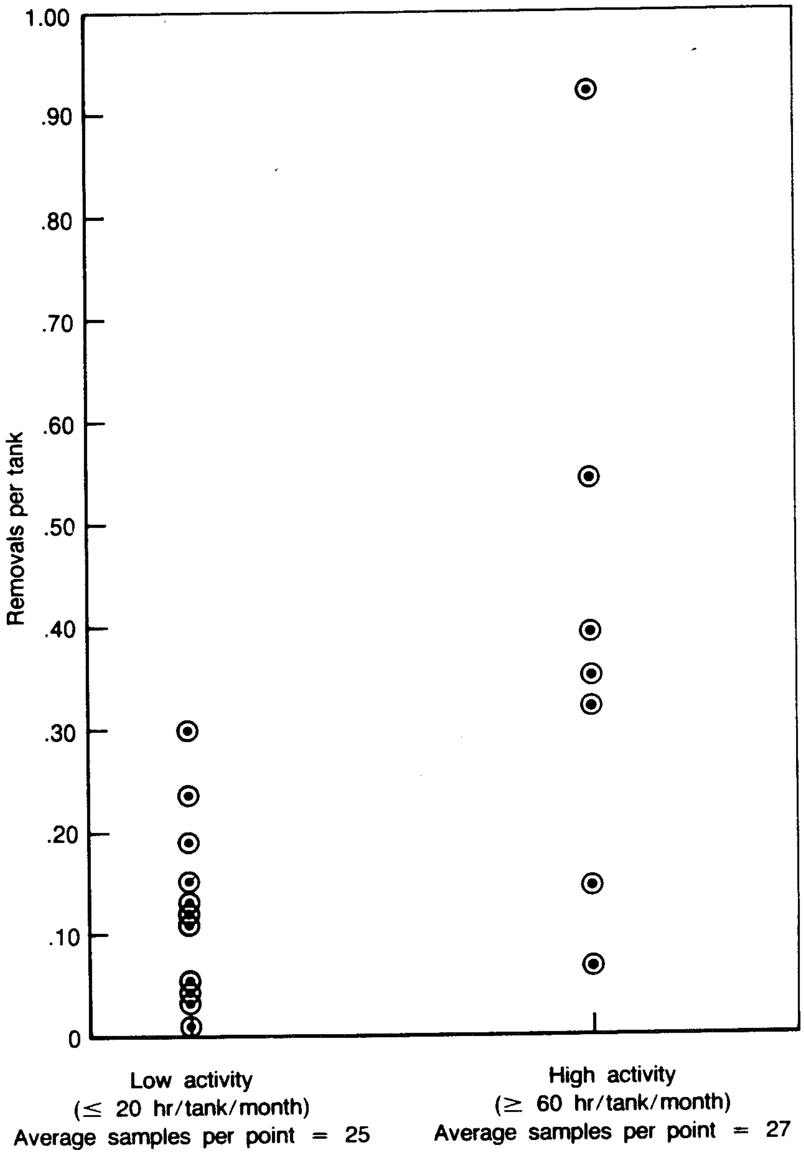

Fig. 2.4—Removals per tank, grouped by level of activity per month

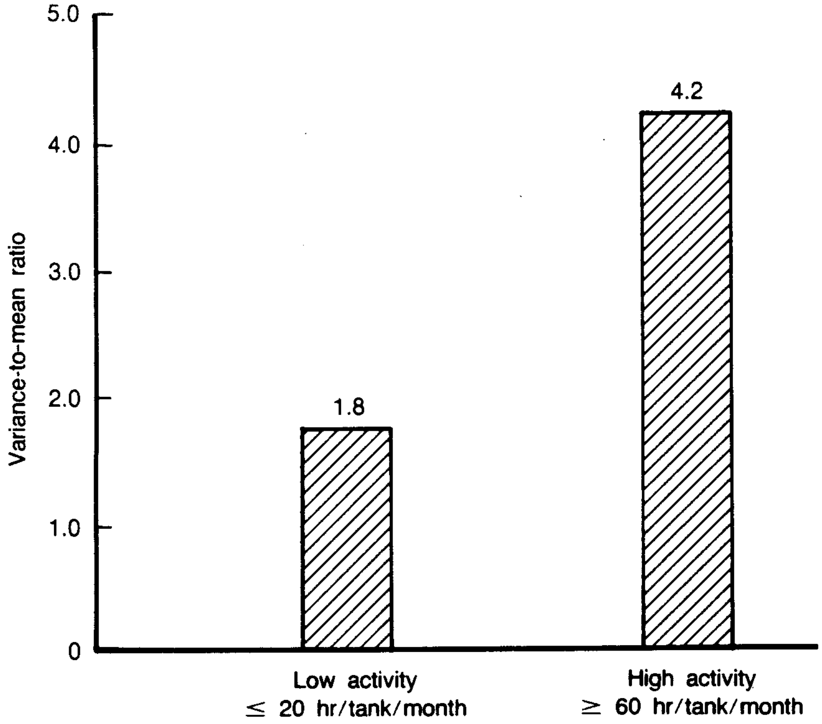

Fig. 2.5—VTMR in fire control system component removals per tank per month by level of M-1 activity

Wartime activity levels will generate both higher variance and higher overall demands. Statistical analysis suggests that the demand rate itself (removals per hour of usage) is flat as tempo increases. We find that the likelihood of removals increases in a manner roughly proportional to the increase in activity and is especially true in the regions of high tempos expected in wartime. This observation is supported by Fig. 2.6, which employs a statistical method, the logit technique, to relate the number of hours a tank is used in a month to the likelihood of a fire control removal in that month.[6] The four-standard-deviation

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[6] The logit model estimates the probability that a binary event (removal/nonremoval) will occur at variable levels of the explanatory variable (here, hours). Given that for a single tank in a single month, there tends to be either zero or one fire control removals,

gray area represents the 90 percent confidence level; that is, we expect approximately nine-tenths of all cases to fall somewhere in that spread.

Evidence from the FEDC, which records maintenance and usage information on exercises at Grafenwoehr and the National Training Center (NTC), gives partial validation of this result. The logit curve based on SDC data predicts a removal rate of about 6.2 fire control components per 1000 hours for tanks that operate at 60 hours per month. Tanks at Grafenwoehr averaged around 62 hours and also averaged a fire control removal rate of 6.5 per 1000 hours of tank activity. At NTC, where tanks are used on average over 100 hours per rotation, the fire control removal rate was curiously low at 3.3 removals per 1000 hours. However, the unique character of operations at NTC appears to explain this discrepancy. (See Appendix B.)

The direct effect of high variability is to limit the effectiveness of standard stock provisioning. An example using the Dyna-METRIC model (introduced in the next section) illustrates this effect. The example estimates the additional spare parts needed in the present logistics structure to achieve 80 percent availability of M-1 tanks at high confidence in three divisions. Using just the LRUs studied in this section, the model estimates the marginal costs at $96 million through Day 60 of the war and $129 million when pipelines stabilize. This, however, makes the standard assumption that all VTMRs equal 1. If, as is argued here, VTMRs are at least three times greater than that in peacetime, the recalculated costs for ensuring 80 percent availability jump substantially: to $178 million through Day 60 and $213 million when pipelines stabilize. That is, a tripling of VTMRs from the standard (though incorrect) assumption yields a near doubling in cost.

The situation is far worse if removal rates or VTMRs change between the time the stock is bought and the war is fought. The $213 million to purchase 80 percent availability was based on 1985 SDC removal rates and VTMRs. If, however, in combat the tanks suffered removals as seen in the 1986 SDC data, that $213 million, instead of

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standard statistical techniques, like regression, will not work. Logit generates a curve that says not how many removals are associated with some levels of operating hours, but with what probability a removal will occur in a single tank in a single month at some activity level. (See Ref. 11.)

The effect is not truly proportional because of the nonzero intercept. Why this should be the case—removals occurring when the tank is not in use—is not clear. It could be a "start-up" effect (like a light bulb popping when switched on); or it might be that failures occurring in one month are sometimes recorded only in the next month. The available data are insufficient to resolve this issue.

In some additional analyses, we compared the effect of hours operated, rounds fired, and miles driven on the probability of a removal occurring. The last variable had no effect; the first two had coefficients that were highly significant (<0.0001) and of approximately the same size.

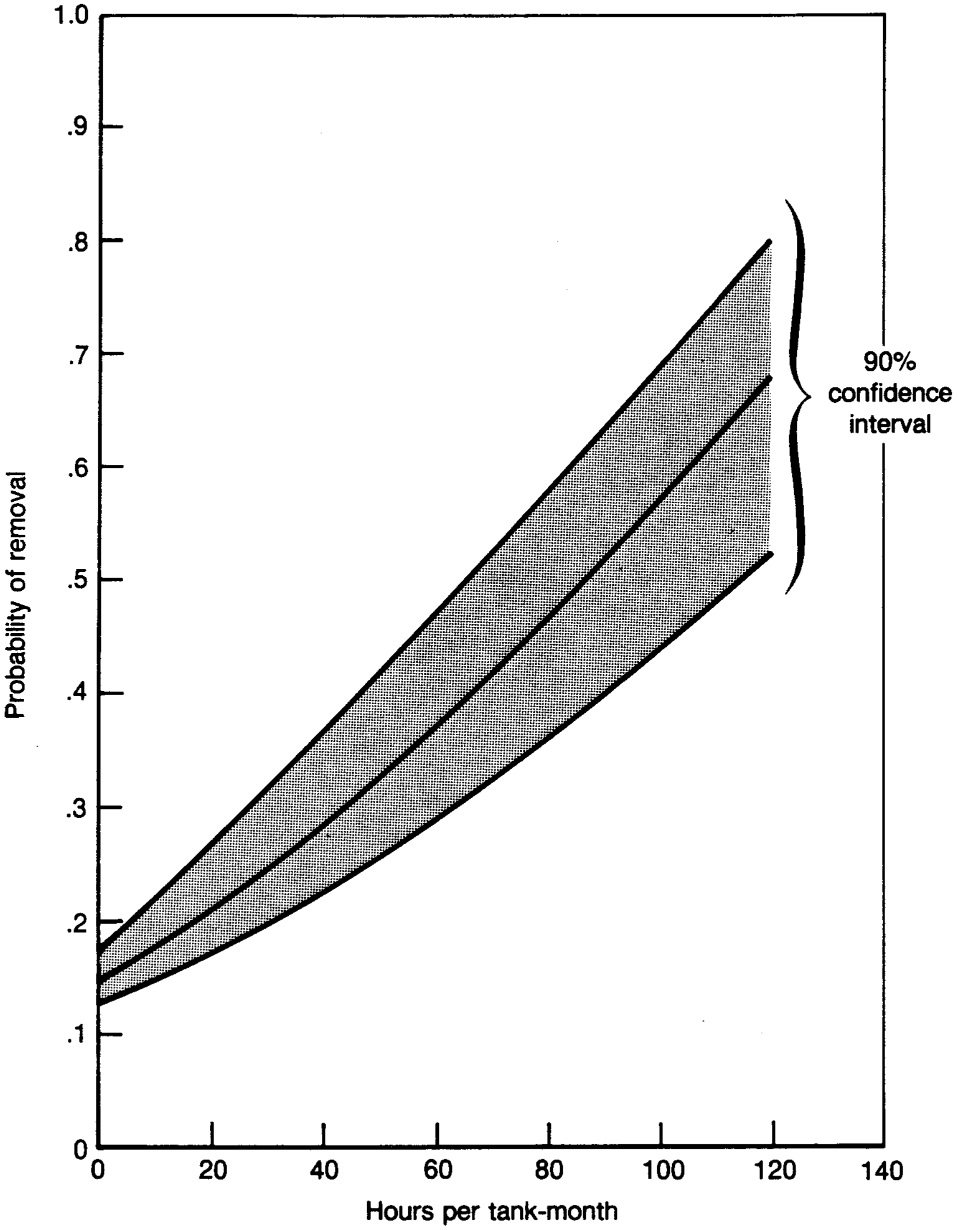

Fig. 2.6—Relation between tempo and fire control removal rate

buying 80 percent tank availability, would yield only about 22 percent fully mission-capable tanks on Day 60 and about 16 percent when pipelines stabilize. Appendix A gives additional information on the effect of such mismatches.

