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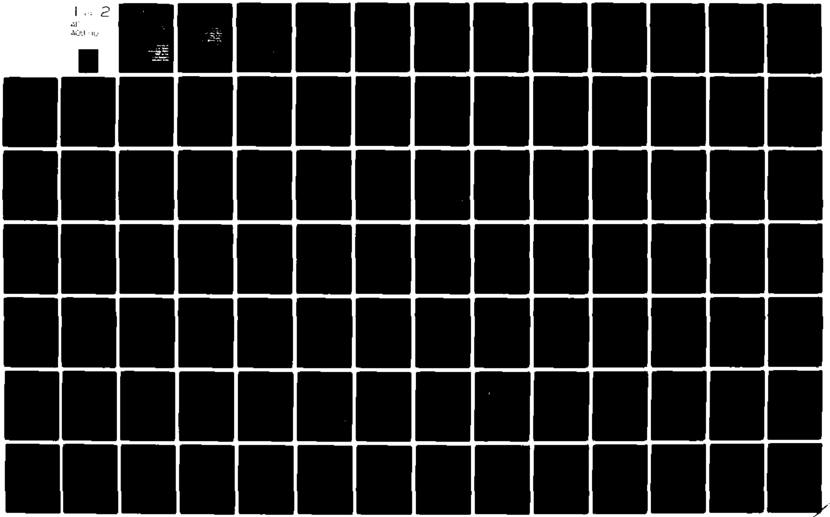

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Survey of U.S. Army Technology Base R&D in the Fire Support Mission Area

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ABSTRACT

This report discusses the U.S. Army Technology Base R&D work units which are relevant to the Fire Support Mission Area. A simple effectiveness model is developed and used to identify needed technological improvements in cannon and rocket fire. R&D work units are then examined in light of their potential contribution to combat effectiveness. Areas of insufficient R&D activity are identified and some relevant management issues are discussed.

FIRE SUPPORT ● ARTILLERY ● CANNONS ● ROCKETS ●

RESEARCH AND DEVELOPMENT ● EFFECTIVENESS ANALYSIS

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AAA	Anti-aircraft artillery
AARADCOM	Army Armament Research and Development Command
AMMRC	Army Materials and Mechanics Research Command
AMP	Army Missile Plan
ASL	Atmospheric Sciences Laboratory
BSI	Directorate of Battlefield Systems Integration (Also known as DRCBSI)
BPDC	Boost phase directional control
CEP	Circular error probable
CHAMP	Canard Homing Artillery Modular Projectile
CLGP	Cannon launched guided projectile
COPPERHEAD	CLGP program in Engineering Development
CSTA	Combat Surveillance and Target Acquisition Laboratory
DARCOM	U.S. Army Development and Readiness Command
DARPA HOWLS	Hostile weapon location systems development program of the Defense Advanced Research Projects Agency
DME	Distance measuring equipment
ECCM	Electronic counter-countermeasures
EW	Electronic Warfare
EWA	Edgewood Arsenal
EWL	Electronic Warfare Laboratory
FAMAS	Field Artillery Meteorological Acquisition System
FAS	U.S. Army Field Artillery School

GLOSSARY OF ACRONYMS AND ABBREVIATIONS (Continued)

FEBA	Forward edge of the battle area
FM	Field manual
GLLD	Ground laser locator-designator
GSRS	General support rocket system
HDL	Harry Diamond Laboratories
HE	High explosive
HEL	Human Engineering Laboratory
HELBAT	Human Engineering Laboratory Battalion Artillery Test
ICM	Improved conventional munitions
IOC	Initial operational capability
IR	Infrared
ISTA	Intelligence, Surveillance, and Target Acquisition
JMEM	Joint Munitions Effectiveness Manual
LCWSL	Large Caliber Weapons System Laboratory
LRGM	Long-range guided missile
MERADCOM	Mobility Equipment Research and Development Command
Met	Meteorology
MIRADCOM	Missile Research and Development Command
NARADCOM	Natick Research and Development Command
P_k	Kill probability
R&D	Research and development
RAP	Rocket assisted projectile
RF	Radio frequency

GLOSSARY OF ACRONYMS AND ABBREVIATIONS (Concluded)

RSTA	Reconnaissance, Surveillance and Target Acquisition
SADARM	Sense And Destroy Armor (munition)
SCORES	Scenario Oriented Recurring Events Sequence
SCWSL	Small Caliber Weapons System Laboratory
SOTAS	Stand-off Target Acquisition System (radar)
STOG	Science and Technology Objectives Guide
TLE	Target location error
TPQ-37	Counter-battery radar set
TRADOC	U.S. Army Training and Doctrine Command

