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TECHNICAL REPORT NO. 184

THE EFFECT OF WEAPON RELIABILITY AND  
MAINTAINABILITY ON ARTILLERY FORCE AVAILABILITY

ROBERT F. CHANDLER

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U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY  
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including the logistic system.

This study investigates the relative effects on artillery force availability resulting from variations in weapon system reliability and associated maintenance downtimes in a multiple-day, combat scenario. The Artillery Force Simulation Model (AFSM) was used as the primary analytical tool in generating the results of this analysis. The model simulates an artillery battle between a blue and a red artillery force. Force and unit availability trends were developed in both "realistic" (battle damage attrition submodel included) and "idealistic" (attrition submodel excluded) combat situations based on various improvement levels in the reliability of the weapons and the responsiveness of the maintenance, logistic support. Simulations were made in an attempt to determine those areas, within the scope of each of these system parameters, where improvement would be most beneficial to overall force availability, hence effectiveness.

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## THE EFFECT OF WEAPON RELIABILITY AND MAINTAINABILITY ON ARTILLERY FORCE AVAILABILITY

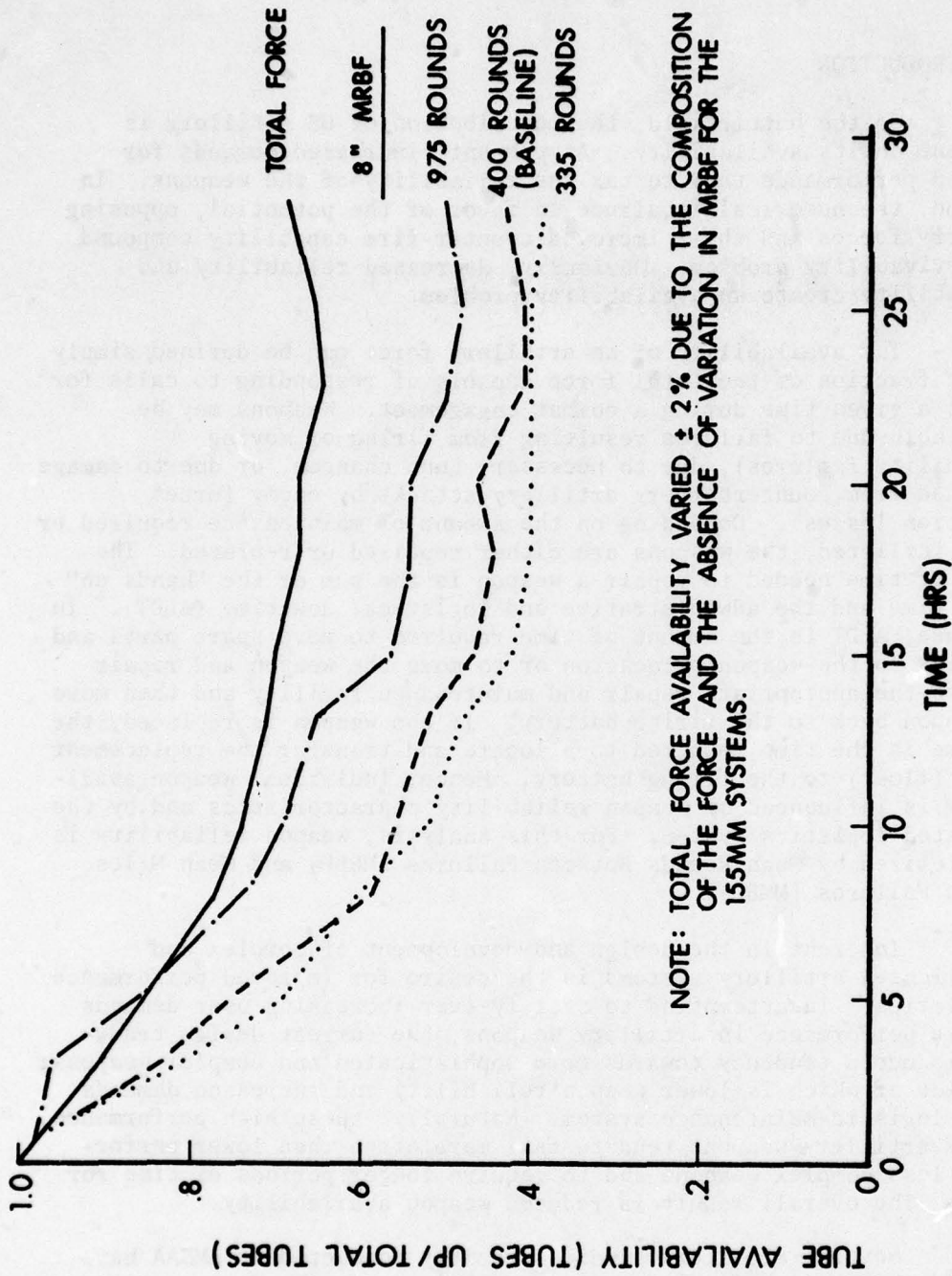
### 1. INTRODUCTION

On the battlefield, the contribution of US Artillery is dependent on its availability. At present, increased demands for expanded performance tend to tax the reliability of the weapons. In addition, the numerical imbalance in favor of the potential, opposing artillery forces and their improved counter-fire capability compound the survivability problem. Obviously, decreased reliability and survivability create an availability problem.

The availability of an artillery force can be defined simply as that fraction of the total force capable of responding to calls for fire at a given time during a combat engagement. Weapons may be unavailable due to failures resulting from firing or moving (reliability failures), due to necessary tube changes, or due to damage sustained from counterbattery artillery attacks by enemy forces (attrition losses). Depending on the amount of maintenance required or damage inflicted, the weapons are either repaired or replaced. The length of time needed to repair a weapon is the sum of the "hands on" repair time and the administrative and logistical downtime (ALDT). In this case, ALDT is the amount of time required to move spare parts and mechanics to the weapon's location or to move the weapon and repair parts to the appropriate repair and maintenance facility and then move the weapon back to the firing battery. If the weapon is replaced, the downtime is the time required to allocate and transfer the replacement weapon (float) to the firing battery. Hence, individual weapon availability is influenced by weapon reliability characteristics and by the associated logistics system. For this analysis, weapon reliability is characterized by Mean Rounds Between Failures (MRBF) and Mean Miles Between Failures (MMBF).

Inherent in the design and development of complex and sophisticated artillery systems is the desire for improved performance capabilities. In attempting to satisfy ever increasing user demands for more performance in artillery weapons, the current design trade-offs produce a tendency towards more sophisticated and complex weapons; the price of which is lower weapon reliability and increased demands on the logistic-maintenance system. Naturally, these high performance, complex artillery weapons tend to fail more often than lower performance, less complex weapons and to require longer periods of time for repair. The overall result is reduced weapon availability.

Several artillery studies recently conducted at AMSAA have examined the availability of a given artillery weapons force. In a Cost and Operational Effectiveness Analysis (COEA) (Ref 1) of the product improved eight-inch howitzer, M110A1, approximately seventy



NOTE: TOTAL FORCE AVAILABILITY VARIED  $\pm 2\%$  DUE TO THE COMPOSITION OF THE FORCE AND THE ABSENCE OF VARIATION IN MRBF FOR THE 155MM SYSTEMS.

Figure 1.1 Force Availability M110A1 MRBF Sensitivity (W/Battle Attrition.)