Uncertainties Concerning Wartime Scenarios and Enemy Attack

Purchases of spare components to satisfy wartime needs are also based on assumptions concerning the wartime scenario. It is highly unlikely, of course, that the projected wartime scenario will match the war that is actually fought. Some simple excursions with the Dyna-METRIC model, introduced in the next section, suggest that equivalent increases in scenario variability and in demand rate variability (that is, VTMR) would degrade weapon system availability by similar amounts.[7] Thus even without inherent demand rate variability, there would still be uncertainty in removals across units.

Depending on the actual war scenario, different units may have widely divergent numbers of working tanks. One excursion into a more variable scenario showed that, on Day 90 of the war, for example, the number of fully capable available tanks ranged from 70 percent to 0 percent of those remaining in a brigade, depending on how intensely the units were pushed. Such major differences pose important questions not only about what to buy but where to put it.

In addition, enemy attacks on critical test equipment, personnel, or spares will have effects comparable to those of unpredicted increases in demand rates. They will add to the confusion caused by high variance in demand rates and unpredictable patterns of fighting. They will raise both the means and variances in the demand for parts even higher.

In summary, warfare is likely to embody so many sources of uncertainty that the sustaining structure for high-technology weapon systems cannot expect to achieve high weapon system availability rates simply by adding stocks of spare parts to the supply system. Consequently, offsetting innovations must be sought in repair, transportation, communication, and information management—i.e., in the logistics *structure* itself.

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[7] One source of this scenario "variance" is how many hours tanks would operate in particular postures. According to the Armor Center scenario, tank hours per day range from roughly eight to 15 depending on whether the tank is disengaged or fully engaged in an offensive. Increasing that spread to four hours (disengaged) up to 22 (fully engaged in an offensive) would increase the spread of tank activity (variance about the mean activity rate) by about a factor of three. Similarly, we compared the effect of the VTMRs listed in Table 2.2, and more "warlike" VTMRs, which were a factor of three greater. In both cases of increased variance, the effect on weapon system availability was about the same: In the first 60 days of war, each source of added variance decreased tank availability by over a quarter.

III. EVALUATING ALTERNATIVE LOGISTICS STRUCTURES

Section II has shown that, for high-technology subsystems, there are serious problems with the underpinnings of the current wartime sustainability structure, largely because it depends so heavily on stock buyout solutions. As a consequence, we need to evaluate alternative logistics structures aimed at ensuring the wartime availability of tanks. These alternative logistics structures must necessarily focus on increasing flexibility in repair, transportation, communication, and information management.

In this section, we demonstrate a methodology for evaluating various alternative logistics structures. Part of this approach was initially developed to help the Air Force ensure the availability of its complex, integrated, high-technology equipment in combat.

After outlining the principles that guided our development of alternative Army logistics structures, this section describes the data and model we used and the initial evaluation results.

PRINCIPLES USED IN DEVELOPING ALTERNATIVE LOGISTICS STRUCTURES

Two mutually compatible logistics philosophies guided our development of alternative Army logistics structures: (1) responsiveness to uncertainty and (2) complex maintenance performed rearward, coupled with assured distribution.

The first recognizes that logistics structures for high-technology systems must deal responsively with uncertainties and complex interdependencies among removals, failures, test equipment, repair, and transportation. Such response requires a "system view" that gives timely visibility to the importance that particular support items have for achieving combat equipment availability. As Sec. II showed, removal rates are very uncertain, with variances often larger than the standard Poisson assumption used in stocking spares. So responses have to be prepared to accommodate sudden bursts of demands. In addition, removal rates in these systems are much higher than failure rates because of problems in diagnosing faults with test equipment. This means that many LRUs are removed in troubleshooting, but then test "good" in repair. These LRUs are a significant part of the workload that test equipment must handle. Again, the system needs to be prepared for this phenomenon. For most high-technology parts, repair depends totally on the availability of both specific test equipment and specific parts, typically the PCBs. Recognizing this is key to having high responsiveness. Finally, at higher echelons of repair the length of time that failed high-technology LRUs and SRUs remain unavailable usually depends more on administrative delay time at a node in the distribution system than on the actual transportation and repair time. These delay times must be reduced through expedited management.

The second view is consistent with the *USAREUR Support Structure Study* (US^3),[1] which recommends:

> a. A concept of maintenance which emphasizes component replacement as far forward as possible and piece part repair as far to the rear as logistically feasible. Concept reduces logistics burden on the combat commander by moving most maintenance/repair responsibility from the maneuver battalion level to the support battalion (brigade level). Concept also proposes a service maintenance facility that would provide peacetime scheduled services and on-condition maintenance services to all units on an area support basis. During wartime this organization would serve as a reconstruction point.
>
> b. A concept of distribution which features centralized management of all distribution functions at each level of command, increased asset visibility and a dedicated transportation service which provides scheduled, responsive delivery of the highest priority items.
>
> c. Logistic force structure based on workload rather than allocation rules.

Taken together, these two views suggest that alternative logistics structures should aim to increase the availability of fully mission-capable tanks by (1) changing the location of LRU repair, (2) increasing the availability of special test equipment, and (3) improving distribution systems and depot management.

Changing the Location of LRU Repair

The high-technology components in the M-1 tank require an integrated, responsive maintenance and supply system. The repair of end items forward and the repair of SRU components such as PCBs at echelons above corps can take advantage of the modularity of modern high-technology equipment. These concepts leave open, however, the question of the level at which high-technology LRUs should be repaired. These LRUs are removed at the tank and currently repaired

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[1] Prepared for the Deputy Chief of Staff for Logistics (see Ref. 12).

at brigade level using complex special test equipment and SRUs such as PCBs. These SRUs are now repaired at echelons above corps. Alternative locations for LRU repair include maneuver battalions, brigade Forward Support Battalions (FSB), Division Main Support Battalions (MSB), corps level, and echelons above corps.

Increasing the Availability of Special Test Equipment

For high-technology components, maintenance depends on special, system-specific test equipment to diagnose and repair failed equipment, removed LRUs, and their component SRUs. This makes test equipment much more critical than in lower-technology components, where much of the test equipment is not system-specific and where maintenance personnel can more easily identify faults. Thus, a second consideration to be addressed in the alternatives is the adequacy of the special test equipment to deal with the workload. The workload includes all LRUs removed in the course of troubleshooting the end-item equipment, not just those that have failed. Removal of LRUs that, when tested, exhibit "no evidence of failure" (NEOF) characterizes the complex diagnostic problem associated with high-technology equipment. Test equipment availability can be increased by consolidating test sets, providing more test equipment spares, and making improvements in diagnostic procedures.

Improving Distribution Systems and Depot Management

The third dimension to be covered is the question of alternative distribution systems (including transportation systems and command and control systems) plus the question of the location of the echelon above corps that will handle repairs beyond the capability of lower echelons.

Transportation resources can be used for many critical items and can take advantage of the relatively small size and light weight of high-technology equipment.[2]

By an improved distribution system, we mean one that can provide *assured,* regular transportation from the direct support LRU repair

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[2] Because transportation capacity always falls short of demand during wartime, the Army places great emphasis on having fully loaded shipments. Although this emphasis might be appropriate for high-volume, high-tonnage items that make up the bulk of transportation requirements, it is inappropriate for the critical, high-cost, small parts that have the uncertain demand rates found in high-technology weapon systems. Even dedicated transportation may make good sense for moving such parts. We estimate that such parts could be provided for one corps' M-1 tanks with a lift capacity of about 3000 lb per day. The alternatives computed in this section that use improved transport do not move the engine or other bulky LRUs—these travel by standard systems.

locations in the corps either to an in-theater repair facility or to a direct link back to the depot repair facilities in the Continental United States (CONUS). The intranodal handling, packing, and scheduling time in typical distribution systems renders them unresponsive when a combat-critical weapon system urgently requires a repair part. Even in peacetime, distribution systems fail to differentiate well between priorities for air cargo. This lack of differentiation will only become worse during wartime, with increases in volume and in high-priority requirements. Examples of ways to improve distribution include tailored transportation assets, "hub-and-spoke" systems based on timely delivery, and information systems to help make priority distribution decisions.

In large repair facilities (either in-theater or in CONUS depots), the management systems need to concentrate on the timely repair of items critical to weapon systems availability. Such concentration is equally or more important than efficiency in the production process. Examples of needed improvements to large facility management include information systems to identify short-term weapon system availability problems, computational support to tie these availability problems to production scheduling decisions, and internal improvements to increase responsiveness in moving reparables and piece-parts to meet short-term production scheduling decisions.

DATA

Evaluation of the wartime performance of alternative logistics structures requires data on the operational scenario, the maintenance and repair process, war reserve stock requirements, test equipment availability, transportation, and damage to assets.

Operational Scenario

This study employs the Army Concepts Analysis Agency's P90E COSAGE scenario of a Central European war to generate demands in the Dyna-METRIC model. In that scenario, we model one corps and all its divisions' M-1 tanks. Thus, we exclude M-1s belonging to the cavalry regiment or to the corps as a whole; their accumulated demand would be very small compared to the divisional demands.

Our results are based on the daily tank activity of one armored and two mechanized divisions. The former has six armor battalions, with 58 tanks each, and the latter two have five 58-tank battalions each, for a total of 928 M-1 tanks. The scenario delineates postures for each brigade (or fraction of a brigade) for each day of a 120-day campaign. These postures include offense, intense defense, and light static defense. The Armor Center Directorate model of battalion-level force-on-force combat provides average combat hours per tank for each posture; these range from 7.7 hours per day for light defense/static to 15.1 hours per day for full offense. Dyna-METRIC uses the brigade as the unit of analysis. Each brigade is assigned an activity level (operating hours per tank) for each day of combat, which applies to all tanks available in the brigade that day.

The logistics structure of this three-division "corps" is standard Army form (see Fig. 3.1). Each brigade has an FSB and each division possesses an MSB. The three divisions are in turn linked to a depot in CONUS (although a theater-level repair facility may be used). Repair forward of the FSB is not modeled in detail here.

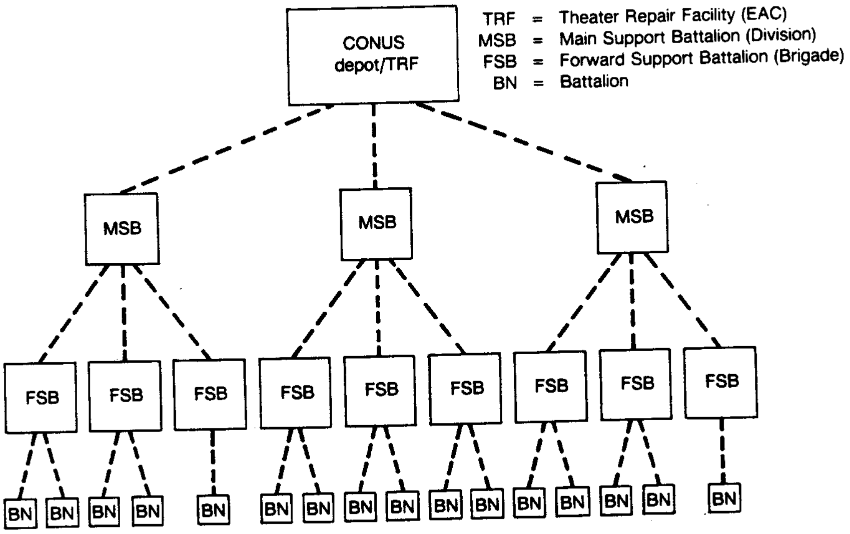

Fig. 3.1—Logistics structure used in scenario

Maintenance and Repair Process

Data used for the maintenance and repair process do not derive from the usual data used in standard Army factors. The Army's SDC system data were used to characterize the rates of failure, removal rate for LRUs, test equipment use and repair times, SRU use rates, and indenture relationships of systems, LRUs, and SRUs.