EXECUTIVE SUMMARY AND RECOMMENDATIONS

1.0 PURPOSE AND SCOPE

This report provides the U.S. Army Directorate of Battlefield Systems Integration (BSI) with an overview of Army Technology Base R&D efforts in the Fire Support Mission Area. In keeping with the central thrust of BSI, the analysis and results are presented in terms of potential contributions to combat effectiveness. This view of R&D makes it possible to identify gaps or underfunded areas and to make estimates of the likely payoff of ongoing efforts. BSI has identified $324M of FY78 funding as Battlefield Related Technology Base work, of which $46M concerns Fire Support, primarily addressing cannon and missile artillery developments. Within these categories, there are about 250 individual work units which are examined in this report. Overall, the Technology Base is expected to investigate new ideas and provide a firm basis for the Army's materiel research, development, test, and evaluation program, which presently costs about $2.5B per year. Thus, it is important fiscally, as well as militarily, that exploratory and advanced development work be well conceived and directed. Although this report addresses only a portion of the total effort, the leverage of Fire Support R&D is great. As a measure of its fiscal impact, note that the cost of a 90-day ammunition reserve for one corps is approximately $2B. The issue of combat effectiveness is paramount, however; BSI in its efforts to integrate the modern battlefield, has identified swift response to targets 5 to 30 km behind the close combat zone as one of the central problems of the modern Army. This review of Fire Support Technology Base activities stresses combat in this Zone IIa region, as it is there that most improvements are needed, and new technology developments may be most useful.

2.0 METHODOLOGY

The methodology adopted in this report is based on the philosophy that Army R&D should be responsive to Army needs. It is not always easy to make the direct connection between research and operations because of differences in level of detail at which these activities are usually studied. Some idea of the desirable Army combat capabilities is given by gaming and analyses such as is used in the SCORES European scenarios, but these say little about what research programs need to be undertaken. Games can establish, however, the general level of combat effectiveness that is desirable. Gaming and combat analysis are not studied in this report, but we do rely on the synthetic experience they provide as justification for the basic idea that improvements are necessary. Estimates of the currently achievable performance of cannons and rockets then show more specifically where we stand. A parametric analysis of individual weapon performance is introduced in order to show which of the technical factors involved are most influential in enhancing effectiveness and what degress of improvement may be valuable. This establishes that there is at least theoretical room for improvement.

A thorough technology assessment is not necessary to show that the scientific potential for further development is present. Rather, in most cases, it is sufficient to refer to demonstrated achievements to become convinced that it is indeed possible to develop better systems. These considerations of what should and what could be achieved provide a basis on which to evaluate ongoing R&D efforts. As the Technology Base work units are examined in this light certain areas where intensified R&D activity would pay off become apparent and the potential benefits of goal-oriented program planning may be considered.

But this methodology cannot lead to an estimate of how much money should be allocated to a particular research area; it can only help to establish goals, illuminate their relative importance, and identify gaps. The appropriate allocation of funds depends on detailed program planning for each research problem and planning has not been attempted here. One of the central conclusions of this report is that there appears to be insufficient program planning within the Army laboratory system - all too many work units stand alone and have no evident relation to the overall development cycle.

One of the primary sources for information on Fire Support R&D is the publication "Base Technology Programs Related to Battlefield Systems"(1) which brings together for the first time a comprehensive listing of R&D work units in their operational context. It is unfortunate that neither Ref. 1, nor any other document, provides a historical view of the R&D funding pattern. Thus, there is no ready way to judge the progress that may have been made by the Technology Base as a whole. It is beyond the scope of this report to attempt a historical review; rather, we focus on the situation as it now exists.

3.0 RESULTS OF THE ANALYSIS

The following points give a brief summary of the findings developed in the body of the report:

- Current cannon artillery practice and equipment are effective against stationary soft targets in Zone I, requiring about 3 battery volleys per target at 10 km range. At ranges of 15-20 km, 25 or more volleys would be required. There is a technological potential to reduce the requirement to 3 volleys at the longer ranges.

- The most promising areas to address in improving cannon system performance are target location error (TLE) and bias errors connected with meteorology. The technological potential exists to achieve at least threefold improvements in performance by control of these errors.

- R&D work units are not addressing TLE and meteorological problems in an organized manner and structured programs should be instituted.

- Further but less significant, improvements in performance could be made by control of weapon precision and ammunition uniformity.

- There are no Technology Base projects addressing long life weapon design or munition uniformity in the field.

- Calculations indicate that even improved cannon systems will not be effective against moving hard targets unless terminal homing projectiles are used.

- The funding pattern for development of homing projectiles is uneven. While there is no ready way to assess progress in prior years, a transition from exploratory to advanced development is not evident.

- At ranges which can be reached by either, rockets are less cost effective than cannons, by a factor of at least two.

- Major improvements in rocket missile performance could be achieved through incorporation of inertial guidance, making rockets effective in an aimed fire mode against soft fixed targets in Zone IIa. Guidance technology adequate to this task is available.

- The main undemonstrated factors necessary to effective performance against moving hard targets in Zone IIa are terminal homing and rapid response fire direction techniques.

- Technology Base programs generally do not address systems analysis and integration issues; this inhibits transition of promising ideas to advanced and engineering development. In particular, system and interface problems in real time fire direction and control are not being studied in Fire Support R&D.

- Successful efforts in navigation, terminal homing, target location and fire direction should make it possible to kill individual tanks at 30 km by a single salvo of about 10 rockets at a cost in the neighborhood of $100K per tank.

- On the whole, user proponents do not seem to place a high value on Technology Base efforts. A review of work unit priorities assigned by users shows that about one-fourth are judged to be of no specific interest while only one-tenth are graded critical or essential.

- Assessment of operational deficiencies and planning and organization to remove them are not widely evident in the Technology Base.