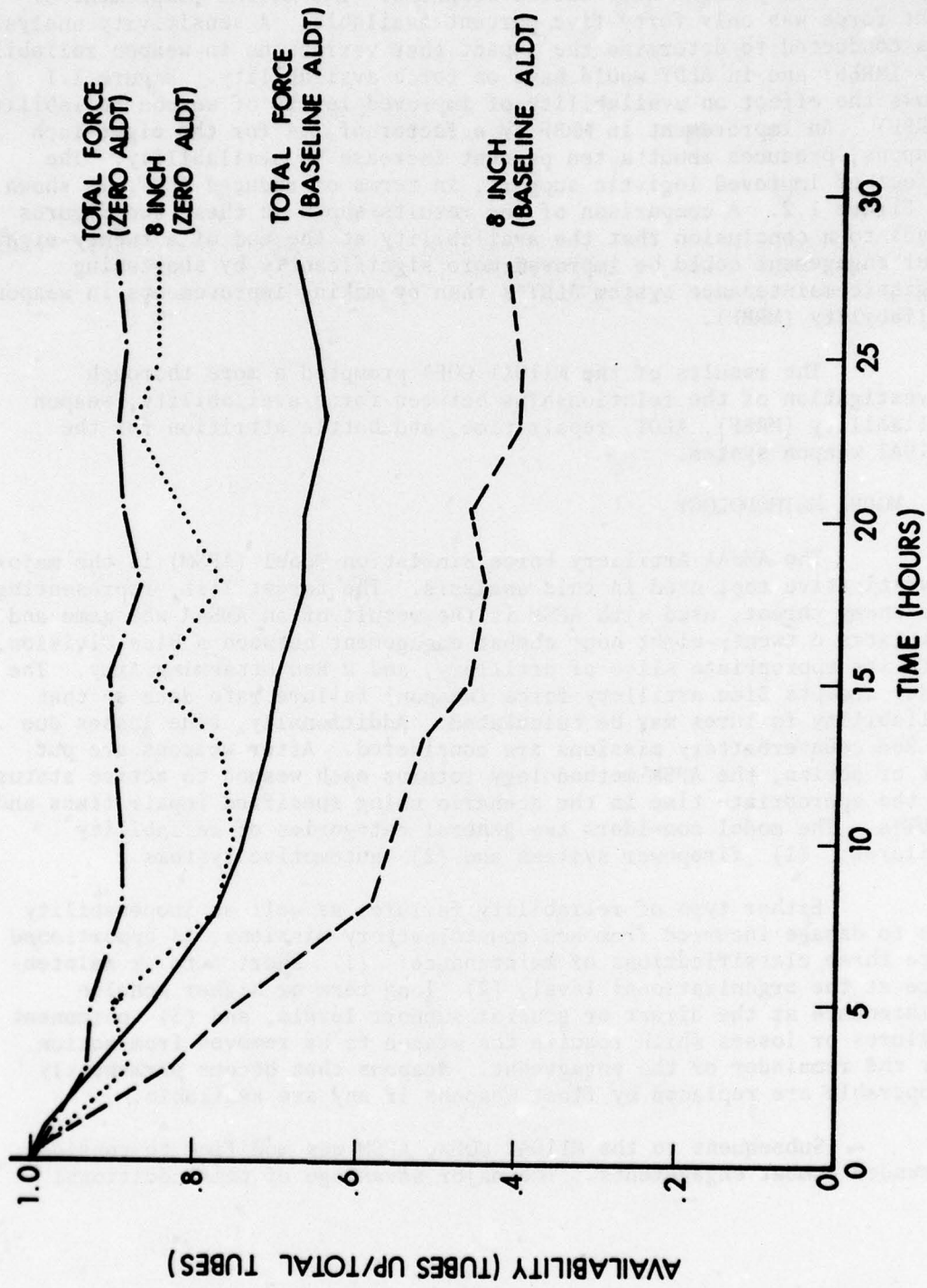


Figure 1.2 Force Availability M110A1 Logistic Support Sensitivity (W/Battle Attrition)

percent of the initial (total) artillery force was available at the end of a twenty-eight hour battle scenario. The M110A1 complement of that force was only forty-five percent available. A sensitivity analysis was conducted to determine the impact that variations in weapon reliability (MRBF) and in ALDT would have on force availability. Figure 1.1 shows the effect on availability of improved levels of weapon reliability (MRBF). An improvement in MRBF by a factor of 2.4 for the eight-inch weapons, produces about a ten percent increase in availability. The effect of improved logistic support, in terms of reduced ALDT, is shown in Figure 1.2. A comparison of the results shown in these two figures leads to a conclusion that the availability at the end of a twenty-eight hour engagement could be improved more significantly by shortening logistic-maintenance system ALDT's than by making improvements in weapon reliability (MRBF).

The results of the M110A1 COEA prompted a more thorough investigation of the relationships between force availability, weapon reliability (MRBF), ALDT, repair time, and battle attrition for the M110A1 weapon system.

## 2. MODEL METHODOLOGY

The AMSAA Artillery Force Simulation Model (AFSM) is the major investigative tool used in this analysis. The target list, representing the enemy threat, used with AFSM is the result of an AMSAA war game and simulates a twenty-eight hour combat engagement between a Blue Division, with its appropriate slice of artillery, and a Red attacking Army. The model accepts Blue artillery force (weapon) failure rate data so that reliability failures may be calculated. Additionally, Blue losses due to Red counterbattery missions are considered. After weapons are put out of action, the AFSM methodology returns each weapon to active status at the appropriate time in the scenario using specified repair times and ALDT's. The model considers two general categories of reliability failures: (1) firepower systems and (2) automotive systems.

Either type of reliability failure, as well as inoperability due to damage incurred from Red counterbattery missions, is apportioned into three classifications of maintenance: (1) short term or maintenance at the organizational level, (2) long term or higher echelon maintenance at the direct or general support levels, and (3) permanent failures or losses which require the weapon to be removed from action for the remainder of the engagement. Weapons that become permanently inoperable are replaced by float weapons if any are available.

Subsequent to the M110A1 COEA, AFSM was modified to consider extended combat engagements. The major advantage of this additional

capability is that the longer engagement time allows a steady state of the interaction of failures and repairs to be achieved. Previously, the ALDT's dominated the battle duration. However, there are some problems associated with the analysis of the results of extended engagements. They are primarily caused by the available target list and the one-sidedness of the model. At the present time, a target list for an extended combat period is not available. Therefore, the same twenty-eight hour target array is repeatedly presented to the Blue artillery force to simulate extended periods of battle. There also exists a possibility of overestimating the Red force's counter-battery capability since a one-hundred percent operationally-ready Red force is available at the start of each subsequent battle period; whereas the Blue force's readiness and availability are a function of the previous periods of engagement and a built-in "slack" time between battle periods. At present, AFSM is being modified to make the Red counterbattery capability a function of the damage inflicted by Blue counter-fire attacks. However, the current methodology does not appear to be unreasonable since Red artillery outnumbers Blue artillery at least three to one. Therefore, if Red artillery losses occur at a rate comparable to Blue losses, a sufficient amount of Red artillery will still be available to conduct the high priority, counterbattery missions during subsequent battle periods. As mentioned above, one modification that was made to reduce the effect of this shortcoming is the six-hour, non-combat interval separating each period of battle to simulate "slack" times in the engagement. Blue maintenance and logistics activities, such as ammunition resupply and weapon repair are continued through both combat and non-combat periods. The model combines the information with the reliability failures and battle losses into a complete time dependent picture of weapon status throughout the battle. The availability of the force at any given time is simply:

$$\text{Availability} = \frac{\text{Number of Artillery Tubes "Up"}}{\text{Number of Artillery Tubes in Initial Force}}$$

An average availability for the artillery force is also computed as follows:

$$\text{Average Availability} = \frac{\sum_{i=1}^N A_i}{N}, \text{ where}$$

$N$  = Total number of hours in the engagement

$A_i$  = Force availability at the end of the  $i^{\text{th}}$  hour of the engagement, i.e. the ratio of "Tubes Up" to the initial number of tubes in the force.

This measure of availability reflects the overall availability level of the total force or of a given weapon system for the entire engagement and hence serves as a useful measure when comparing results from different simulations.