War Reserve Stock-Level Requirements

War reserve stock-level requirements for theater and depot were obtained from TACOM and Armament Munitions and Chemical Command (AMCCOM) for the LRUs of this investigation that they respectively manage. It was assumed that the theater war reserve LRU stock is positioned at the MSB. In addition, each division's ASL was located at the FSB and was derived from a recent Support List Allowance Computation (SLAC) computation from AMC Headquarters. For base case investigations, stock levels were assumed filled, but this was varied in other runs. Wartime analyses assume that peacetime pipelines are full.

Test Equipment Availability

On the basis of discussions with Army personnel on expected unit movements and time to relocate, we estimated test equipment availabilities at 50 percent for the battalion, 60 percent for the FSB, 70 percent for the MSB, and 90 percent for a Theater Repair Facility (TRF).

Transportation

Transportation data were obtained for M-1 tank items from the Logistics Intelligence File (LIF). These data were reviewed with other LIF data and with the Uniform Materiel Movement and Issue Priority System (UMMIPS) standards to arrive at the nominal estimates of 21 days order-and-ship time for serviceables and 28 days retrograde time for reparables.

In any major European contingency, strategic and tactical transportation will be overloaded. A 30-day cutoff of repair parts, supply, and retrograde to CONUS depots was assumed because most inter- and intratheater transportation is involved with unit movement during this period (Ref. 13). Besides reflecting the heavy loading of transportation in the early deployment period, a 30-day cutoff is consistent with the wholesale war reserve computation. For alternatives using a theater repair facility or assured transportation, a 10-day cutoff was assumed because of inevitable lags in establishing support systems in the midst of a major deployment.

Damage to Assets

The damage estimates are based on two sources. Test equipment vulnerability factors are taken from a recent FMC Corporation study of the vulnerability of wheeled vehicles to artillery (Ref. 14). For catastrophic and reparable damage to tanks we use *M-1 Combat Damage Factors* (provided by the Army Materiel Systems Analysis Activity [AMSAA]). AMSAA developed these factors using its Sustainability Predictions for Army Spare Components Requirements for Combat (SPARC). Net attrition of tanks was based on number of tanks destroyed (e.g., the SPARC data factor applied to the exposed tanks of the P90E scenario) subtracted from the number of available filler tanks (e.g., shown in the P90E scenario). Net attrition is included in all runs but is small because of sufficient numbers of filler tanks shown in the requirements.

THE MODEL

Quantitative evaluation of logistics capability requires the use of a model that focuses on a measure of wartime capability (such as weapon system availability), reflects a dynamic wartime environment, and includes the known variability of demands (i.e., VTMRs not equal to 1). The model should also account for the integrated effect of transportation, supply, and maintenance, and the availability of the weapon system.

Over the last eight years, RAND (in Project AIR FORCE) has developed Dyna-METRIC[3] to meet these criteria and has extensively used it to analyze Air Force needs. Using a multi-echelon technique for recoverable item control, Dyna-METRIC reflects wartime uncertainties and dynamics in an integrated logistics structure with repair and supply at different echelons. We have adapted this model to make it applicable to the U.S. Army. Adaptations include extending constrained repair priorities, allowing multiple weapon systems to be allocated at a unit, and aggregating LRUs to improve run time and input and output changes. The model allowed us to represent NEOFs, test equipment availability and capacity constraints, cross-substitution, priority repair, repair part indenture, and repair overflows to higher echelons.

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[3] For a detailed description of the model's mathematics and capability, see Refs. 15–18.

Version 4 of Dyna-METRIC is expressly suited to conducting worldwide analyses of logistics support for reparable components. It provides for three echelons of interaction (including the depot-to-theater link) and three levels, or indentures, of components (for which demand processes, repair processes, and spares levels may vary). It also contains a submodel that assesses the effect of limited repair resources. Output reports include capability assessments (for full- and partial-cannibalization assumptions), lists of problem-causing components and subcomponents, a depot workload summary, and recommended spares levels.

The basic mathematics underlying the model computed the expected number of components being processed by each function and echelon. Dyna-METRIC represents component support processes as a network of pipelines through which reparable components flow as they are repaired or replaced within a single theater. Pipeline segments are characterized by a delay time that arriving parts must spend in the segment before leaving. Some delays (e.g., local repair times) vary by component; others (e.g., base-to-depot transportation time) vary by base. The expected numbers of components in each segment, then, depends on the rate at which demands occur and the time the components spend in each segment.

Using the sum of all pipeline segments, Dyna-METRIC determines the complete probability distribution for the number of parts in repair and on order. Combining such distributions for all components provides the estimate of weapon system availability. The probability distributions are also used to compute spares requirements and to identify problem-causing parts. In this requirements mode, Dyna-METRIC recommends additional LRU, SRU, and subSRU stock to achieve fully mission-capable systems at the lowest cost. The strategy employed buys spares with a marginal analysis technique so that all LRUs jointly achieve that goal.

SAMPLE EVALUATIONS OF ALTERNATIVE LOGISTICS STRUCTURES

Using Dyna-METRIC, we evaluated alternative logistics structures under a range of circumstances that fall into two main groups:

- Cases without battle damage to test equipment or tanks, and
- Cases with battle damage to test equipment and tanks.

We then estimated the dollar costs and operational benefits (i.e., expected tank availability) of each logistics structure.

No Battle Damage to Test Equipment or Tanks

In the base case, each battalion is supported by nine sets of test equipment and spares at its brigade's FSB. Initially, the division's ASL is at the FSBs and the theater war reserve stock is available at the MSB. The wholesale war reserve stock is in the CONUS depot. In addition, each battalion is supported by the current distribution system.

Figure 3.2 shows the expected availability of *fully* mission-capable corps' M-1 tanks in the base case scenario—tanks that can use their high-technology systems at full specification levels. Tanks not fully mission-capable are significantly degraded when they have to fire at longer ranges, at night, or on the move. As shown in the figure, the

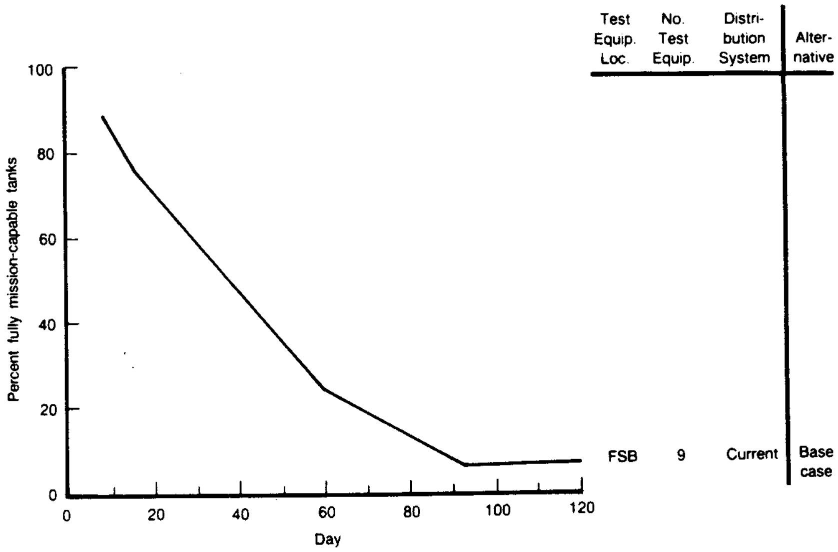

Fig. 3.2—Expected tank wartime availability with no damage: base case

expected availability of such tanks[4] in the base case drops from 90 percent at Day 8 to 55 percent at Day 30, continuing down to 24 percent at Day 60 and 6 percent at Day 90. This occurs primarily because the tempo increase used, although in agreement with Army scenarios, is not currently included in its stockage calculations. Also, unlike the Commodity Command failure factors, we account for the variability of removals along with NEOFs.[5] As shown in the previous section, operating tempo clearly affects removals, although with considerable uncertainty.

Relocation of Test Equipment and Spare SRUs. Figure 3.3 shows two alternatives to the base case:

- **Alternative 1** consolidates the nine sets of test equipment at the MSB and uses the current distribution system.
- **Alternative 2** increases the sets of test equipment to 16, decentralizes them to the battalions, and uses the current distribution system.

In Alternative 1, the test equipment and spare SRUs are consolidated at the MSB located in the division rear area. As Fig. 3.3 indicates, this modestly improves tank availability by 6 to 8 percentage points after Day 30. This improvement results from having the test equipment and spare SRUs, grouped at the MSBs, support three FSBs, thereby tending to average the variation seen at each FSB.[6] This consolidation also reduces from nine FSBs to three MSBs the number of locations that have to deal with LRU repair and spares for LRU repair. These advantages come, however, at the cost of longer transportation times to and from the malfunctioning tanks. In addition, moving the test equipment back to the MSB tends to reduce the battalion commander's control of repair assets.

Alternative 2 is a more "unit self-sufficient" approach that decentralizes the LRU repair forward to the battalion trains. For this

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[4] Reference to "fully mission capable" in all the following figures and text means the *expected* value. Further, to present a realistic estimate of the fully mission-capable rate, the analysis added the 13 low-technology LRUs with the highest removal rate. They were the engine instrument panel, distribution box, fan and drive unit, fluid cooler, transmission, wiring harness (mobility subsystem), engine starter, centrifugal pump, grip assembly, control handle (fire control), periscope, valve and bottle assembly (fire extinguisher), and collimeter. Altogether, these 43 LRUs represent nearly 70 percent of the M-1 LRU workload.

[5] For the prime 13 items tested by the Direct Support Electrical System Test Sets (DSESTS), the average NEOF rate is 44 percent and the range is from 22 to 65 percent. The NEOF rate in wartime is likely to be higher yet. This effect is being explored in on-going work and will be reported in the future.

[6] The LRUs are left at the FSB to provide forward stocks.

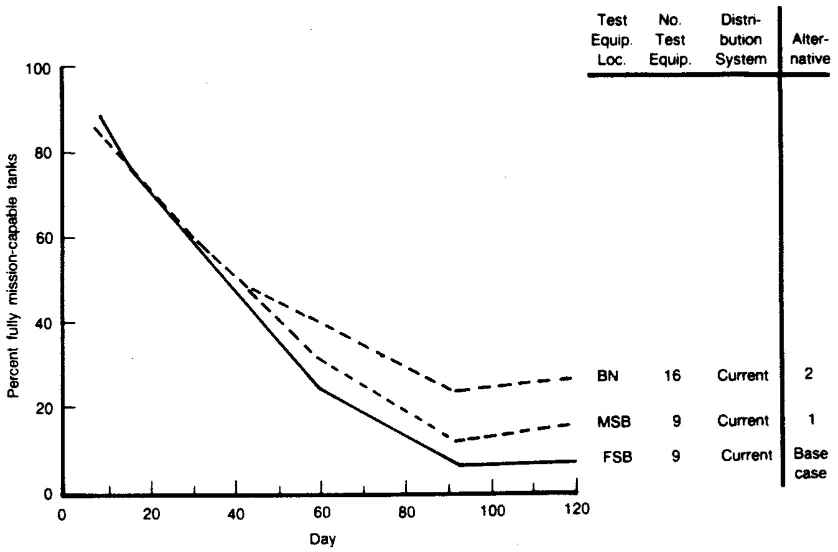

Fig. 3.3—Expected tank wartime availability with no damage: consolidation of test equipment and spare SRUs

alternative, repair would usually be made at the field trains, but if the combat commander felt that he needed even more responsive repair, he could move it to the combat trains. Moving test equipment and spare SRUs forward to the battalion trains requires increasing the number of test equipment sets (DSESTS and Thermal System Test Sets—TSTS) from nine to 16 to provide one set for each battalion. It reduces the average time to and from the tank by three hours. This approach improves availability after Day 30 to 30 to 40 percent.[7]

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[7] When we increase the sets of test equipment from nine to 16 in Alternative 1, we notice an even greater improvement (exceeding Alternative 2) because of the ability to smooth loads.