- The Science and Technology Objectives Guide (STOG) is emerging as the primary requirements document for the Technology Base. By requiring program responses and user-developer dialogue, it can help to ensure that Technology Base activity is more responsive to needs in the field.

- The procedure of assessing Technology Base work units in terms of likely contributions to combat effectiveness is helpful in identifying areas where extra effort is necessary and in establishing worthwhile goals for R&D programs.

4.0 RECOMMENDATIONS

In assessing Technology Base activity, the single most apparent shortcoming is the lack of goal-oriented program structure. The majority of the work units have individual scientific merit but are not coordinated to resolve recognizable operational deficiencies in a timely manner. Allocation of R&D resources should be made on the basis of the potential contributions to combat effectiveness, as well as by scientific opportunity.

- Administrative efforts are required to assure that the current and desired performance of Army systems is well understood and documented within the Technology Base so that responsive R&D program efforts can be structured.
- There should be a focal point for the collection and dissemination of information on the performance of current and projected battlefield systems in order to provide guidance to the development community on the relative need and worth of planned efforts.
- Technology Base programs should be reviewed for technological opportunities to address integration and interoperability problems as well as to measure progress in the evolution of improved individual weapons and equipment.

- Specific to the Fire Support Mission Area, reorientation and strengthening of R&D efforts should be encouraged in the following technical areas:
  - Precise target acquisition
  - Rapid response fire direction and control
  - Correction of meteorological errors
  - Terminal homing munitions, especially armor seekers and ARM
  - Inexpensive inertial guidance for small rockets
  - Battle damage assessment and fire adjustment in Zone II
  - Crew protection effectiveness and requirements
  - Logistic supply systems, especially reduction of fuze and ammunition type requirements
  - Uniformity of fielded munitions
- The concept of using expensive inertial guidance on only one lead rocket and follower guidance on the remainder of the rockets in a salvo appears attractive and should be studied further.
- Time-of-flight considerations indicate that, when addressing moving hard targets, the acquisition range for terminal homing devices must be greater than 1 km. It is probable that multi-mode or multi-spectral sensing will be required, and additional efforts on this problem should be mandated.
- Coordinated efforts in target location, fire control, guidance, and terminal homing are required to be successful in addressing moving hard targets. Even though the Technology Base does not normally undertake system development, the technology and system requirements are so initimately linked that a broadened conception of Technology Base responsibility is recommended for this problem.

1.0 INTRODUCTION

This report examines Army Technology Base Research and Development (R&D) activities pertaining to the Fire Support Mission Area in the context of their potential contributions to combat effectiveness. As defined by the Army Development and Readiness Command (DARCOM), Technology Base work units in Fire Support are those which address improvements in cannon artillery, mortars, and rockets. Less than 2% of the Fire Support Technology Base budget is devoted to mortars, so the focus here is on cannon and rocket artillery weapons. Two thousand individual work units representing a Fiscal Year 1978 budget of $46 M are included in these categories. These efforts fall within the purview of fourteen Army Laboratories under six major commands.

Some idea of the relative significance of Fire Support costs can be gained from the fact that 20% of the total costs of an armored division are ascribed to artillery activities. Ammunition outweighs the other categories of Fire Support costs by a wide margin, and 80% of all ammunition costs are attributable to artillery. The cost of a 90-day artillery ammunition reserve for a three-division corps is estimated to be $2 billion. R&D relevant to Fire Support thus has important fiscal implications as well as its impact on military effectiveness.

The work reported here was supported by the Directorate of Battlefield Systems Integration (BSI), U.S. Army Development and Readiness Command. Among its interests and objectives with respect to the Technology Base, BSI wishes to identify gaps and trade-offs and to promote a more viable interaction between Army users and developers. As a part of this program, BSI arranged for the publication of the document "Base Technology Programs Related to Battlefield Systems,"(1)* which for the first time brings together a listing of R&D work units from all Army Laboratories and shows the relationship of these to Army Standard Capability Categories and Functional Groups of Systems. Within the Fire Support Mission Area, the present report provides to BSI an overview of the existing R&D efforts contained in Ref. 1. However, it supplements that material by providing estimates of the degree to which technological developments can and should be pursued to enhance the Army's combat effectiveness within the Fire Support Mission Area. The analysis begins with an assessment of current performance and potential improvements in order to construct a framework within which groups of R&D work units may be judged. Then the Technology Base efforts as reported in Ref. 1 are examined and some gaps and potential trade-offs are identified. In this process certain management issues become apparent and these are also discussed in the context of improving user-developer dialogue.

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*Numbers in parentheses indicate reference documents listed at the end of this report.

2.0 FIRE SUPPORT PROBLEM AREAS

The Fire Support Mission objective is to neutralize enemy troops, armor and artillery, fire direction and C^3 centers, and fixed positions in order to permit friendly infantry and armor to accomplish their missions of controlling territory. The proliferation of target types and ranges makes it difficult to assess combat effectiveness in a simple way. It is helpful to divide the battle area into zones: Zone I, encompassing line-of-sight operations, extends from the Forward Edge of the Battle Area (FEBA) to a depth of approximately 5 km. Zone II extends beyond Zone I to 50 km. Zone II is further broken into Zone IIa, from 5 to 30 km, approximately the range that can be addressed by cannon artillery, and Zone IIb from 30 to 50 km which is still a primary area of Army concern. Beyond this range, Air Force responsibility predominates. Targets may be roughly grouped into point targets such as vehicles and equipment, or area targets such as command areas and supply dumps.