TABLE 3.1 BLUE FORCE MIX AND TACTICAL ASSIGNMENTS

DIVISION			
DIRECT SUPPORT	(2)	M110A1	
REINFORCING	(1)	M110A1	
GS REINFORCING	(1)	M110A1	
CORPS			
GS REINFORCING	(3)	M110A1	

TABLE 3.2 M110A1 WEAPON SYSTEM CHARACTERISTICS  
(BASELINE)

<u>SYSTEM VARIABLE</u>	<u>INPUT VALUE</u>
NUMBER OF TUBES/BATTERY (TUBES)	4
SUSTAINED RATE OF FIRE (RDS/HR/TUBE)	30
MAXIMUM RANGE (KM)	26
BATTERY BASIC LOAD (RDS)	748
BATTERY HOURLY RESUPPLY RATE (RDS/HR)	54
TIME TO REPAIR A FAILURE DUE TO FIRING, MOVING, OR ENEMY ATTRITION - SHORT TERM (INCLUDING ALDT) (HRS)	5.1
TIME TO REPAIR A FAILURE DUE TO FIRING, MOVING OR ENEMY ATTRITION - LONG TERM (INCLUDING ALDT) (HRS)	27.3
TIME TO OBTAIN A MAINTENANCE FLOAT DIVISION ECHELON (HRS)	8
CORP ECHELON (HRS)	16
MEAN ROUNDS BETWEEN FAILURES (EFC RDS)	400
MEAN MILES BETWEEN FAILURES (MILES)	155
TUBELIFE (EFC ROUNDS)	3000

TABLE 3.3 RELIABILITY VARIATIONS

<u>PARAMETER</u>	<u>FAILURE TYPE</u>	<u>BASELINE</u>	<u>ONE HALF ALDT</u>	<u>DOUBLE MRBF</u>	<u>COMBINED IMPROVEMENT</u>
MRBF (RDS)	SHORT	1,429	1,429	2,858	1,643
	LONG	769	769	1,538	884
	PERMANENT	2,000	2,000	4,000	2,300
MMBF (KM)	SHORT	891	891	891	891
	LONG	480	480	480	480
	PERMANENT	1,247	1,247	1,247	1,247



TABLE 3.4 ALDT VARIATIONS

<u>PARAMETER</u>	<u>FAILURE TYPE</u>	<u>BASELINE</u>	<u>ONE HALF ALDT</u>	<u>DOUBLE MRBF</u>	<u>COMBINED IMPROVEMENT</u>
MTTR*	SHORT	1.1	1.1	1.1	1.1
(HRS)	LONG	3.3	3.3	3.3	3.3
ALDT	SHORT	4.0	2.0	4.0	3.2
(HRS)	LONG	24.0	12.0	24.0	19.2
TOTAL DOWN TIME (HRS)	SHORT	5.1	3.1	5.1	4.3
	LONG	27.3	15.3	27.3	22.5

15

\*MTTR = MEAN TIME TO REPAIR A GIVEN FAILURE TYPE

### 3. STUDY APPROACH

In this analysis, AFSM was used to investigate the relative effects on artillery force availability due to variations in weapon system reliability (MRBF) and associated ALDT's. Computer simulations were made to develop trends in force availability based on various improvement levels in ALDT and weapon MRBF.

Both a twenty-eight hour battle and an extended combat engagement were simulated using AFSM. The extended engagement scenarios consist of five consecutive twenty-eight hour battle periods to take maximum advantage of the model's capability in constructing a data base for analyses. Computer simulations were made with and without the inclusion of the attrition submodel in order to gather data in both "realistic" and "ideal" combat situations. The non-attrition case provides a clearer look at the direct inter-relationship of weapon reliability (MRBF) and ALDT without the impact of attrition caused demands for weapon maintenance on the logistics system.

In this study, a seven battalion Blue artillery force, as shown in Table 3.1, and an AMSAA European target array are the basic model inputs. Obviously, the M110A1 is not the usual direct support weapon. The reason for using this particular artillery force was to magnify the effects on force availability of variations in weapon reliability (MRBF) and ALDT for the M110A1 weapon system, while minimizing the compensating effects of other weapon systems with their varying reliability and vulnerability characteristics. Table 3.2 summarizes the baseline performance, logistical, and reliability characteristics of the M110A1 system.

Variations in weapon reliability (MRBF) and ALDT for the M110A1 system were made independently in each simulation to isolate the effects of each parameter on force availability. Tables 3.3 and 3.4 illustrate the baseline values and the improved values for each parameter. Note that variations in reliability are considered only in weapon MRBF, while MMBF (Mean Miles Between Failures) remains constant. MMBF is not varied because the distance travelled by a given weapon in this scenario is nominal and therefore any variation in this parameter has little or no effect on force availability.

However, in scenarios which necessitate more extensive movement of the weapons, the relationships between MMBF and ALDT are expected to be similar to those developed between MRBF and ALDT in this analyses.

### 4. ANALYSIS

The sensitivity analysis in Ref 1, comparing the benefits of improved weapon reliability and logistic support indicated that improvements in ALDT were more beneficial to force availability than improvements in weapon reliability. Figures 4.1 and 4.2 illustrate that the single battle period results for the seven battalion M110A1

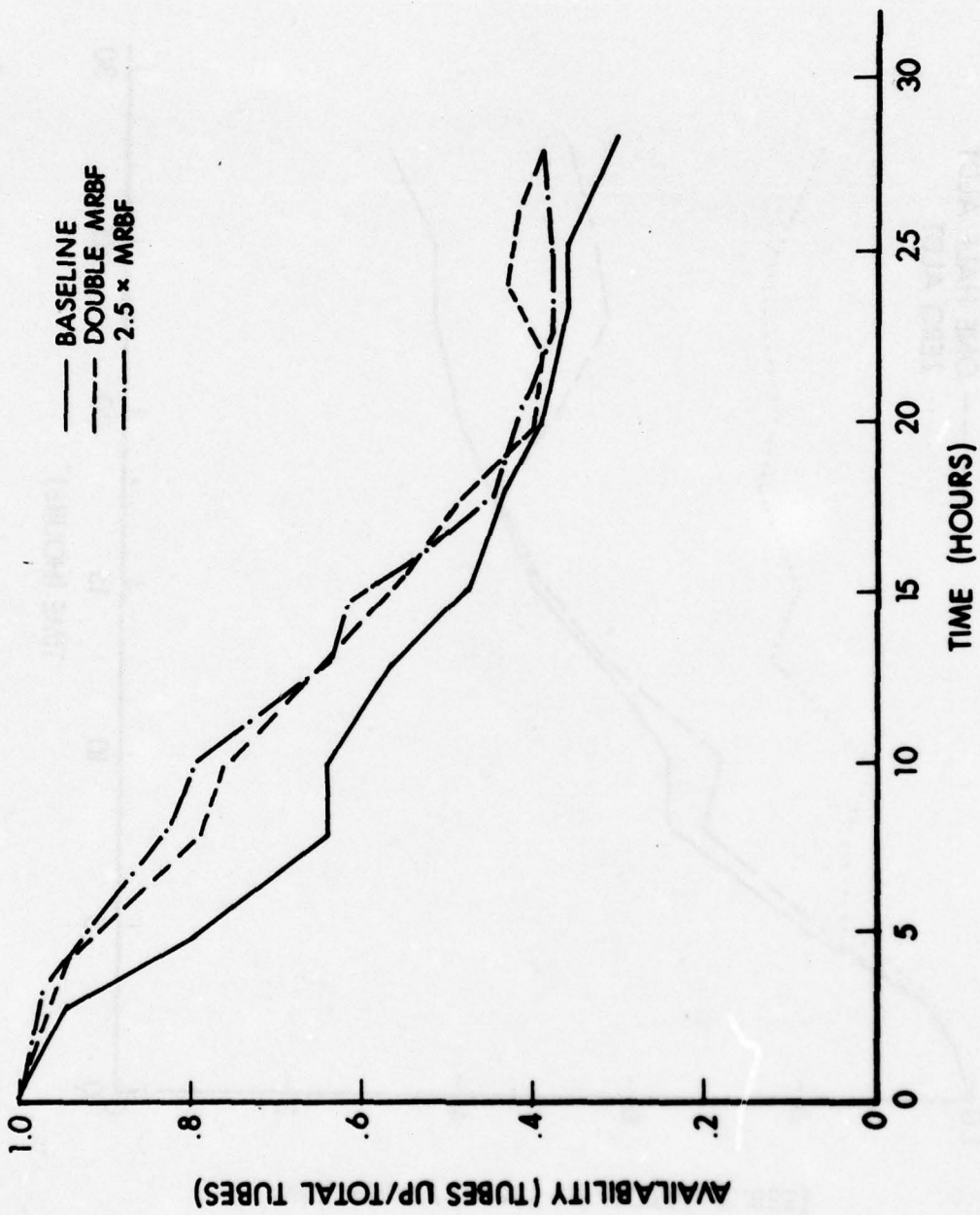


Figure 4.1 Force Availability MRBF Variation (W/Battle Attrition )  
SINGLE BATTLE PERIOD