Alternatives 1 and 2 provide only modest improvements in system availability because the depot pipeline is still very long—including the 28-day retrograde time, the 10-day administrative plus repair time in depot, and the 21-day shipment time.

Improved Distribution and Responsive Depot. These resupply times would be reduced, however, if transport from the Direct Support (DS) units were regularly connected to an assured transportation link to CONUS depots (or to a theater depot-level capability).

Figure 3.4 adds three additional alternatives:

- **Alternative 3** keeps the nine sets of test equipment in the FSB and improves the distribution system.
- **Alternative 4** consolidates the nine sets of test equipment at the MSB and improves the distribution system.
- **Alternative 5** increases the sets of test equipment to 16, decentralizes them to the battalion, and improves the distribution system.

All alternatives that include an improved distribution system assume that the transportation segments for serviceables and reparables are reduced to seven days and serviceables are returned to units with greatest need. Figure 3.4 shows that this would improve tank availability dramatically without additional spares assets. After Day 30, availability under Alternative 3 improves to the 50 to 60 percent level, availability under Alternative 4 improves to the 60 to 65 percent level, and availability under Alternative 5 improves to the 60 percent level. Limited peacetime data for the depot at Mainz show turnaround times through the depot of over six months. This undoubtedly reflects the lack of urgency in peacetime. Wartime urgency will improve turnaround, and we have assumed so in our base case. However, additional improvements in depot materiel handling and management are probably needed to meet the 10-day depot time we are using. In the base case, we are fairly insensitive to this assumption because the relatively long transportation times (49 days) leave slack for occasional "expedited" transportation when faced with longer production times. But in the improved transportation cases, it is critical that repair and distribution be responsive to meet variation in demand. Our modeling assumes that the most urgent items are always produced in 10 days; such response will require advances in depot and distribution management systems.

Purchase of Additional Test Equipment. Figure 3.5 adds one additional alternative:

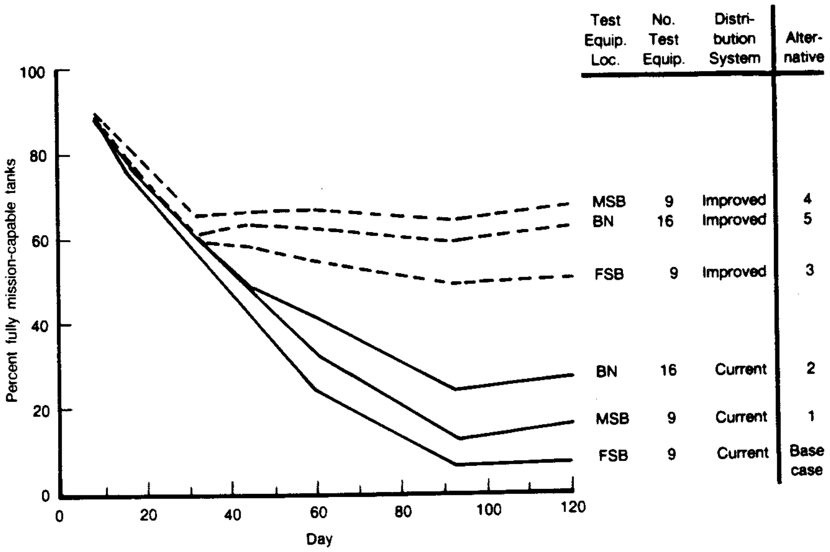

Fig. 3.4—Expected tank wartime availability with no damage: consolidation of test equipment and improvement of the distribution system

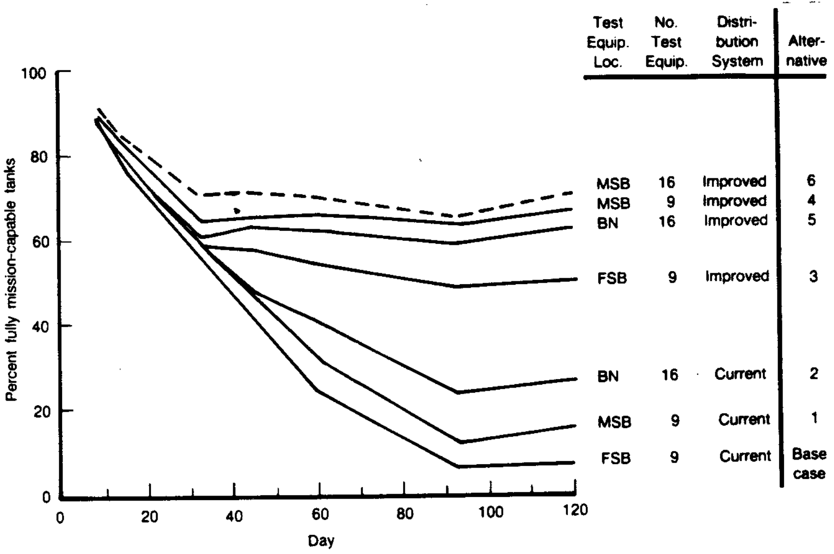

Fig. 3.5—Expected tank wartime availability with no damage: purchase of additional test equipment

- **Alternative 6** increases the number of sets of test equipment to 16, consolidates them at the MSB, and improves the distribution system.

As Fig. 3.5 shows, adding seven DSESTSs to the MSBs modestly improves availability in the MSB option to about 70 percent after Day 30. This results from the reduction in queues formed at the test equipment.[8]

Extremely Responsive Distribution System. An *extremely* responsive distribution system would bring even further improvements. Achieving an in-theater electronics depot-level repair facility (or rapid shipment to CONUS depots) with two days for transportation to and from the facility and with a three-day in-facility administrative repair time (for a total seven-day cycle) would be very optimistic but possible if one considers an assured "Federal-Express-like" intratheater (or perhaps fast intertheater to CONUS depot) transportation operation.

Figure 3.6 adds this additional alternative:

- **Alternative 7** increases the sets of test equipment to 16, consolidates them at the MSB, and makes the distribution system *extremely* responsive.

This would raise fully mission-capable tank availability to the 80 percent level throughout the 120-day scenario, without requiring any additional stock.

These results demonstrate the importance of distribution and depot system alternatives in achieving high availability rates in the face of uncertainty. Such tradeoffs can only be examined using a methodology that considers uncertainty of demands and the integrated support system including transportation, visibility over resources, stock, priority repair, controlled substitution (or cannibalization), intermediate test equipment, and the depot or theater repair facility.

Excursions. Such a methodology also allows excursions to see the effect of reduced resources. For example, Fig. 3.7 shows two additional alternatives:

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[8] The model limits queues to two days' workload including handling times (before evacuating them to a higher repair echelon) to avoid unrealistically long queues. This makes the model roughly consistent with the 36-hour FM-43-12 guidelines (Division Maintenance Operations, April 1986). In addition, there is a second DSESTS for automotive maintenance in the FSB. For this analysis, we assumed that the Bradley Fighting Vehicle workload requires all this test set's capability. If later information shows that this test set has unused capacity, it would reduce the costs shown for additional test sets.

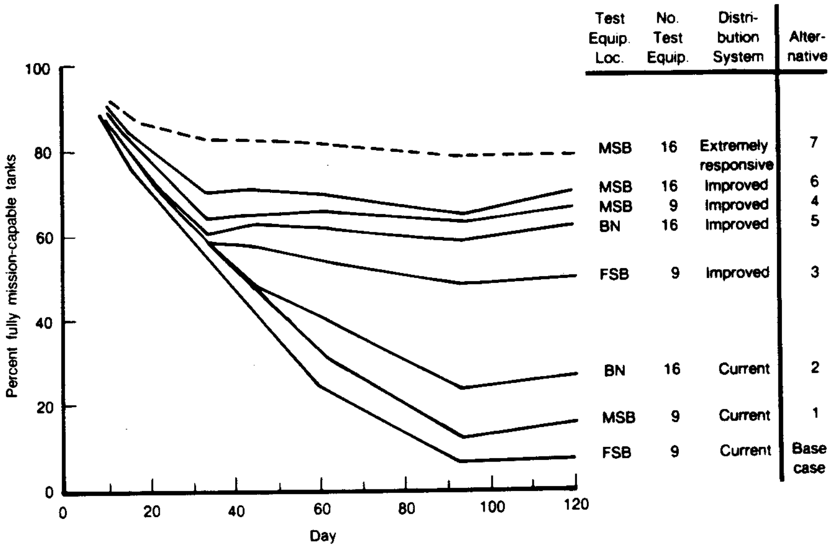


Fig. 3.6—Expected tank wartime availability with no damage: extremely responsive distribution system

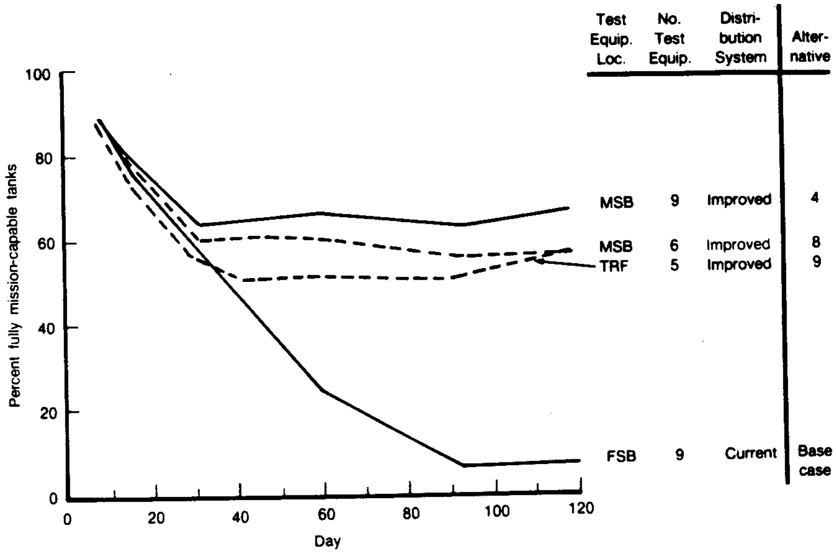


Fig. 3.7—Expected tank wartime availability with no damage: decreased test equipment at each MSB

- **Alternative 8** decreases the sets of test equipment to six, consolidates them at the MSB, and improves the distribution system.
- **Alternative 9** decreases the sets of test equipment to five, consolidates them at a TRF, and improves the distribution system.

As Fig. 3.7 indicates, decreasing the number of DSESTSs (with associated personnel) at MSBs from nine to six would reduce availability for Alternative 4 by 5 to 10 percentage points. In addition, consolidation of repair at the TRF (with very fast turnaround and no MSB or FSB intermediate repair) would produce 50 to 57 percent availability after Day 30—which is equivalent to Alternative 3 but with a savings in test equipment and personnel.