The current capability of artillery against area targets is reasonably good in both Zone I and Zone IIa. Effective fire can be spread over one half to one kilometer diameter areas almost at will. Harassment and interdiction fire (H&I) is of tactical value and can be placed as directed. Major problems in area fire to which Technology Base efforts can contribute are concerned with weapon reliability and speed of response.

Point targets offer a more difficult challenge to Fire Support systems, however, and here the demarcation between Zone I and Zone II becomes very important. In Zone I, adjusted fire techniques predominate. For fixed targets, successive reductions of miss distance can be accomplished through use of forward observers so that a high assurance of target destruction is possible. Technology Base efforts in communications and both tactical and technical fire control should be expected and are necessary to enhance effectiveness. For moving targets, accurate control and speed of response are key elements; Technology Base work in designated munitions and system automation for rapid response are of prime importance.

The response to point targets in Zone II is the most difficult and modern challenge in Fire Support, and it is here that the Technology Base may be able to make the greatest contribution to combat effectiveness. Accuracy, range, and response speed are the major problems to which technological solutions must be sought. Current doctrine calls for deep fire, and combat analyses indicate clearly that in order to defend successfully against a numerically superior force, it is necessary to disrupt enemy operations beyond the light of sight and slow the introduction of enemy units into the close combat arena. Such analyses provide ample justification for R&D efforts to improve on current capabilities.

3.0 COMBAT EFFECTIVENESS

3.1 Current Performance of Cannon Artillery

Ideally, one would like to see an R&D program structured to respond to the problems just outlined. There is little formal documentation, however, which analyzes research efforts in terms of combat effectiveness. In order to provide a measure of the potential payoff of fire support research, this paper begins with a simplified analysis of mission effectiveness. The analysis identifies those parameters which can be affected by technological improvements and shows their relative worth; the Technology Base program is then examined in the light of these findings, and areas where new or increased R&D emphasis is required are pointed out.

It is useful to start with some estimate of current capabilities. As an example, we focus on a problem of fire in Zone IIa. From the Joint Munitions Effectiveness Manual (JMEM),(2) "Effectiveness Data for Howitzer, 155 mm M109," FM101-60-4, we select a fixed AAA radar van as a typical target of interest. Using the lethality data for high explosive rounds given there and the weapon characteristics drawn from JMEM, "Indirect Fire Accuracy," FM101-61-5-1, it is possible to calculate the rounds expended to destroy this target with an assurance of 80%. A battery of six weapons is assumed. Factors affecting the solution include target location error (TLE), expressed in meters of standard deviation, firing doctrine (converged or parallel sheaf), and bias errors, primarily arising from staleness of meteorological data (represented by a five knot uncompensated wind error in this example). The results are shown in the following table. The analysis on which these and subsequent calculations are based is described fully in Appendix II.

TABLE I

AMOUNT OF ARTILLERY FIRE REQUIRED TO PROVIDE 80% ASSURANCE OF DESTRUCTION OF A AAA RADAR VAN

Range	Mode of Fire	Technique	TLE	Required Volleys	Ammunition Cost*
5 km	Converged	Adjusted	50 m	3	$6.7 K
5 km	Parallel	Adjusted	50 m	6	$13.5 K
15 km	Converged	Predicted	150 m	25	$56.2 K
15 km	Parallel	Predicted	150 m	27	$60.7 K
20 km	Converged	Predicted	150 m	27	$88.3 K
20 km	Parallel	Predicted	150 m	29	$94.8 K

*Based on $375 per round for HE and $545 per round for HE RAP at 20 km range.

It is evident from Table I that Zone II targets are much more demanding of resources than are Zone I targets. The situation is worse at longer ranges because a majority of the factors which degrade effectiveness are range dependent. In general, costs increase exponentially with range for a given system.

Two factors make it well worthwhile to consider how to apply technology to improve combat performance. First, there is the natural concern over ammuniton expenditure rates as it affects procurement cost and the logistics burden. Of perhaps even greater importance, however, is the fact that more effective weapons can service more targets per unit time. In these terms, halving the cost to kill a target is nearly equivalent to doubling the effective number of available tubes.

3.2 Potential Improvements in Cannon Artillery

In order to determine the potential for improvement of combat effectiveness of fire support weapons systems, the ammunition expenditure rates for various targets have been developed in this report as functions of the following technical parameters:

Munition Lethal Radius
Weapon Precision
Bias Errors (principally wind, air density, and crews errors)
Target Location Errors
Number of Weapons Firing Simultaneously
Individual Weapon Aim Points

The first four of these can be altered by technology; the last two are mainly affected by doctrine. Several example calculations for both cannon and rocket fire are collected in Appendix I. From these, and from consideration of weapon error budgets, it is concluded that TLE and meteorological errors are the most important to control, followed by weapon precision and munition lethality. As there do not appear to be fundamental physical reasons constraining current performance levels of these factors, technological improvements are judged possible, so that the Fire Support Technology Base work units can be examined in these terms.