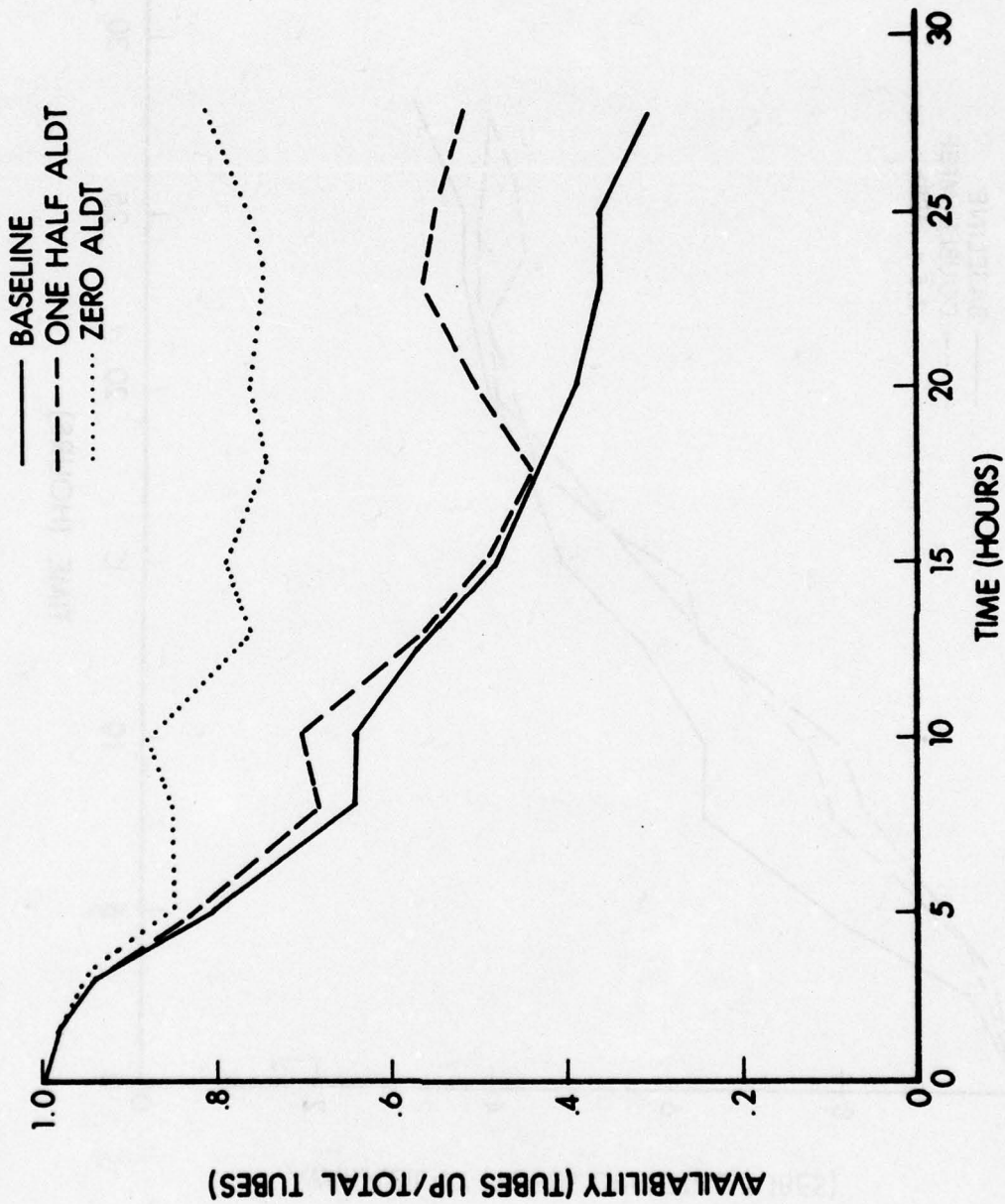


Figure 4.2 Force Availability ALDT Variation (W/Battle Attrition )  
SINGLE BATTLE PERIOD

force of this analysis are similar to those obtained in the M110A1 COEA as shown in Figures 1.1 and 1.2. That is, improved ALDT appears to make a greater contribution to force availability at the end of the first combat period of the engagement. This occurs simply because reduced ALDT affects the repair of weapons that are inoperable from reliability failures and from counterbattery inflicted damage (attrition); whereas improved weapon MRBF only affects weapon reliability failures.

Figure 4.3 shows average availability of the artillery force as a function of percent improvement in weapon reliability (MRBF) or in ALDT. For a single period of battle, improvements in ALDT are more beneficial to average availability than corresponding percentage increases in weapon MRBF. That is, average availability improves at a greater rate with reduced ALDT than with increased MRBF.

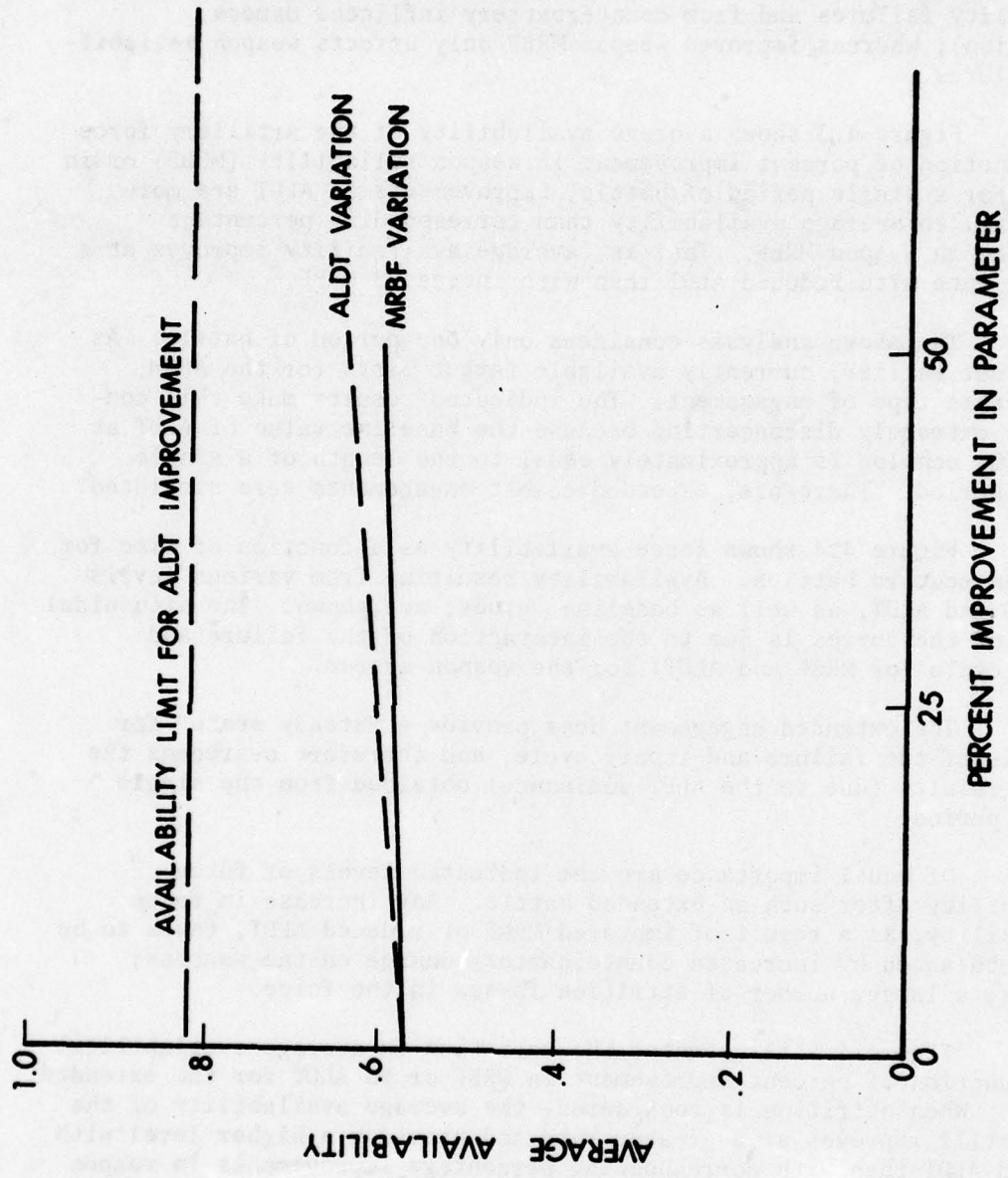
The above analysis considers only one period of battle. As pointed out earlier, currently available target lists for the AFSM depict this type of engagement. The indicated results make this constraint extremely disconcerting because the baseline value of ALDT at the DS/GS echelon is approximately equal to the length of a single battle period. Therefore, extended combat engagements were simulated.