Battle Damage to Test Equipment and Tanks

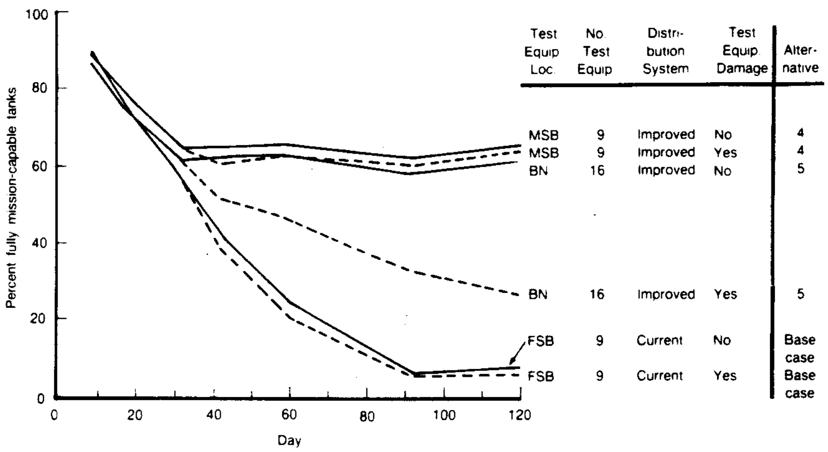
Battle Damage to Test Equipment. Figure 3.8 illustrates the dramatic effect that battle damage to test equipment can have on tank availability. For the three cases shown, levels of risk to test equipment were assigned as a function of distance from the forward edge of the battle area (FEBA) and intensity of battle. The probability of test equipment damage per set from enemy artillery fire thus ranged from 0.5 percent to 7.0 percent per day at the battalion level, from 0.25 percent to 3.5 percent at the FSB, and stayed at a constant 0.25 percent at the MSB. (A 30-day replacement period for any destroyed test equipment was also assumed.)

In two cases, test equipment lost through attack had little effect. For the base case (FSB + current distribution), this was because long queues and overflow back to depot had already overwhelmed the test equipments contribution. For Alternative 4 (MSB + improved distribution), the distance from enemy artillery implies that little test equipment should be lost.

In Alternative 5 (battalion + improved distribution), however, the relatively great vulnerability of forward-deployed test equipment eliminates much of the advantage gained from having rapid turnaround and increased test equipment.

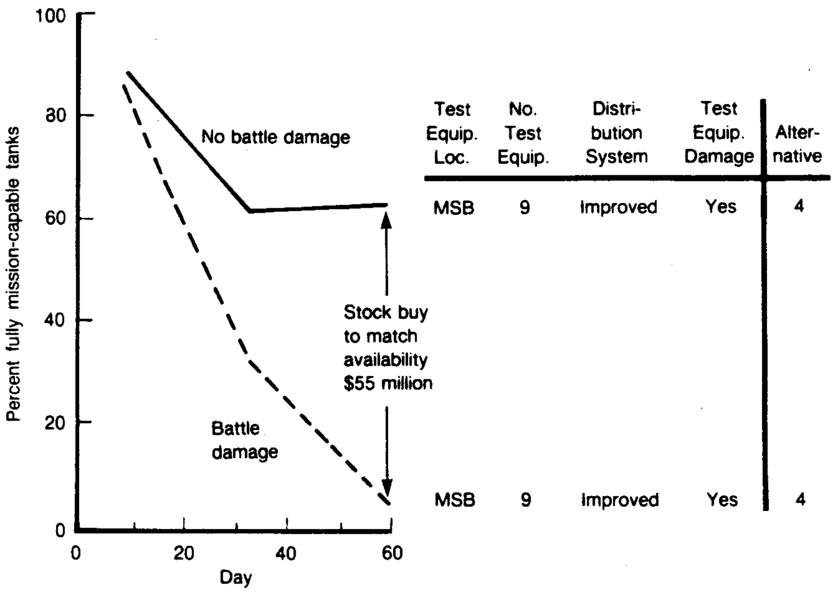
Battle Damage to Tanks. Figure 3.9 illustrates the additional dramatic effect of battle damage to tanks in combination with damage to test equipment. For Alternative 4 (MSB + improved distribution), virtually no tanks would be operable at the end of 60 days. This finding reinforces the need for war reserve computations to include allowances for battle damage to spare parts.

According to data in a recent AMSAA SPARC study of the M-1 tank, the replacement stock for LRUs at the end of 60 days of combat



Test Equip Loc	No Test Equip	Distribution System	Test Equip Damage	Alternative
MSB	9	Improved	No	4
MSB	9	Improved	Yes	4
BN	16	Improved	No	5
BN	16	Improved	Yes	5
FSB	9	Current	No	Base case
FSB	9	Current	Yes	Base case

Fig. 3.8—Expected tank wartime availability: effects of battle damage to test equipment



Test Equip. Loc.	No. Test Equip.	Distribution System	Test Equip. Damage	Alternative
MSB	9	Improved	Yes	4
MSB	9	Improved	Yes	4

Fig. 3.9—Expected tank wartime availability: effects of battle damage to tanks

for a corps of tanks would cost approximately $116 million. Some of these replacement LRUs could be made available by cross-substitution from tanks awaiting normal reliability and maintainability (R&M) repair. After computing these R&M removals, we were able to estimate that only $55 million worth of additional LRU stock would allow the same availability as would be attained without any battle damage.

Overall, these results show that dramatic improvements in sustainability can be achieved without increasing spares, but such improvements depend on responsive, assured transportation and on responsive, priority repair at theater repair facilities and depots. Such response will require different depot management and distribution systems dedicated to serving high-cost, critical spares assets for selected weapon systems.

Costs and Benefits

Table 3.1 summarizes the costs and benefits of the alternative logistics structures.[9] The benefits are shown as the average number of tanks gained over the 120-day period through improved availability

Table 3.1

COSTS AND BENEFITS OF ALTERNATIVE LOGISTICS STRUCTURES

Structure				Benefits		Costs	
Alternative	Test Equipment Location	No. Test Equipment	Distribution System	Initial Tanks	Tanks Gained	Cost of Alternative ($ millions)	Cost of Stock Buyout ($ millions)
Base case	FSB	9	Current	306	—	—	—
3	FSB	9	Improved	—	+195	11.9	57
9	TRF	5	Improved	—	+239	11.1	72
8	MSB	6	Improved	—	+260	8.3	74
4	MSB	9	Improved	—	+288	11.9	102
6	MSB	16	Improved	—	+353	20.3	149
7	MSB	16	Extremely responsive	—	+450	20.3-41.3	232

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[9] This cost evaluation uses marginal analysis. In it, we address only a small part of the overall system—the high-technology components of the M-1 tank. We add or subtract from existing multiweapon units; we do not totally restructure them. See Appendix C for more detailed information on our cost analysis.

from the alternative.[10] With Alternative 6, for example, if (1) test equipment and LRU repair is moved to the MSB, if (2) seven additional sets of test equipment are procured for the MSB, raising its total number to 16, and if (3) the life-cycle cost of a Blackhawk utility helicopter (for improved distribution) is included, an additional 353 tanks are made available on average. This approach will cost $20.3 million.[11] By contrast, if one were to try to achieve this benefit by buying additional stocks, it would cost $149 million (and that availability might still not be achieved because of the uncertainties in demand).[12] For Alternative 9, the cost of the facilities is included along with decreased test equipment and increased transportation costs. For Alternative 7, upper costs are a rough estimate for a theater depot electronics repair capability.[13] (The same benefit might be achieved at lower cost by using wartime intertheater air transport—whether using Military Airlift Command (MAC),[14] Civil Reserve Airfleet (CRAF), or commercial

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[10] "Tanks gained" were calculated as follows. For each alternative, the average number of tanks available over the 120-day period was computed; for the base case an average of 33 percent of the tank fleet was available and for Alternative 3 an average of 53 percent of the tanks were fully mission-capable. Stock costs were calculated in the base case that would allow a minimum FMC rate of 53 percent (at 90 percent confidence) across the 120 days of combat. It should be noted, of course, that this weights all 120 days of combat equally and that most of the stock costs will be incurred to improve tank availability in the second half of the time period.

[11] These costs include the acquisition cost of the test equipment, van, and 20-year discounted cost of two operators. The cost of the helicopter includes the equipment, crew training, and the 20-year discounted cost of two crew members, four enlisted maintenance men, and annual operating costs; however, it excludes the cost of a distribution management system. We have assumed that the helicopter is assigned to a current corps or division aviation unit.

[12] The analyses were performed with removal data from 1985; as Appendix A shows, removal rates and variances changed considerably in the next year, adversely affecting any inventory "buyout" solution. This reinforces the value of robust logistics structures that emphasize repair and efficient distribution over increases in inventory. We plan to extend our analyses to demonstrate the value of robust structures, especially in combined arms employments.

[13] Our analysis of the facility and equipment costs of M-1 repair at Mainz Army Depot showed added costs of about $17 million plus $4 million to split the equipment among two buildings for increased survivability (see Appendix C). However, until we know more about depot repair and administrative handling times, we cannot know the adequacy of this in-theater electronic repair capability.

[14] One option for this transportation link is to use MAC C-141s to transfer components between the theater and a CONUS aerial port. The weight and volume of the high-technology M-1 components are small enough that only a partial C-141 load is required. Once at the aerial ports in CONUS, priority handling procedures would be applied to ensure rapid dispersal to the depots. The use of C-141s should result in no additional costs.

airlift[15]—to link with the CONUS depot and using good distribution control systems). In contrast (comparing Alternatives 6 and 7), the cost to employ the stock buyout approach would require more than $80 million to gain the 100 additional tanks.

Overall, impressive gains appear possible from improving distribution and repair systems. The gains approach 450 tanks, and the costs are likely to be far below the $232 million stock buyout costs per single corps. Since the same management and distribution systems can be used across weapon systems, there should be even greater combat gains when the M-60A3, AH-64, M-2/3, and other high-technology weapon systems are included.

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[15] The intra-CONUS link could be provided by narrow-body domestic aircraft under CRAF agreements. In addition, it may be possible to arrange agreements whereby commercial aircraft would be dedicated to the intra-CONUS network in wartime. Because of the small weight and volume requirements, no structural modifications of the aircraft should be required. Furthermore, the CRAF agreements usually do not require annual payments in peacetime.

IV. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

CONCLUSIONS

This research shows—given the inevitable uncertainties in peacetime and wartime demands—that the Army must increase the *responsiveness* in its logistics structures or face a loss in combat capability. The research also demonstrates a new methodological approach for assessing logistics structures.

Certain conclusions are obvious, and the effects of their implementation are fairly clear. For example, moving the DSESTS to the MSB improves the availability of test time for items that most affect combat availability, and it permits priority allocation of repair capacity across three brigades much more easily than would be possible by using locally focused repair at each brigade's FSB.[1]

Other conclusions are also obvious, but the effects of their implementation are less clear. For example, devoting a Blackhawk helicopter and an associated distribution system to collecting and distributing repair parts increases responsiveness and thus combat capability. Additionally, if there were severe damage to one MSB's capability, assets could be shared more easily. But, can the Army achieve the necessary visibility over repair actions and stockage and couple it with current command and control systems?

Traditionally, field maintenance, supply, transportation, and repair at echelons above corps have been functionally separate and have even had separate measures of efficiency. The approach used in this study provides a way to assess alternative improvements in the entire logistics structure by comparing tradeoffs across separate functions. With this methodology, the Army can more confidently assess the overall effects of changing parts of its logistics system.

We have concluded that the Army can probably achieve large gains in combat capability at lower than current costs by improving its logistics management systems. To this end, we intend to concentrate our future research on exploring ways to enhance logistics management systems.

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[1] A cushion against transportation uncertainties could be achieved by leaving some ASL stocks at the FSBs.

FUTURE RESEARCH

Our future research would determine the requirements for attaining three main goals: improving transportation and distribution systems, attaining necessary command and control systems, and developing responsive GS/depot capabilities.

Improving Transportation and Distribution Systems

All responsive logistics structures that rely on consolidation of repair assets will also need a distribution system consisting of a supply and transportation system tied into a strong logistics command and control system. For example, an alternative that employs a consolidated intermediate repair facility in the theater and remove-and-replace maintenance at the units would need assured transportation to move LRUs to and from the facility. Trucks alone may not be sufficiently responsive because the distances can exceed 200 km. And in wartime, specialized European commercial delivering services, such as the Rapid II System, may not be available (Ref. 19).