The ammunition cost to kill a given target has been selected as a measure of effectiveness because it provides a ready basis for comparison of different systems, as well as an indication of the potential worth of successful R&D. For example, Figure 1 shows the cost of HE ammunition required to destroy the AAA radar van mentioned above as a function of TLE and weapon system bias errors. The factors entering the calculations are as follows:

Range: 15 km
Target: AAA Radar Van
Munition: M107 High Explosive
Munition Cost: $375 per Round, $2.25 K per Volley
Lethal Radius: 25 Meters
Weapon Group: 155 mm Howitzer Battery of six Guns
Burst Pattern: Parallel Sheaf, 200 Meters Long
Dispersion Pattern: 2:1 Ellipse
Weapon Range Dispersion: 75 Meters Standard Deviation
Bias Error: 10 knot, Typical of 4-Hour Stale Met
5 knot, typical of 2-Hour Stale Met
Target Location Error: Standard Deviation Shown Parametrically

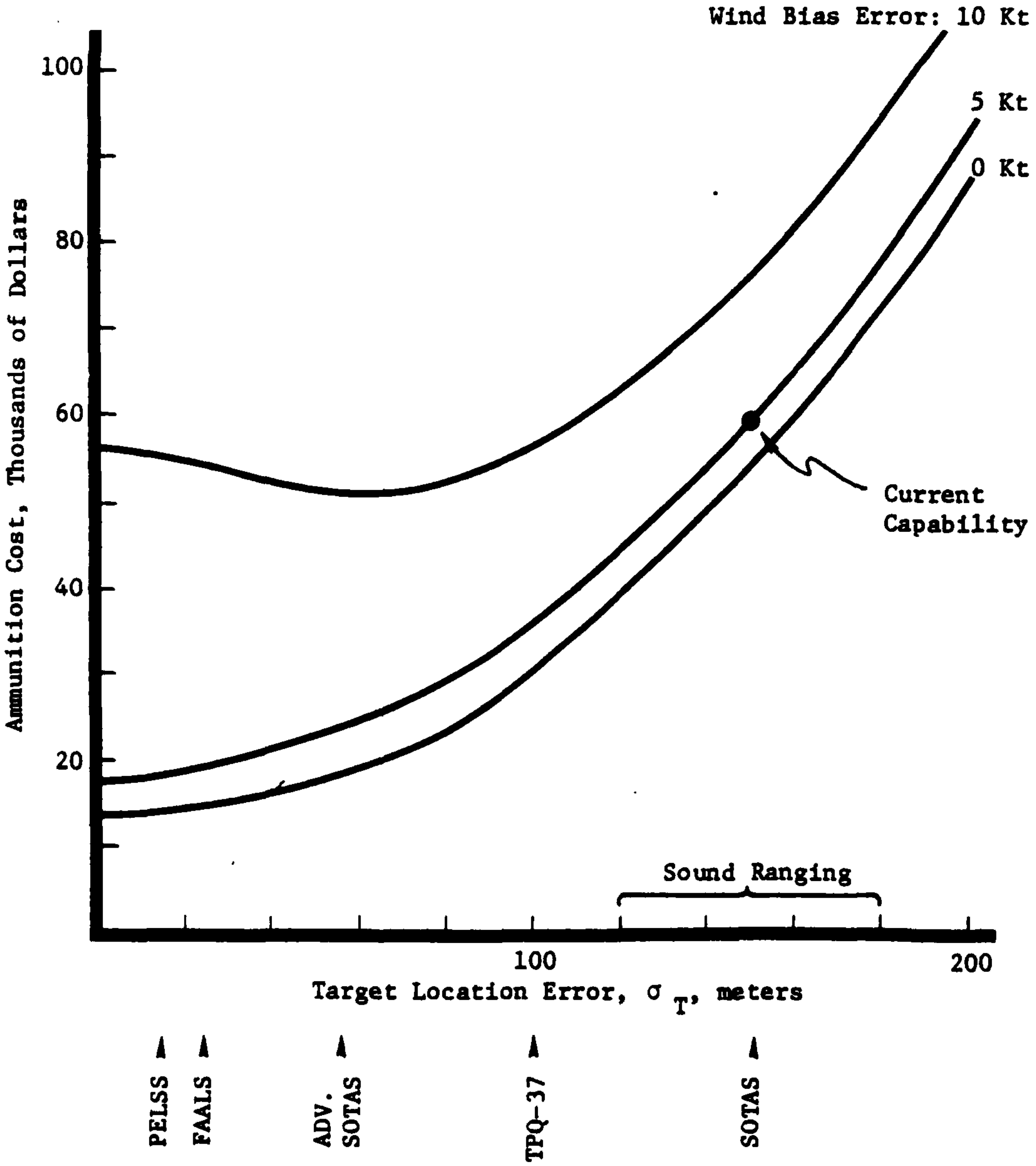

FIGURE 1
AMMUNITION COST TO KILL A TYPICAL ZONE II TARGET VS. TLE FOR VARIOUS BIAS ERRORS. RANGE=15 KM

The performance* of several target locations systems is also indicated on Figure 1. Sound ranging systems provide 150 m accuracy, as does the current (1/3°) SOTAS system when operating 25 km from the target. The TPQ-37 radar has an accuracy of 0.4 percent of range, while the advanced SOTAS is expected to yield about 50 m performance. Precision Emitter Location and Strike Systems (PELSS) (airborne time of arrival) and the Field Artillery Acoustic Locating System (FAALS) have potential performance in the 15 to 25 m range. Thus, it appears that technology is available to reduce target location errors at least to 25 m. On this basis, Figure 1 indicates that cannon artillery effectiveness may be increased threefold if TLE and bias errors can be controlled effectively. Meteorological factors are the largest source of bias errors, so the potential gains from practical development work in this field are evident. For small TLE, large bias errors cause the burst pattern to lie far from the target, and fire becomes ineffective as indicated by the 10-knot error curve in Figure 1. The effect is much more damaging in the converged sheaf mode of fire, as discussed in Appendix I, adding extra urgency to the technical control of bias errors.