Figure 4.4 shows force availability as a function of time for five consecutive battles. Availability resulting from various levels of MRBF and ALDT, as well as baseline values, are shown. The sinusoidal nature of the curves is due to the interaction of the failure and repair cycle (or MRBF and ALDT) for the weapon system.

The extended engagement does provide a "steady state" for analysis of the failure and repair cycle, and therefore overcomes the biased results (due to the ALDT dominance) obtained from the single battle period.

Of equal importance are the indicated levels of force availability after such an extended battle. Any increase in force availability, as a result of improved MRBF or reduced ALDT, tends to be counterbalanced by increased counterbattery damage on the weapons; that is, a larger number of attrition losses in the force.

Figure 4.5 illustrates the variation in average availability as a function of percent improvement in MRBF or in ALDT for the extended battle. When attrition is considered, the average availability of the force still improves at a greater rate and provides a higher level with reduced ALDT than with corresponding percentage improvements in weapon reliability (MRBF). This is again due to the fact that reduced ALDT affects availability by shortening weapon downtimes arising from two sources: (1) reliability failures, and (2) attrition losses. Whereas, improved weapon MRBF influences availability only by reducing the reliability failure rate.



**Figure 4.3 Force Average Availability MRBF/ALDT Variation (W/Battle Attrition)**  
SINGLE BATTLE PERIOD

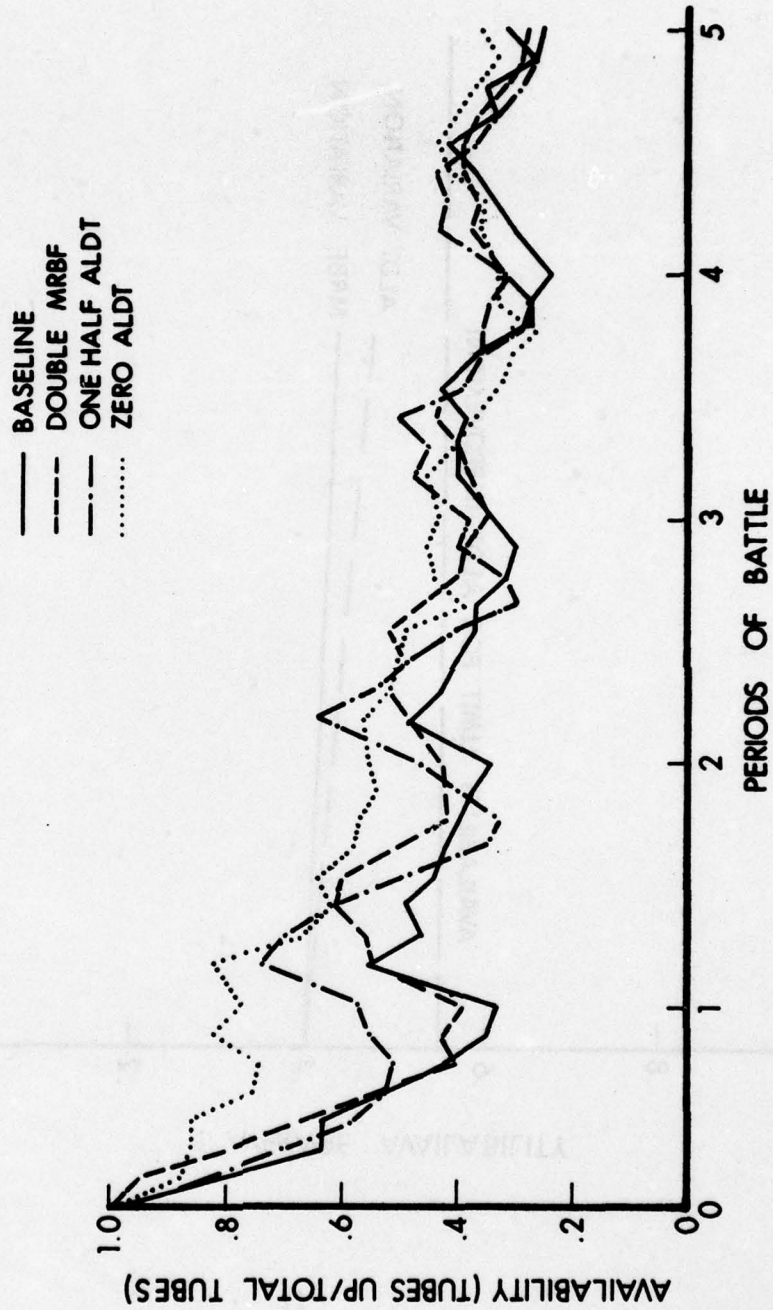
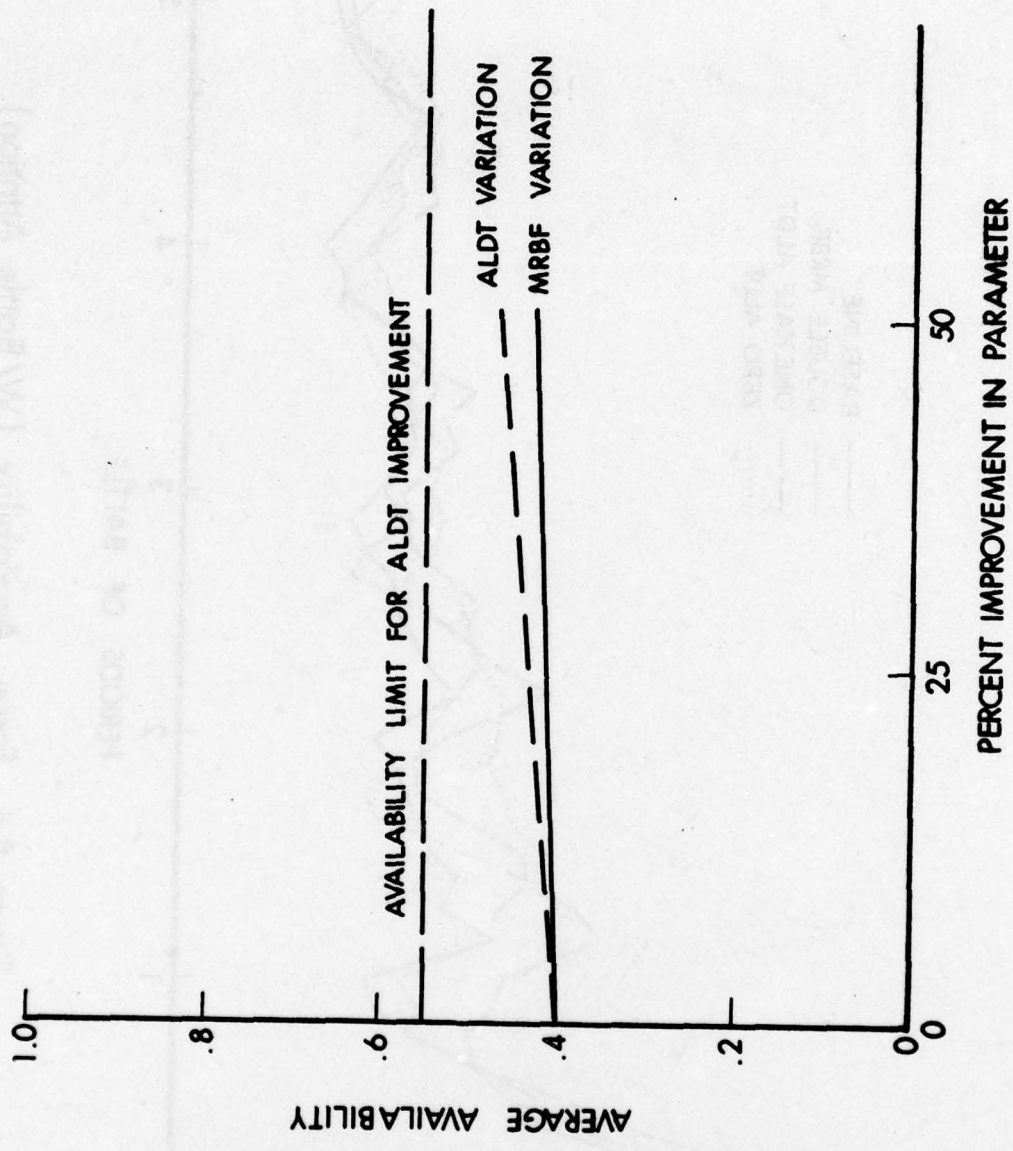