Technologically sophisticated subsystems have LRUs such as target and gun positioning computers that are typically small and light.[2] Thus one or two utility helicopters with a 2000 to 4000 lb lift capacity could transport a division's high-technology repair parts requirements to a centralized facility. Several divisions' repair parts requirements might also be handled by a combination of trucks and Short-Take-Off-and-Landing (STOL) aircraft, having, say, a 5000 to 8000 lb lift capacity. Aircraft like the Dehaviland Buffalo or Air Force C-23A would do. Or, helicopters could operate in a "Federal Express" hub-spoke arrangement. The Air Force currently uses the European distribution system of 18 low-cost STOL aircraft to connect over 40 locations (with 12-hour response) in a similar manner. Thus, fast theater transportation is quite feasible for high-cost, high-technology, critical reparables that are also small and lightweight.

In alternatives that require more responsive depots, transportation becomes both more critical and more difficult to implement. The requirement is to connect CONUS depots to theater facilities with turnarounds measured in days, rather than weeks. The light weight of transported components means that the Army could use a few narrow-body aircraft, such as DC-8s or 707s, rather than C-5s. It may even be plausible to use existing MAC aircraft in peacetime and, in wartime, uncommitted narrow-body CRAF aircraft (or other commercial

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[2] An entire corps of M-1 tanks requires only about 3000 lb per day of sophisticated repair parts.

carriers) if MAC could not assure support. Connecting depots with the theater distribution network[3] would allow such aircraft to be far from the actual battle area.

Naturally, any transportation alternative that uses increased numbers of aircraft would also have to be assessed in terms of increased system costs, vehicle loss rates, and competition from other sources for use of the aircraft.

Attaining Necessary Command and Control Systems

Responsive logistics structures also require an ability to "see" the current state of stocks, the relative needs of combat units, and the contents of retail and wholesale repair pipelines. For example, the US^3 study[4] forecasts the need to know (1) theater assets in all divisions aggregated by corps and (2) total (across-corps) assets by theater. The US^3 recommends having theater distribution centers distribute stocks based on operational priorities and the state of current stockage levels.

Such enhanced command and control concepts make feasible the idea of repairing components in priority order based on the changing needs of weapon systems in combat. The Army is currently developing systems that can serve as building blocks for such enhanced command and control. It now has an automated Direct Support Units Standard Supply System (DS^4), and it will soon field the Standard Army Retail Supply System (SARSS). In addition, the Army can potentially determine assets in depot pipelines by exploiting the LIF that records, among other things, the movements of retrograde and serviceable assets. Even with improved command and control systems, responsive logistics structures will also require assured transportation, repair, and supply assets.

Developing Responsive GS/Depot Capabilities

The Army has already developed theater repair facilities with some depot-level capability in the European theater—an important capability that should be recognized in any logistics alternative. The Army also has some depot-level capability for PCBs in GS units. However, the majority of depot capability currently resides in CONUS. Harnessing these depots—with over 40,000 skilled workers and billions of dollars in capital equipment and facilities—may provide the key to quicker and improved combat responsiveness.

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[3] Such theater networks are recommended for the Army in Ref. 12, pp. 3-26 to 3-29.

[4] Ref. 12, p. 3-5, pp. 3-9 to 3-15.

Depots currently are expected to provide limited resupply and to receive limited retrograde from combat theaters in the early days of a conflict.[5] Their specialized capability is assumed effectively cut off in the critical early days.

Tapping this capability would require increased attention to:

- Developing an assured airlift capability from the repair depots to the theater. This might be an adjunct to (or an assured slice of) the Air Line of Communication (ALOC) or other arrangements discussed above.
- Selectively shortening depot repair and administrative processing times.
- Selectively reducing the pipeline time (probably through airlift) for those items most affecting combat availability. This will require predictive methodology for identifying limiting components and that, in turn, will require knowledge of the "state of the theater."
- Changing rules for depot induction and distribution decisions so that requisitions most affecting combat availability are given priority attention.[6] (One must be judicious here because of the implications involved in changing management systems that have been in place for years.)

Workloads programmed into the depots are currently based on information from the Commodity Command Standard System (CCSS) and negotiations among the Materiel Readiness Centers (MRCs) and the Depot Systems Command (DESCOM). Much of the data they use are projections based on demand rates that span a number of calendar quarters and that are several calendar quarters old. As we saw above, forecasting uncertain demands on the basis of old data can create many mismatches. Workload needs to be based on the requirements of the current—and not the past—state of the force, especially when rapid transportation is made available.

In addition, the depot repair process is currently geared to raise productivity, as measured by manhour utilization rates and units produced. To ensure wartime capability, the primary focus should be on raising weapon system availability rates.

RAND's Project AIR FORCE is conducting experiments at the Air Force's Ogden Air Logistics Center with a model called DRIVE (Depot

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[5] Units in theaters currently try to compensate for such limited flows by stocking depot spares. We expect that demand variability will cause this prestockage to be insufficient in many cases for many items.

[6] The Army has developed priority systems such as Aviation Intensively Managed Items. Such systems may provide key ingredients to improve systemwide responsiveness.

Repair Induction in Variable Environments). This model gives depot managers ranked lists (both in wartime and peacetime) of items to be repaired that would maximize the probability of achieving desired availability rates (by weapon system and location) at a specified (but not distant) future time. Army models like this would obviously require information about the current state of divisions and weapons, and this information may (because of mobility and the frictional wear) be more difficult to determine in the Army than in the Air Force. Nevertheless, the potential benefits of a model like DRIVE are so large that we intend to assess current and potential abilities to gain such information about Army repair processes and to study the pertinent repair policies in detail.

Studies of GS/depot operations and resources naturally involve examining the relative worth of GS facilities, CONUS depots, and theater repair facilities. The methodological structure now available enables us to make these evaluations. The approach needs repair and processing data describing each GS/depot work center. These data must be collected from within the current depot operation. Then the Dyna-METRIC model and other analyses can be used to describe costs and benefits of each resource.

Since the new Intermediate Forward Test Equipment (IFTE) may supplant most electronics TMDE both in the field and at depots, we think it fundamental to include it in examinations of the relative value of GS, depot, and theater facilities. We expect to provide data that would be useful in IFTE planning.

GS and depot workloads come from many weapon systems, so we need to expand our analysis base. We expect to include the AH-64 Apache helicopter next. Given that it currently is in an early stage of procurement, we may be better able to influence logistics structural and resource decisions relating to this system than we could for older sunk-cost systems like the M-1.

Appendix A

VARIABILITY IN FIRE CONTROL REMOVAL RATES

Stockage policies must base their component buys on available peacetime data. Unfortunately, data on weapon systems removals are not consistent over time.

Comparison of SDC data covering two years demonstrates the fluctuation in fire control removal rates and VTMRs and we suspect that this high variance would persist whether longer or shorter periods were studied. If longer periods were used, variance could stay high because of component modification and aging of the weapons; over shorter periods, the small sample sizes could keep the variance high.

Tables A.1 and A.2 show removal rates and VTMRs, respectively, for selected fire control components on the M-1 tank in 1985 and 1986. Data come from the same three battalions (Ft. Hood, Schweinfurt and Bamberg, Germany) in both years; more than half of the actual tanks carry over between the two years.[1]

Although the overall removal rate did not change appreciably between the two years, there was great change in the individual components' removal rates from year to year. In 1985, the turret network box and the computer created significant problems but became less of a problem in 1986. Components of the thermal imaging system showed far higher removal rates in 1986 than in 1985.

Overall variance was much greater in 1986 than in 1985. The individual VTMRs show that the thermal imaging system components were a particular problem in 1986: Not only did their removal rates increase but so did their VTMRs, and the latter precipitously.

Clearly, ordinary stockage calculations not only dictate extensive (and expensive) inventories, but they also frequently recommend the wrong inventories. Unless removal rates in war match those used in peace to determine stock levels, there will be shortages no matter how much money is spent. For one example, if stock were bought on the

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[1] The data cover October 1984 to August 1985 and October 1985 to August 1986. Monthly activity rates are calculated based on cumulative totals from month to month. Since the earlier data (from 1984) were not available, it was not possible to generate activity data for September 1984; to balance the number of months, we also deleted September 1985, giving us two sets of eleven months each.

Table A.1

SELECTED FIRE CONTROL AND STABILIZATION REMOVAL RATES IN 1985 AND 1986

LRU	Removal Rates (per 1000 Hours) 1985	1986
Turret network box	1.80	1.29
Computer	1.29	0.34
Crosswind sensor	1.27	0.75
Laser rangefinder	0.62	0.74
Line of sight electronic assembly	0.82	0.30
Computer control panel	0.17	0.06
TIS power control unit	1.22	1.67
TIS image control unit	0.78	1.38
TIS thermal receiver	0.72	1.51
TIS electronic control	0.97	0.89
Gunner body assembly	0.95	0.74
Servomech traverse	0.53	0.42
Servomechanism	0.42	0.32
Panel assembly—upper	0.23	0.23
Slip ring assembly	0.19	0.11
Gyro assembly	0.21	0.38
Head assembly	0.08	0.13
Panel assembly—lower	0.19	0.11
All fire control components	12.4	11.4

SOURCE: SDC data, FY 1985 and 1986.

NOTE: Turret drive is not included because of system changes.

basis of 1985 demand rates, but wartime saw rates like those found in 1986, then serious spares shortages in the thermal imaging system would most probably ensue. If the opposite were the case—stocks were bought at 1986 rates, wartime entailed 1985 rates—then the supply system would most likely be short on turret network boxes and computers.

A simple evaluation using the Dyna-METRIC model suggests the effect of these kinds of mismatches. A stockage buyout for three divisions through Day 60 of the war would require $411 million at 1985 rates and $654 million at 1986 rates to achieve 85 percent fully mission-capable tank availability.[2] This availability can be achieved if

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[2] Different logistics structures, such as the ones proposed in Sec. III, will reduce the impact of mismatched inventories and removal rates. To illustrate the difficulties of such mismatches, this appendix assumes a "discard only" strategy—i.e., with no repair or

Table A.2

SELECTED FIRE CONTROL AND STABILIZATION VARIANCE-TO-MEAN RATIOS IN 1985 AND 1986

	Ratio	
LRU	1985	1986
Turret network box	2.94	0.91
Computer	0.88	1.41
TIS image control unit	0.66	5.94
TIS power control unit	3.35	4.43
TIS thermal receiver unit	1.51	5.76
TIS electronic control unit	0.93	3.48
Laser rangefinder	2.33	2.45
Line of sight electronic unit	1.94	2.32
Gunner body assembly	0.73	1.32
Servomechanism traverse	1.03	3.12
All fire control components	5.72	18.4

SOURCE: SDC data, FY 1985 and 1986.

wartime removal rates match the rates planned. If there were a mismatch as in the first example, the $411 million inventory would provide only 25 percent tank availability. In the other case, the $654 million would only buy 35 percent tank availability.

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resupply available. A similar example in Sec. II assumed availability of the resources required by the current repair structure.

Appendix B

FIRE CONTROL REMOVAL RATES IN THE FIELD EXERCISE DATA COLLECTION

The FEDC provides data on tank operating hours and component removals at Grafenwoehr, Federal Republic of Germany, and the National Training Center, Ft. Irwin, California. This permits a comparison with similar data from the SDC.[1]

Figure B.1 compares SDC and FEDC results. It repeats the logit curve of SDC data from Fig. 2.6; the gray area around the curve represents approximately a 90 percent confidence range. The curve shows the expected probability of a fire control removal in a tank that operates at a given level of activity. Each dot represents the results from eight battalions' rotations at NTC and Grafenwoehr, with the point representing the average number of fire control removals per tank at the rotation's average level of activity per tank.

The Grafenwoehr data appear fairly consistent with the SDC-based statistical model. Virtually all the NTC points, however, lie far below expectations based on the SDC-based statistical model. We believe, however, that the NTC fire control removal rates are unrealistically low because of the special nature of NTC.

Two factors at NTC condition the results: First, the MILES uses a laser, and so makes certain fire control components (e.g., rangefinder, ballistic computer, crosswind sensor) much less important, and hence less used and less maintained. In fact, these components are often cut out of the system to let the MILES function effectively. Clearly, less reliance on the fire control system would reduce the number of component removals.