Further calculations have been made to investigate the influence of bias, weapon precision, munition lethality, and firing doctrine; the results show the potential payoff of research in these areas. For the same target, range, and weapon group shown in Figure 1, and

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*Cf. References 3 through 6.

presuming a TLE of 30 m standard deviation, the incremental values of changing the other parameters are as follows:

Change	Ammunition Cost Saving
Reduce bias error to 2.5 kt wind equivalent	$4 K (~ 2 volleys)
Improve weapon precision to 50 m standard deviation in range	$3 K (~ 1 volley)
Switch to converged sheaf fire	$9 K (~ 4 volleys)
Increase munition lethal radius to 35 m	$2 K (~ 1 volley)

Applying all of these postulated improvements at once, the calculated cost to destroy the target with 80% assurance is $5 K, which represents slightly in excess of two volleys. Firing only two volleys (12 rounds) yields a kill assurance of 77% in this case.

To investigate whether it is technologically feasible to achieve the postulated improvements, it is necessary to examine the error sources in some detail. A typical artillery error budget is compared with relevant R&D work unit funding in Section 4.2, but the major errors and prospects for improvement can be listed here:

- Target location errors: Demonstrated technology and design studies (PELSS and FAALS) have achieved TLEs of the order of 20 m. Exploratory development of operational systems should be vigorously pursued.
- Weapon precision errors: Primary contributors are propellent and drag variations and weapon tolerances and wear. Improvements in manufacturing technology

and quality control as well as the use of RAP rounds to reduce weapon stress appear to offer prospects for 20 to 30 % improvements in weapon precision.

- Bias errors: Round-by-round observation of meteorological effects is a technological possibility via radar or acoustical techniques. A central issue is the provision of fresh wind and air density information to firing batteries; errors due to these factors grow approximately linearly with data age. In practice, data used as the battery averages two to three hours old. Accurate hourly met updates could reduce bias errors by at least half. Other major bias contributors are incorrect estimates of powder temperature and muzzel velocity; technology exists to control these factors much more precisely than is now done in the field. Reduction of bias errors to one-third of present values is a definite technological possibility.

- Increasing munition effectiveness: High fragmentation steel projectiles appear to offer promise, but their reliability is low thus far. A scientific breakthrough is needed here, but none seems to be on the horizon. The chemistry of explosives is well enough understood to make possible more lethal fills, but research on storage and stability properties is required to speed the long process of adopting new fills. Dramatic improvements of munition effectiveness are judged to be unlikely in the near future. Most gains will probably come from improved conventional munitions (ICM) for area targets and the adoption of precision guidance techniques.

- Doctrine: As technical improvements are introduced, it will become more profitable to replace the usual parallel sheaf mode of fire by converged sheaf fire. This will be made easier by the introduction of gun laying computers for which technology is available. Accurate fire makes damage assessment important. Remote viewing systems are well within the possibilities of current technology, for example. Thus, it should not be necessary to waste time and ammunition by firing a doctrinally determined number of rounds at a target.

All in all, the prospects appear bright for the application of new technology to improve the effectiveness of cannon artillery systems addressing stationary targets in Zone IIa. Within Zone I, where adjusted fire is more usual, much less dramatic improvements are to be expected. As indicated in Table I, cumulative kill probabilities of .8 can be achieved by firing only three volleys at a cost of $6.7 K. This performance is already comparable to that of precision guided munitions such as COPPERHEAD when compared on a cost basis. Compared to the Zone IIa case, there is relatively less room for improvement, so feasible reductions of TLE and weapon precision and bias errors cannot contribute so dramatically in Zone I.

The situation is quite different for moving hard targets such as tanks. At a velocity of only 10 km per hour, a tank in Zone I may travel over 50 m while a shell is in the air. For tanks in Zone II, over 150 m displacement can occur during the time of flight. Considering also the necessarily small lethal radius associated with these targets (of the order of 5 m) single volley kill probabilities become vanishingly small, approaching 10^{-4}, even when perfect control of bias errors is assumed. Tens of thousands of rounds would be necessary to achieve satisfactory assurance of target destruction, and a large part of the service life of tube artillery weapons would be expended on a single target. Thus, it is impracticable to address moving hard targets in Zone II by conventional artillery. The necessity of precision terminal homing munitions is evident.