Figure 4.4. Force Availability (W/Battle Attrition).  
EXTENDED ENGAGEMENT



**Figure 4.5 Force Average Availability MRBF/ALDT Variation (W/Battle Attrition).**

**EXTENDED ENGAGEMENT**



When attrition losses are not considered however, weapons become unavailable only due to reliability failures. In this case, reduced ALDT and improved MRBF can influence weapon availability by affecting this single source of inoperable weapons. Figure 4.6 shows the force availability for several improvement levels of weapon MRBF and ALDT when attrition losses are not considered. A significant point is that the baseline availability on Figure 4.6 is approximately forty-five percent higher (.58) than the baseline availability (.40) on Figure 4.4. In Figure 4.6, it appears that improved weapon reliability (MRBF) contributes more than reduced ALDT to force availability. This observation is quantified in Figure 4.7. It shows average availability as a function of the percent improvement in MRBF and ALDT. Since the two curves are coincident throughout the range of improvements that are "realistically achievable" (i.e. up to approximately twenty-five percent), improvements in weapon reliability (MRBF) and ALDT provide equal benefits to average availability when battle attrition losses are not considered.

As a result of the modest gains in average availability indicated for independent percentage improvements in weapon reliability or ALDT that appear to be realistically achievable, AFSM was used to determine the effect of concurrent, or combined, improvements in these parameters. For this analysis a fifteen percent increase in MRBF was combined with a twenty percent decrease in ALDT. Reference 2 indicates that these levels of improvements are a reasonable assumption for the M110A1 weapon system. Weapon attrition was reintroduced to provide the most realistic combat conditions.

Figure 4.8 presents the hourly force availability for the combined improvements compared to the baseline availability shown in Figure 4.4.

Even though the combined improvement does enhance force availability, it is not as beneficial to availability as might have been predicted from the individual slopes shown in Figure 4.5. The average availability is improved approximately seven percent. Although this particular combined improvement in both weapon reliability (MRBF) and ALDT does not significantly increase force availability, any effort towards improvement should consider both parameters. This is indicated in Figure 4.9. In this figure, the average availability for the combined improvement, forty-three percent, is compared to the average availability for the independent variations as shown in Figure 4.5. The points of intersection indicate that individual improvements of twenty-five percent in ALDT or fifty-five percent in MRBF are required to attain the average availability of the combined improvements.

Of course, the effect of attrition is the major obstacle to more impressive gains in force availability from any improvements in MRBF or ALDT. AMSAA has analyzed the feasibility and effect of improved weapon survivability. This is a significant area of analysis in itself and is not included here. [Refs 3, 4, and 5 may be helpful to those interested in this subject.]

— BASELINE  
 - - - DOUBLE MRBF  
 - · - ONE HALF ALDT  
 ····· ZERO ALDT

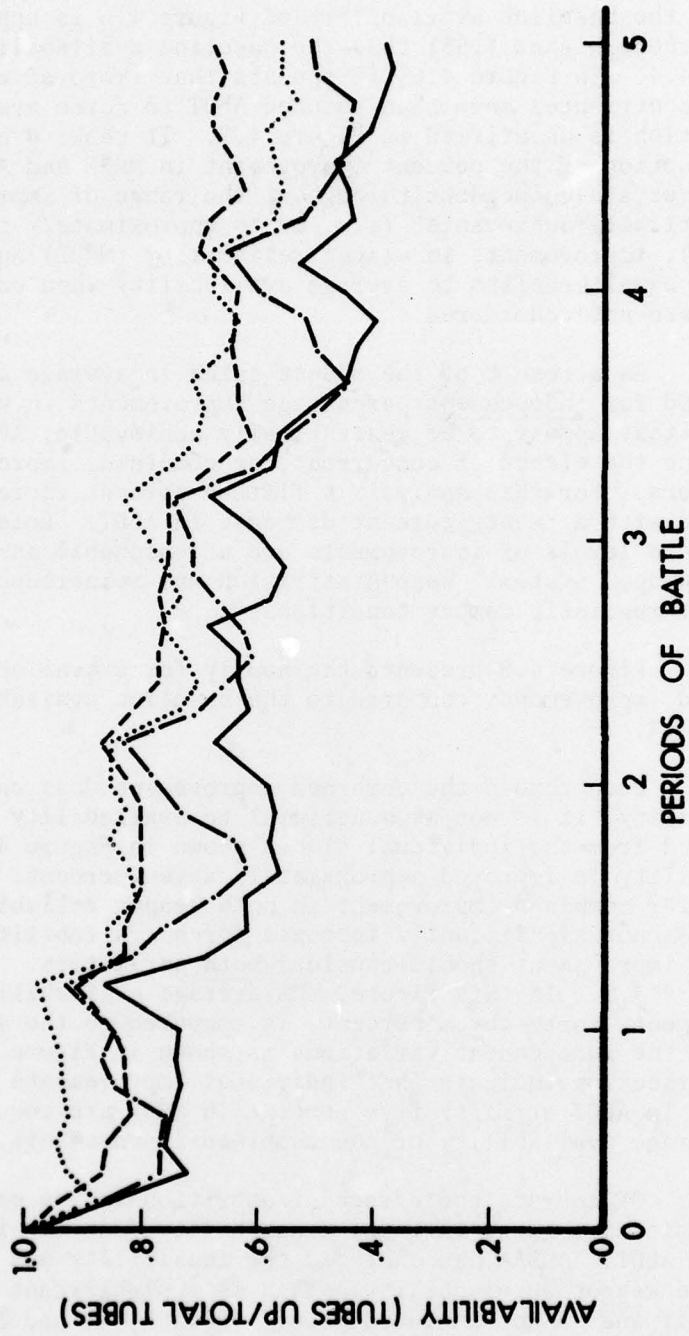
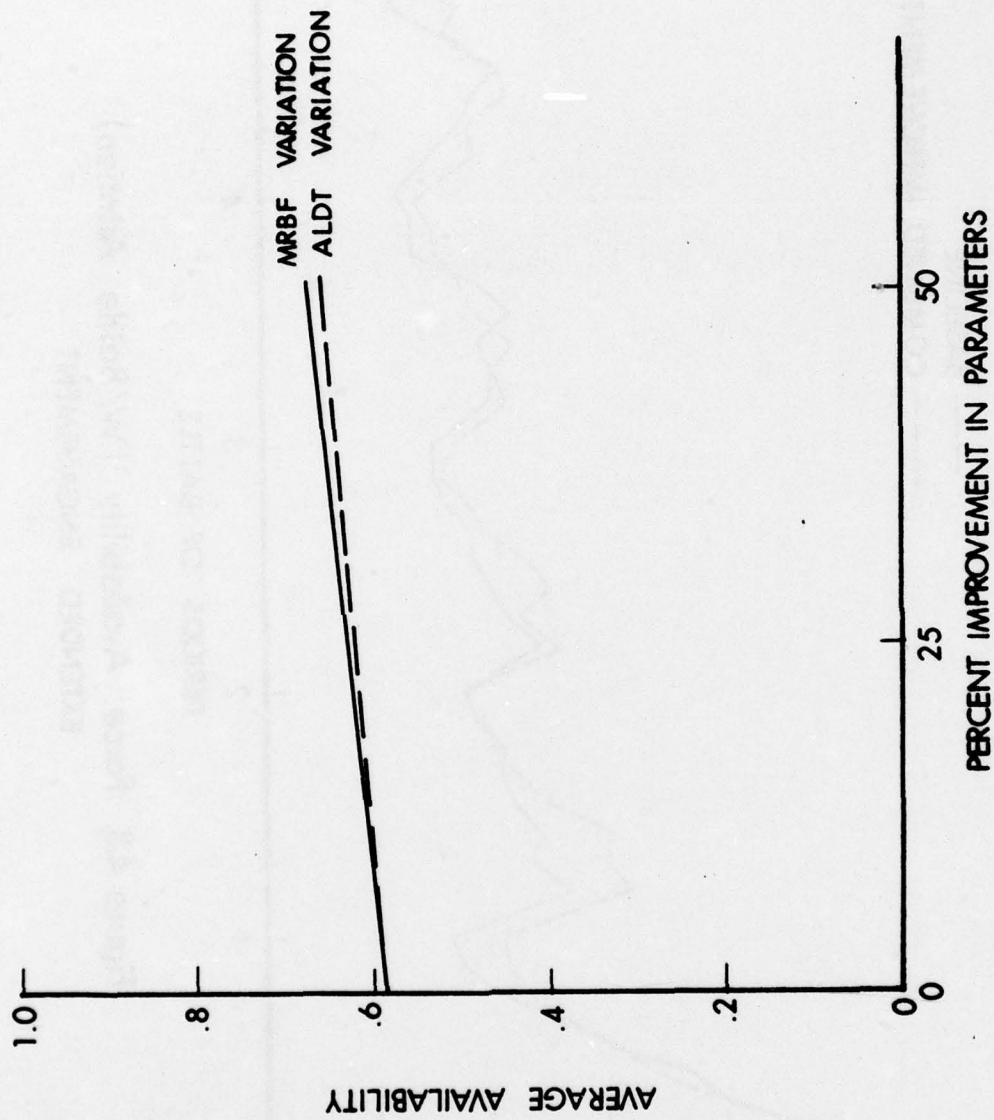