Second, the object of NTC is not tank gunnery proficiency, as it is at Grafenwoehr. It is instead developing competence in force-on-force attacks, with emphasis on movement, mass, surprise, effective use of tactics, and so on. Tanks with a degraded fire control system may still be useful to the commander as long as they can move and shoot in some fashion. Thus they are less likely to be withdrawn from the

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[1] The data systems do differ in some respects. SDC is based on monthly activity data, FEDC on two-week rotations. The FEDC data collection method is also far less intrusive than the SDC's. Such differences may diminish the comparability of the two data systems.

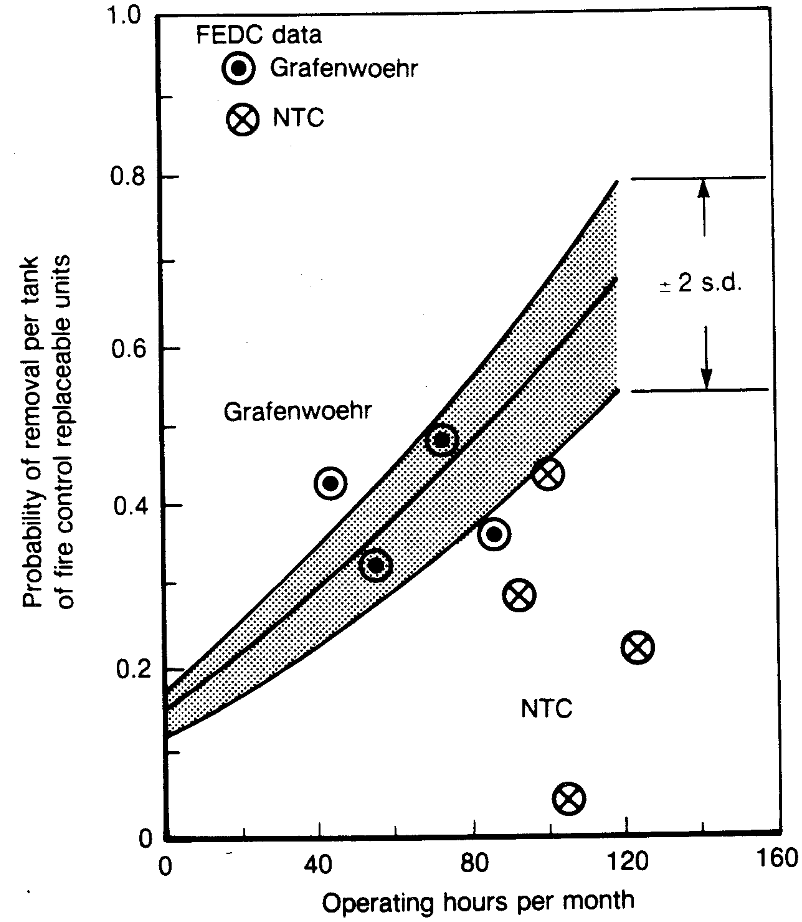

Fig. B.1—Fire control removals in SDC and FEDC data

battle for repairs unless it is absolutely necessary. Only when the fire control component is necessary for fighting might a tank be pulled out of combat to replace a failed LRU. The thermal imaging system and the turret networks box constitute almost 80 percent of all fire control removals at NTC; they account for 58 percent at Grafenwoehr and 43 percent in the SDC system. These components are necessary for turret movement, night fighting, and seeing through smoke. On the other hand, there were only two removals of computers, laser rangefinders, and crosswind sensors at NTC (or 5 percent of the total); in the SDC, these three items accounted for 27 percent of all fire control removals.

It might be expected that NTC would demonstrate relatively high powerpack removal rates, given the importance of tank movement. Figure B.2 supports that notion. It shows a logit curve plotted on the basis of SDC data, again with the Grafenwoehr and NTC cases added.

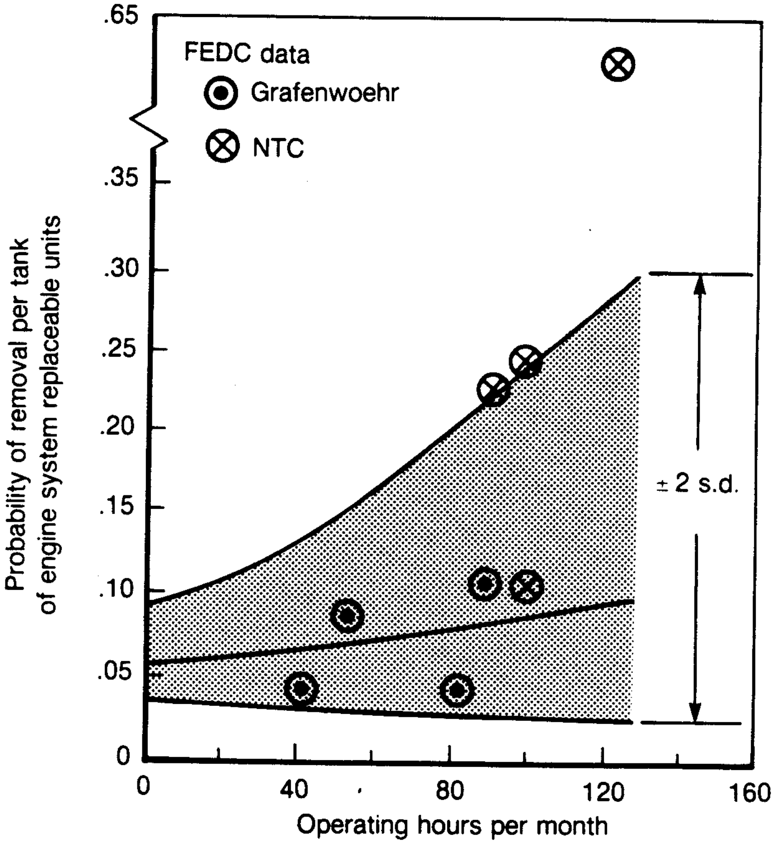

Fig. B.2—Engine system removals in SDC and FEDC data

Here it can clearly be seen that not all removal rates are low at NTC (as might happen if, say, data collection was inadequate); certainly they are, however, for the fire control system.

Appendix C

COSTS OF ALTERNATIVE LOGISTICS STRUCTURES

This appendix describes the cost information used in the body of this report. Using the most recent data available from Army sources, we express costs in FY 1987 dollars unless otherwise noted. Table C.1

Table C.1

LOGISTICS COSTS FOR SUPPORT ALTERNATIVES
(In thousands of FY 1987 dollars)

Additional test equipment (per set)	
DSESTS	$175
Van	
Procurement	78
Operation and support (20-year life cycle)	46
Two operators (20-year life cycle)	897
	1,196
Transportation using Blackhawk helicopters (per helicopter)	
Procurement	5,800
Operation and support (20-year life cycle)	1,483
Personnel (20-year life cycle)	
Maintenance	1,795
Aircrews	1,887
Training of aircrews	975
	11,940
Theater repair facility	3,000–5,000
Depot TRF, operations and personnel	
Personnel (20-year life cycle)	2,000
Facility	3,000–5,000
Facility upkeep (20-year life cycle)	1,000
Equipment	10,000
	16,000–18,000

summarizes the estimated cost elements used in assessing alternative logistics structures.

Our cost analysis focuses on but a small portion of the overall logistics system, namely, support for the fire control system on the M-1 tank. It does not examine how proposed alternatives might affect other weapon systems. Specifically, we estimate the costs associated with

- Additional test equipment,
- Transportation using helicopters, and
- Procurement of a TRF.

ADDITIONAL TEST EQUIPMENT

Alternatives 2 and 5–7 require the purchase of additional test equipment. Adding test equipment to existing units results in procurement costs of DSESTS and for the van to house and transport it. It will not add significantly to the costs of maintaining the DSESTS or to personnel costs, aside from the two personnel needed to operate each set of test equipment.

Procurement of DSESTS

Using the most recent AMCCOM contract procurements, Table C.2 shows the costs of each additional DSESTS configured for the M-1 tank.

Table C.2

DSESTS EQUIPMENT PROCUREMENT COSTS
(In thousands of FY 1987 dollars)

Test Equipment	Cost
Operator interface unit	128
M-1 cable case number 1	15
M-1 cable case number 2	12
M-1 cable case number 3	20
Total	175

SOURCE: AMCCOM.

Van to House and Transport Test Equipment

Information from the Ordnance School on the current configuration of these systems indicates that the DSESTS could fit into a single M109A3 van. A recent TACOM study estimated the procurement cost of an updated M109A3 version at $78,341, which includes procurement-funded initial spares. This cost is based on a large buy and includes the fixed, nonrecurring costs amortized over the large base.

In addition, the TACOM study estimates the annual operating and support costs for the van, based on worldwide fleet average costs and an annual mileage figure of 2535 miles, to be approximately $4600 (or $46,000 over a 20-year life cycle).[1] This figure includes replenishment spare parts, maintenance material, fuel and lubricants, and maintenance, including depot maintenance.

Maintenance of DSESTS

Since DSESTS is very reliable and incurs very little annual maintenance costs, we assume that the current system can support this test equipment at no additional cost.

Personnel for DSESTS

Any analysis of maintenance personnel requirements for test equipment is hindered by three main problems:

Lack of Agreed Upon Requirements from Which Changes Can Be Evaluated. The lack of an accepted Table of Organization and Equipment (TOE), especially for new weapon systems, is caused by the change from the Army of Excellence (J Series) TOE to the new "living" (L Series) TOE and from the introduction of the Manpower Requirements Criteria (MARC) process to replace the older Manpower Authorization Criteria (MACRIT) process.[2] As a result, the TOE process is in transition, especially regarding the support of the M-1 tank. Therefore, it is difficult to evaluate how proposed alternative structures will affect maintenance manning because no baseline currently exists from which to evaluate the changes.

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[1] This analysis computes the 20-year life cycle cost by multiplying the annual costs by 10; this assumes a discount rate of 7.75 percent. This factor is chosen primarily for analytical convenience. However, the cost multiplier is not very sensitive to the rate; for example, using a discount rate of 10 percent results in a multiplier of approximately 9.36. (Similarly, a present value factor of three is used when dealing with our assumed five crew turnover during the 20-year life cycle.)

[2] The "living" TOE concept affects when Basis-of-Issue Plan and other substantive changes are applied to a base TOE. The MARC process attempts to model analytically the personnel requirements, which serve as the starting point for TOE development.

Support of Many Weapon Systems by Intermediate-Level Maintenance Personnel. Unlike comparable maintenance personnel in the Air Force and Navy, Army intermediate-level maintenance personnel typically support a wide variety of weapon systems. For example, the MARC data base lists approximately 20 different systems supported by the 45K Military Occupational Specialty (MOS), the M-1 tank turret repairer. Since we are considering only a subset of the components on the M-1 tank, we are focusing on only a part of a given maintenance person's workload.

Physical Distribution of Intermediate-Level Maintenance Personnel. A portion of the repair personnel for the M-1 stay at the base maintenance company of the FSB to repair faulty components removed from the M-1 tank. These personnel operate the DSESTS and are the primary personnel affected by changes in the support concept. The remaining repair personnel in the FSB form System Support Teams that are positioned with the combat battalion to assist organization-level personnel. The support team personnel help to identify faulty components and to remove bad components and install workable ones. This mission should not be affected by the alternative support structures.

Because of these problems, we do not attempt to evaluate the effects that proposed logistics alternatives have on repair personnel requirements, except for the two additional DSESTS operators. Since the total workload probably does not change with the different logistics alternatives, we assume that the other personnel would merely be redistributed within the force.

Table C.3 shows the figures used to compute the costs of additional personnel, both officer and enlisted. Costs in Table C.3 do not include costs of any specialized training required by maintenance personnel or aircrew members.