3.3 Projected Performance of Rocket Systems

Relative to cannon artillery, there is a paucity of hard data on the performance of General Support Rocket Systems (GSRS). A comprehensive and detailed study of the performance of GSRS candidates is found in the Rapid Fire Area Saturation System (RFASS) Reports,(7) however, where theory, analysis, and experience with the HONEST JOHN and LITTLE JOHN systems is brought together. Typical results* from RFASS show that GSRS free rockets of six- to eight-inch diameter are expected to have a CEP of 360 m at 30 km range, and cost approximately $1 K per round. Performance can be improved by the addition of boost phase direction control (BPDC) which essentially eliminates errors associated with the variability of rocket motor total impulse and surface winds. The RFASS study concludes that BPDC would cost about $1 K per round, essentially doubling the price of each rocket. Analysis shows that the addition of BPDC is not cost effective and, further, that free rocket performance is nearly independent of the precision of the target location system so long as this parameter is less than about 250 m.

If inertial guidance is considered, accuracy improves markedly, and although costs per round go up, there is a large overall improvement in both absolute and cost effectiveness, provided that precise target location systems are used. Further, there is a definite

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*These results are representative of current GSRS development.

technological potential for the achievement of relatively economical inertial guidance systems, so that these gains may be realized in practice. For example, the Precision Products Division of Northrup Corp. is prepared to supply guidance packages accurate to 5°/hr at \$5 K each in quantity. For a 30 km range, this translates to about 2 mil overall accuracy. Estimating that such fully guided rockets would cost \$10 K each, the calculated cost to destroy a stationary soft target, typified by the AAA radar van mentioned previously, would be about one-third of the cost with free rockets if 50 m TLE is achieved.

Another concept is that of providing precise inertial guidance on only a single lead rocket and a follower guidance package on the remaining rockets in a salvo. For example, slave rockets can be commanded to follow a coded beacon signal (like that of the COPPERHEAD designator) emitted by the lead rocket. Costs for slave rockets should then be approximately the same as for COPPERHEAD rounds, estimated at \$5 K. A salvo would then cost about half as much as a salvo of fully guided rockets.

Figure 2 shows ammunition costs for these rocket systems. The warhead lethal radius is again taken as 25 m to provide a basis of comparison with the curves of Figure 1. BPDC does not correct for winds aloft; the resulting miss distances are costly for small TLE, just as discussed for tube artillery. The improved overall accuracy is offset by the doubled cost in this case. The gains that accrue from good guidance and small TLE are evident. Separate calculations considering the free rocket as an area weapon indicate that for the entire range of TLE shown on Figure 2, approximately 90% of the rounds fired can be expected to fall within a circle one-half kilometer in diameter. Comparatively, free rockets are much more effective as area fire weapons. If bias errors due to meteorological effects can be compensated, nearly 90% of the free rockets fired will impact within a one-third kilometer circle.

The preceding discussion provides some basis for consideration of the moving hard target problem. When firing on a tank, say, the lethal radius is so small that essentially direct hits are required. Just as in the case of cannon artillery, calculations show that the number of rounds required is prohibitively large unless terminal homing is incorporated. The cost and performance if terminal homing is included can be calculated. The analysis is somewhat speculative, but nevertheless interesting. For the lead rocket costing $10 K with the type of inertial guidance mentioned above, and slave rockets at $5 K each, the cost of dispatching a tank at 30 km range depends on the hit probability achievable by the terminal homing package, as well as on the cost of this package. There simply are no reliable figures on the likely cost of terminal homing, but let us take $5 K per warhead as an estimate. Then, lead guidance rockets would cost about $15 K and slave rockets would cost $10 K. The number of rockets per salvo to achieve at least 80% assurance of kill can be calculated as