Figure 4.6. Force Availability (W/O Battle Attrition).  
EXTENDED ENGAGEMENT



**Figure 4.7 Force Average Availability MRBF/ALDT Variation (W/O Battle Attrition) EXTENDED ENGAGEMENT**

EXCESSIVE ENGINEERING  
(M.O. FOR YOUNG)  
LIFE IS NOT YOURS / YOURS IS NOT LIFE

— BASELINE  
- - - COMBINED IMPROVEMENTS

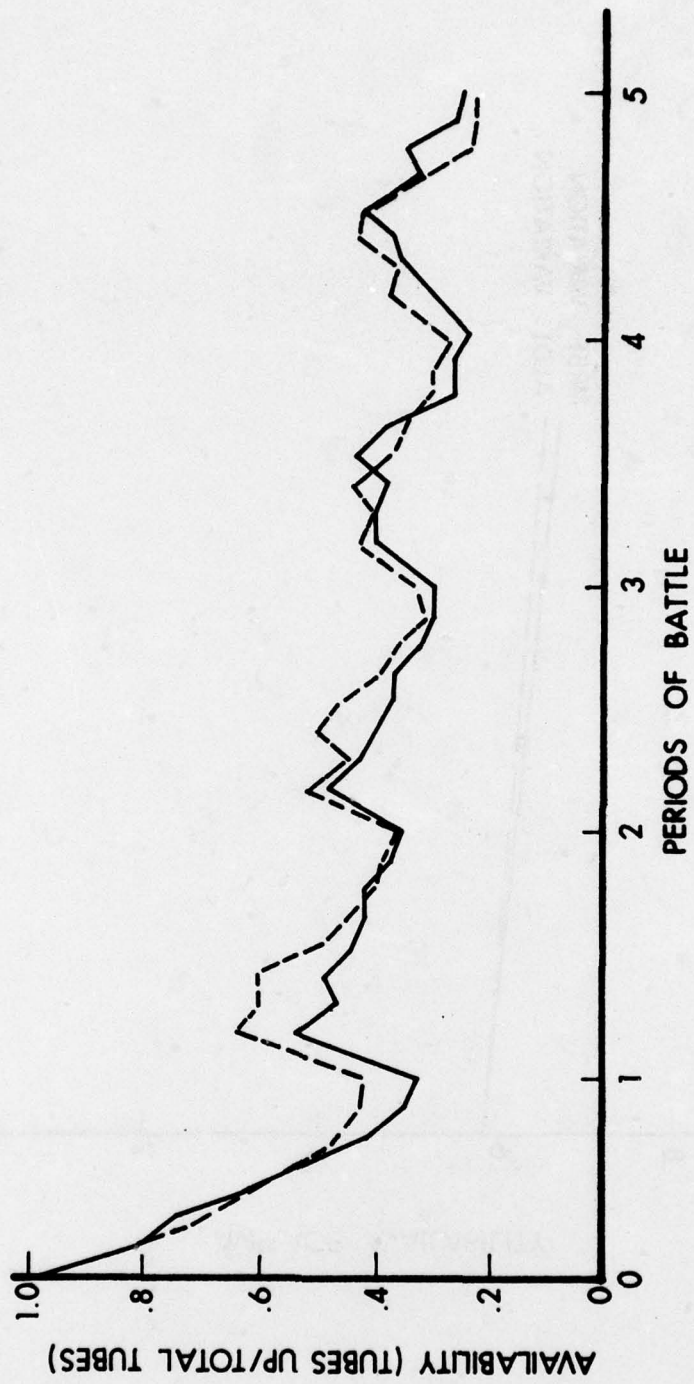


Figure 4.8. Force Availability (W/ Battle Attrition)  
EXTENDED ENGAGEMENT

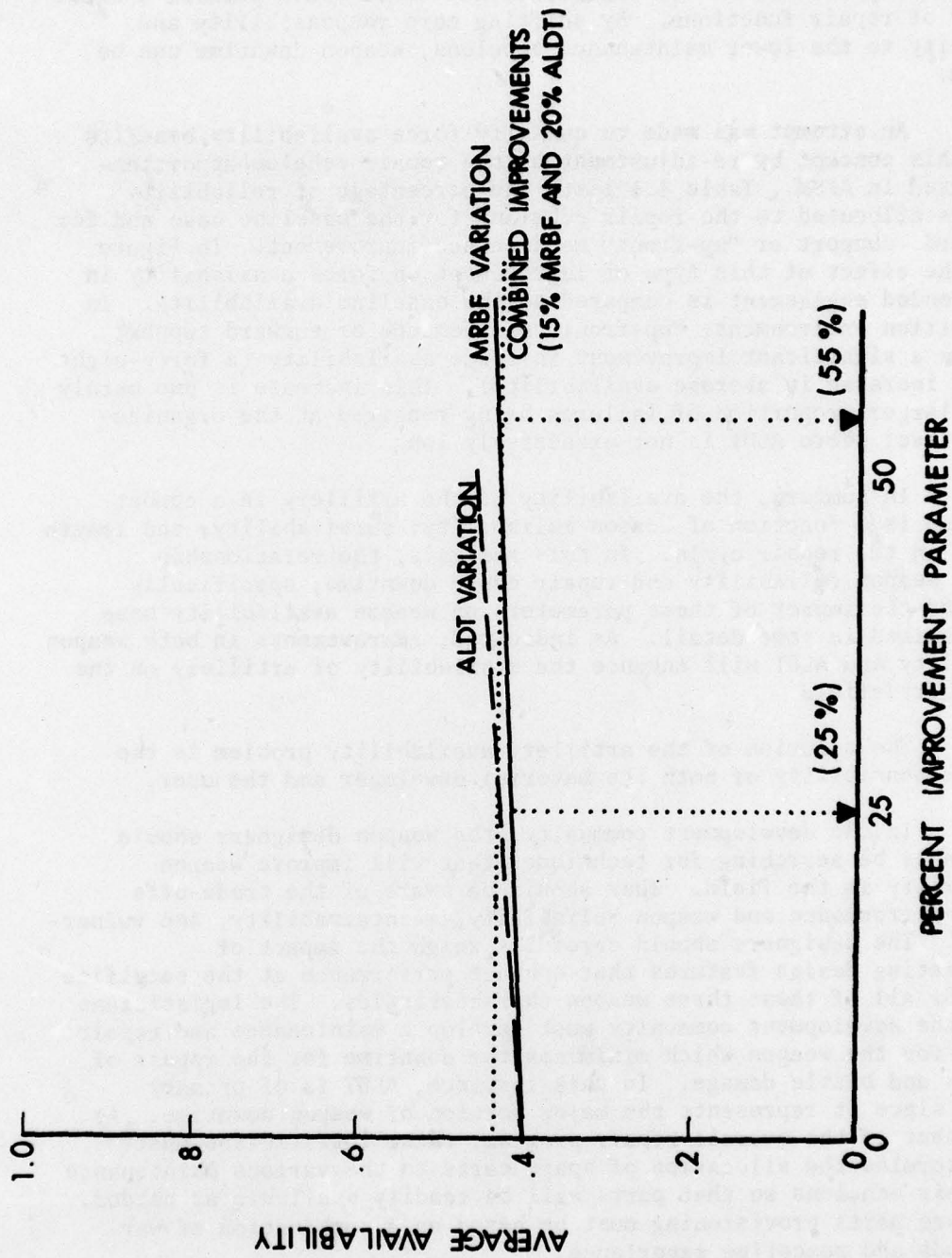


Figure 4.9 Force Average Availability Combined Improvement Comparison (W/Battle Attrition)