The two enlisted men (an MOS 45K and an MOS 63G) needed to operate the DSESTS each cost \$25,900 (\$20,900 + \$5,000 specialized maintenance training) in nonrecurring expenses and \$37,100 annually in recurring expenses. Thus the total 20-year life cycle cost[3] for both operators equals \$897,000 (rounded).

In sum, the alternative of placing an M-1 configured DSESTS in each armor battalion costs a total of \$1,196,000 for each test set. This total includes \$175,000 for the DSESTS, \$78,000 for procurement of the van, \$46,000 for the operation and support of the van over a 20-

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[3] The life cycle cost estimate includes the annual cost of the two operators (2 × 37,100 × 10) plus the nonrecurring cost of acquiring and training five sets of operators over the 20-year period (2 × 25,900 × 3). This latter factor is an estimate that allows for the turnover of five crews over the 20-year period.

Table C.3

PERSONNEL COSTS

Cost Element	Nonrecurring Officer/Enlisted	Annual Recurring	
		Officer	Enlisted
Program 2 (org., clothing, and equipment)	1,550	9,300	9,300
Program 7S (supply transportation)	2,980	1,950	1,950
Program 8T (training base operations)	1,450	940	940
Program 8M (medical)	60	350	350
Program 8O (other personnel)	1,550	520	520
Accession	2,350	—	—
Initial clothing	480	—	—
Initial entry training	8,900	—	—
Pay and allowances	—	34,700	15,600
Retired pay accrual	—	13,800	5,700
Total (FY 1985 $)	19,320	61,560	34,360
Total (FY 1987 $)	20,900	66,400	37,100

SOURCE: Ref. 20.

year life cycle, and $897,000 for the 20-year life cycle of the two DSESTS operators.

TRANSPORTATION USING HELICOPTERS

Alternatives 3 through 9 require the use of helicopter transportation to ship items among transportation nodes and repair facilities. Although both the Blackhawk (UH-60A) and the Chinook (CH-47D) are considered for this mission, cost estimates in this report are based exclusively on the use of the Blackhawk. The Blackhawk and Chinook have carrying capacities of 8,000 and 24,000 lb, respectively. Both can carry loads either internally or externally using hooks.

No more than two helicopters are required under the various logistics alternatives. We assume that these helicopters would be added to an existing unit (the division or corps aviation unit). As a consequence, we estimate costs using this marginal assumption. The additional costs include the procurement of the helicopter, its operation and support, additional maintenance personnel and aircrews, and initial training costs for additional aircrew members.

Procurement of Helicopter

The procurement cost estimates from the Deputy Chief of Staff, Research, Development, and Acquisition, Aviation Systems Division, are $5.8 million for the Blackhawk and $11.5 million for the Chinook.

Operation and Support Costs for Helicopters

Table C.4 shows the annual operation and support costs for the Blackhawk and Chinook helicopters.

Table C.4

HELICOPTER ANNUAL OPERATION AND SUPPORT COSTS
(In FY 1987 dollars)

Cost Element	Blackhawk	Chinook
Cost per flying hour		
Replenishment parts	181	345
Petroleum/oil/lubricants	110	299
Civilian field maintenance[a]	120	487
Per diem	25	25
Depot: end item overhaul[b]	50	296
Depot: secondary items[c]	376	906
Total cost per flying hour	862	2358
Annual peacetime flying hours	172	150
Total annual costs[d]	148,264	353,700
Total 20-year life cycle costs[e]	1,482,640	3,353,700

SOURCE: Deputy Chief of Staff for Logistics, Aviation Logistics Office (DALO-AV).

[a] Includes (1) O&M funded costs for civilian maintenance below depot and (2) labor to install modification kits; excludes civilian labor at depot.

[b] Includes overhaul of the helicopter plus depot-installed modifications.

[c] Includes repair of components sent from organizational and intermediate maintenance.

[d] Costs are worldwide averages. CONUS and European costs and flying hours may differ somewhat.

[e] This analysis computes 20-year life cycle cost by multiplying the annual costs by 10; this assumes a discount rate of 7.75 percent.

Costs of Additional Maintenance Personnel and Helicopter Aircrews

Maintenance Personnel. The costs in Table C.4 exclude Army maintenance personnel at the organizational and intermediate levels. Through the MARC process, the Army calculates maintenance men per aircraft using MOS figures. Although MARC has recently completed an aviation MOS study, the final results have not been officially approved. Table C.5 shows interim organizational- and intermediate-level maintenance figures for the Blackhawk and Chinook.

It is difficult to determine on a marginal basis the maintenance manpower effects of adding a helicopter or two to an existing unit. Manpower requirements are governed by the integer effects of personnel, and the criterion used by the MARC process is to add an additional person when the fractional part of the requirement is 0.5 or greater. For certain skills, there may be sufficient personnel to adequately maintain a few additional helicopters. For other skills, an additional helicopter may result in the requirement for an extra maintenance man.

As an approximation, we have added personnel when the product of the number of helicopters added and the MOS figures in Table C.5 results in a fractional part greater or equal to 0.5. Therefore, adding a single Blackhawk requires four additional maintenance personnel (the assumption we have used in our cost estimates), and adding a single Chinook requires five additional personnel.[4]

Based on figures in Table C.3, the estimated total 20-year life cycle cost for the four maintenance personnel is $1,795,000 (rounded).[5]

Aircrew Personnel. Each Blackhawk has a three-man crew (pilot, copilot, crew chief), and each Chinook has a four-man crew (pilot, copilot, crew chief, flight engineer). Usually, pilots and copilots are officers and other crew members are enlisted or warrant officers.

Based on figures in Table C.3, the total 20-year life cycle cost for the two officers and one enlisted man needed to operate a Blackhawk helicopter is $1,887,000 (rounded).[6]

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[4] Adding two Blackhawks requires 10 additional personnel, and adding two Chinooks requires 15 additional personnel.

[5] Includes the annual cost of four enlisted (4 × 37,100 × 10) plus the nonrecurring cost of acquiring and training five sets of maintenance men over the 20-year period (4 × 25,900 × 3).

[6] Includes the annual cost of two officers (2 × 66,400 × 10) plus one enlisted person (1 × 37,100 × 10) plus the nonrecurring cost of acquiring and training five crews over the 20-year period (3 × 20,900 × 3).

Table C.5

MAINTENANCE MEN PER HELICOPTER

		Blackhawk		Chinook	
Duty Title	MOS	Operation Level	Intermediate Level	Operation Level	Intermediate Level
Avionic mechanic	35K	0.1770	0.0629	0.3258	0.0786
Avionic nav. rep.	35M	0.1053	0.0549	0.1037	0.0669
Avionic spec. eq. rep.	35R	—	0.0720	0.0625	0.0108
Tac tran. hel. tech. insp.	66T	0.6552	0.2596	—	—
Med. hel. tech. insp.	66U	—	—	0.3333	0.0208
Tac. tran. hel. rep.	67T	1.7766	0.8630	—	—
Med. hel. rep.	67U	—	—	5.0000	0.1042
Aircraft powerplant rep.	68B	0.0891	0.0820	0.3465	0.1294
Aircraft powertrain rep.	68D	0.0314	0.0458	0.2545	0.0998
Aircraft electrician	68F	0.1275	0.3021	0.3066	0.0686
Aircraft structural rep.	68G	0.0735	0.2340	0.1833	0.1354
Aircraft pneudraulics rep.	68H	0.0845	0.1822	0.1604	0.0829
Aircraft fire control rep.	68J	0.0048	0.2673	—	—
Aircraft weapon system rep.	68M	0.0042	0.0163	—	—

SOURCE: MARC.

Initial Training Costs for Additional Helicopter Aircrews

Each pilot and copilot must complete the Undergraduate Pilot Training (UPT) course plus the aviator qualification course in the specific helicopter. The flight engineers and crew chiefs must complete the appropriate flight courses. The required pilot and copilot courses and the approximate costs (based on information from the training cost analysis personnel at TRADOC) are as follows:

UPT (2C-15B/2C-100B)	$125,000
CH-47D (2C-ASI1G)	$ 75,000
UH-60 (2C-ASI1N)	$ 25,000

No cost data were available for the crew chief and flight engineer training costs. As an initial assumption, we will use a cost of $25,000 for each of these crew members. In summary, the initial training cost for a Blackhawk aircrew is estimated at $975,000[7], and the cost for a Chinook crew is estimated at $1,350,000.[8]

Table C.6 summarizes the total costs for the lower cost Blackhawk helicopter procurement and operations.

PROCUREMENT OF A THEATER REPAIR FACILITY

Alternative 9 calls for repairing failed components at a TRF (a consolidated intermediate-level facility). This facility would be located well behind the combat zone in extreme southwest Germany, or possibly in a country such as Spain or England. The facility could possess a complete range of repair capabilities.

Costs of setting up a TRF include the initial costs for acquiring and modifying a building and for procuring the necessary test equipment. The facility cost depends greatly on whether a suitable building is bought or leased and to what degree the building can satisfy the environmental requirements of electronic repair (air conditioning and clean room requirements).

As examples of potential facility costs, the modification of the second floor of an existing building at Mainz for the repair of the

Table C.6

TOTAL HELICOPTER TRANSPORTATION COST ESTIMATES
(In thousands of FY 1987 dollars)

Procurement	5,800
Operation and support (20-year life cycle)	1,483
Personnel (20-year life cycle)	
Maintenance	1,795
Aircrews	1,887
Training of aircrews[a]	975
Total	11,940

[a] Excludes MOS maintenance training.

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[7] The pilot and copilot both take the $125,000 UPT course and the $25,000 UH-60 course (2 × 150,000 × 3); training for the crew chief costs an estimated $25,000 (1 × 25,000 × 3). A requirement for five crews is assumed over the 20-year period.

[8] The pilot and copilot both take the $125,000 UPT course and the $75,000 CH-47D course (2 × 200,000 × 3); training for the crew chief and flight engineer each costs an estimated $25,000 (2 × 25,000 × 3). Again, the requirement for five crews over the 20-year life cycle is assumed.

Bradley fire control components cost approximately $1.1 million. Adding an annex to building 6012 at Mainz for the fire control component repair of the M-1 and M-60A3 also cost approximately $1.1 million. However, neither project included a clean room. A third project at Mainz, involving the addition of a third floor to an existing two-story building, did include a clean room and had a construction cost of approximately $3.3 million. Although the facility cost greatly depends on the specifics of a particular location, a reasonable estimate of total facility costs (including procurement, leasing, and construction) falls in the $3 million to $5 million range.

For a consolidated intermediate-level TRF (Alternative 9), all test equipment and personnel are asumed to be derived from the current structure. For a depot-level TRF (Alternative 7), we assume that no excess test equipment is available in the overall support system, a complete set of approximately 28 different test stations, including the EQUATE system if depot-level capability is included, would have to be bought. Information provided by DESCOM on the M-1 equipment cost at Mainz and by AMCCOM on the cost of depot-level test equipment for the M-1 suggest that these items of test equipment would cost approximately $10 million.

We have not in this initial analysis fully addressed the issue of how the depot-level TRF would be manned and operated in peacetime. A peacetime operating concept for the depot-level TRF could range from a caretaker type of facility to a fully operational repair source for units stationed in Europe. As an initial approximation, we assume that the TRF would be minimally manned in peacetime by active force personnel currently assigned to depot-level. These personnel would maintain the facilities and equipment and provide a minimal support capability to deployed units. This cadre force would be augmented in wartime by reservists to provide a fully operable theater support facility.

The annual costs of this mode of operation would be minimal. The active force personnel already exist and their cost is considered sunk. Reserve force personnel, because of their part-time commitment in peacetime, cost approximately one-sixth of active force personnel.[9] Initially, we estimate that 50 reserve personnel would be required at a total 20-year cost of $2.0 million.

The annual cost of operating the facility (utilities, upkeep, and so on) would be minimal in this caretaker type of operation; we estimate the 20-year life cycle cost of facilities to be $1.0 million.

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[9] Ref. 21 estimates that the annual cost of an enlisted reservist is approximately $4000.

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