EXTENDED ENGAGEMENT

Without addressing weapon attrition, another possible approach to improved weapon availability is to shift some maintenance tasks presently performed at direct support (DS), general support (GS), and depot levels to a lower repair echelon; that is, provide more "up front" maintenance or forward support. Under this concept, gun crews and maintenance personnel at the organizational level would perform a wider variety of repair functions. By shifting more responsibility and capability to the lower maintenance echelons, weapon downtime can be reduced.

An attempt was made to quantify force availability benefits under this concept by re-adjustment of the repair echelon apportionments used in AFSM. Table 4.1 lists the percentage of reliability failures allocated to the repair echelons for the baseline case and for a forward support or "up-front" maintenance improvement. In Figure 4.10, the effect of this type of improvement on force availability in the extended engagement is compared to the baseline availability. In an attrition environment, "up-front" maintenance or forward support produces a significant improvement in force availability (a forty-eight percent increase in average availability). This increase is due mainly to the larger proportion of failures being repaired at the organizational level where ALDT is not excessively long.

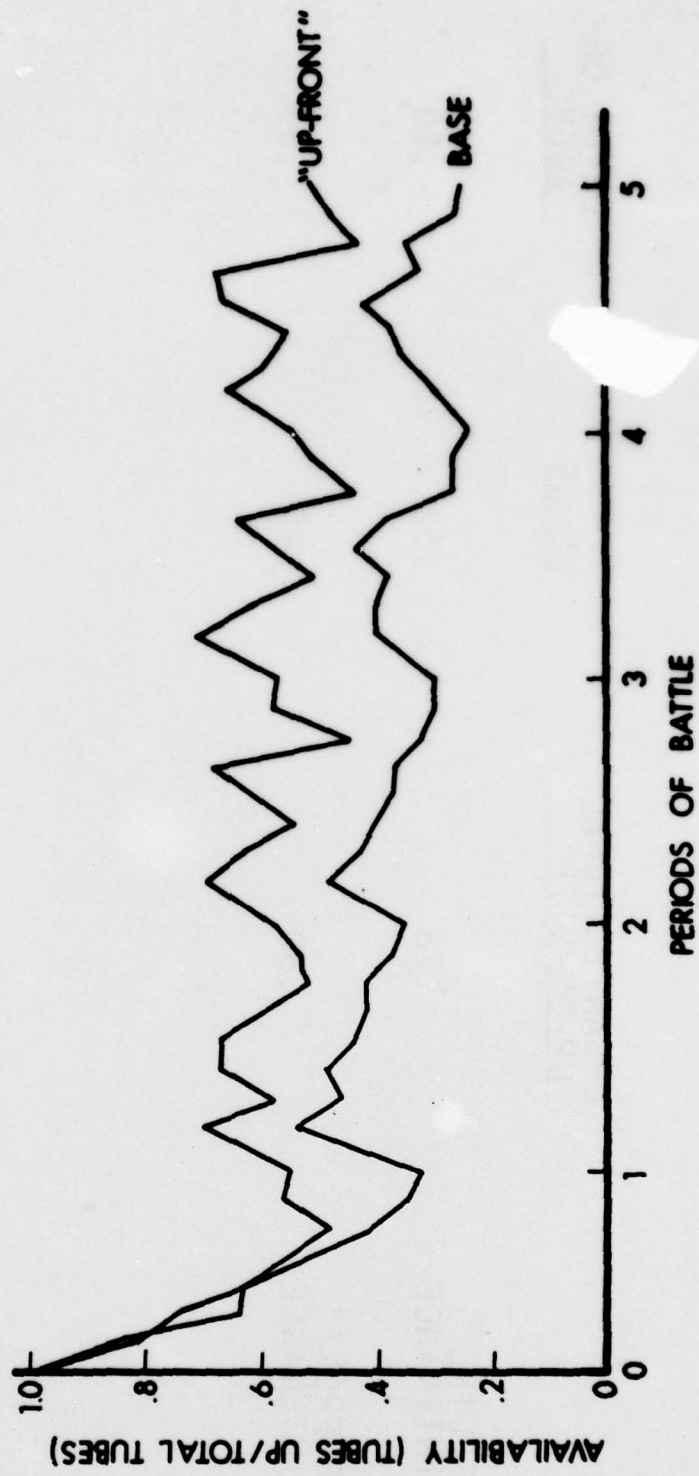
In summary, the availability of the artillery in a combat situation is a function of weapon reliability, survivability, and length of time in the repair cycle. In this analysis, the relationship between weapon reliability and repair cycle downtime, specifically ALDT, and the impact of these parameters on weapon availability have been examined in some detail. As indicated, improvements in both weapon reliability and ALDT will enhance the availability of artillery on the future battlefield.

The solution of the artillery availability problem is the joint responsibility of both the materiel developer and the user.

In the development community, the weapon designers should continually be searching for techniques that will improve weapon availability in the field. They should be aware of the trade-offs between performance and weapon reliability, maintainability, and vulnerability. The designers should carefully weigh the impact of incorporating design features that enhance performance at the sacrifice of any or all of these three weapon characteristics. The logisticians within the development community must develop a maintenance and repair program for the weapon which minimizes the downtime for the repair of failures and battle damage. In this instance, ALDT is of primary concern since it represents the major portion of weapon downtime. As a component of the overall repair program, these logisticians must also determine the allocation of spare parts to the various maintenance and repair echelons so that parts will be readily available as needed. This spare parts provisioning must be based on a combination of wartime needs and peacetime experience.

TABLE 4.1 ALLOCATION OF RELIABILITY FAILURES  
TO MAINTENANCE FACILITIES

	<u>ORGANIZATIONAL OR ON-SITE</u>	<u>DS/GS</u>	<u>DEPOT OR ABOVE</u>
BASELINE MAINTENANCE	.28	.52	.20
"UP-FRONT" MAINTENANCE	.50	.45	.05



**Figure 4.10. Force Availability (W/Battle Attrition)  
EXTENDED ENGAGEMENT**



At the same time, the user should continually be aware of any problems that may arise in operating and supporting the weapon in the field. In particular, continued emphasis should be directed to (1) training requirements for the personnel who will operate and maintain the weapon, and (2) any necessary changes in existing TO&E's and personnel staffing of Army units so that adequate logistical support can be provided in a timely manner.

To conclude the obvious, if the artillery is to accomplish its mission, weapon components should be designed to be more durable and more survivable, and repair parts and trained mechanics should be more readily available in the field.

## 5. CONCLUSIONS

- In an extended engagement, availability of the artillery may be a significant problem.
- Any improvement in weapon reliability (MRBF) and/or ALDT is beneficial to artillery force availability.
- If combat attrition is not considered, "realistically achievable" percentage improvements in weapon reliability (MRBF) and ALDT contribute equally to increased availability.
- If combat attrition is considered, reduced ALDT appears to be more beneficial to force availability than improved weapon reliability (MRBF).
- A combined improvement in weapon reliability (MRBF) and ALDT produces a greater increase in average force availability than does a corresponding improvement, made independently, in either parameter.
- Application of a forward support or "up-front" maintenance concept, in which greater responsibility and increased capability are shifted to lower echelon maintenance facilities, produces meaningful increases in average force availability for extended battle periods.
- The solution of the artillery force availability problem must address battlefield attrition, i.e. weapon survivability and vulnerability, as well as, weapon reliability and maintenance support.
- Both the materiel developer and the user share the responsibility of improving artillery weapon availability.

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