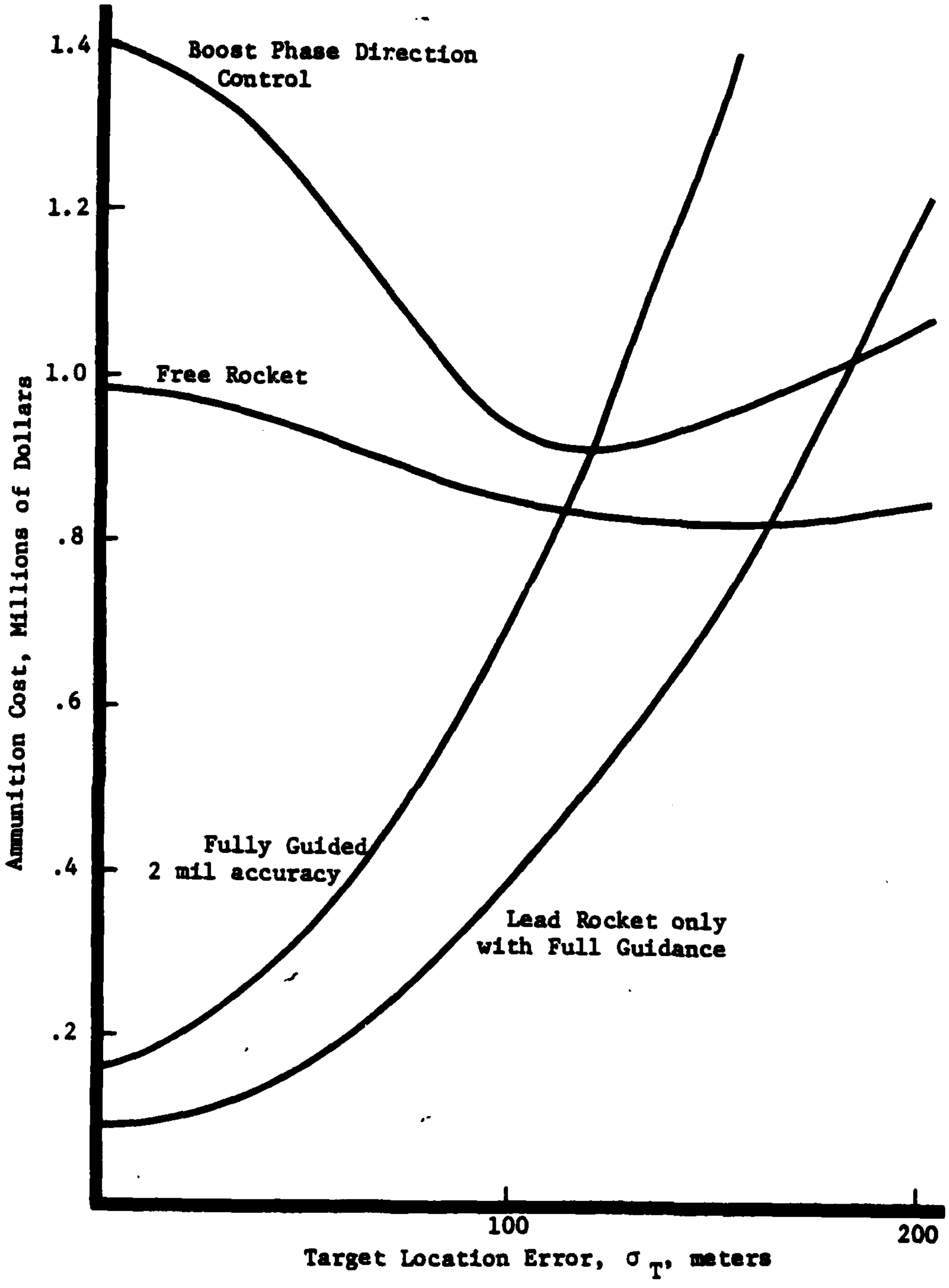

FIGURE 2
ROCKET COST TO KILL A TYPICAL ZONE II TARGET VS. TARGET LOCATION ERRORS. RANGE=30 KM

a function of the P_k of the individually terminally guided warheads. Two mil inertial guidance accuracy is again presumed. During the time of flight, a target might displace ½ km, and the terminal homing system is assumed to be able to operate effectively within the resulting search area. Results are shown in Table II.

TABLE II

CONCEPTUAL PERFORMANCE IN TANK KILLING

Terminal P_k	Required Rockets per salvo	Ammunition Cost per Kill	Assurance of Kill
.10	15	$155 K	.79
.15	10	$105 K	.80
.3	5	$55 K	.83
.5	3	$35 K	.87

Even if a P_k of only .1 could be achieved for the terminal homing warhead, such a system would impose a reasonable and acceptable logistic burden. Even if the cost estimates here are too small by a factor of two, it would cost only some $1.5 M to address five hundred tanks per day on a division front, killing four hundred of them. For comparison, divisions are expected to use $4.5 M worth of 155 mm HE ammunition per day in the early stages of battle. The actual value of postulated systems must, of course, be judged on the basis of detailed combat modeling, which is far beyond the scope of this report. On the basis of the analysis proposed here, however, there is a strong case for the active pursuit of those technologies which can provide the indicated enhanced effectiveness. For the destruction of moving hard targets, the unachieved technologies of primary importance relate to near real-time direction of the weapon and target acquisition by the terminal homing unit. The required capabilities for target location, navigation, rockets, and warheads are essentially in hand, although major development and integration efforts are necessary.

3.4 A Framework for Judging R&D

Based on the discussion of the preceding sections and some further analytical results which are collected in Appendix I, we can now summarize the main technical areas where Technology Base R&D is most likely to contribute to the combat effectiveness of cannons and rockets in the Fire Support Mission Area. The following annotated outline presents the information:

a. Cannon Artillery

1. Area fire in Zones I and IIa.

- Current capabilities are largely satisfactory to a range of 18 km.
- RAP rounds will extend range to 25 km, but cost reduction is desirable.
- Weapon life extension is desirable. Wider use of RAP could help greatly to lengthen tube life.
- Unobserved area fire, such as mine emplacement, would be aided by devices to measure impact patterns.

2. Aimed fire against fixed targets in Zone I.

   - Current accuracy with forward observers to adjust fire is good.

   - Overall combat effectiveness would improve with greater speed of response achievable through technical and tactical fire control.

3. Aimed fire against moving targets in Zone I.

   - Cannon accuracy is sufficient, but target maneuverability and armor protection makes terminal homing essential.

4. Aimed fire against fixed targets in Zone IIa.

   - Current maximum ranges, even with RAP rounds, do not cover all of Zone IIa.

   - Current performance can be improved by an order of magnitude.

     - TLE of 30 m or less is required.

     - Advantages of reduced TLE can only be obtained if bias errors are tightly controlled. Both problems must be addressed simultaneously.

     - Successful TLE and bias error control alone would improve performance by a factor of three.

     - If TLE and bias are controlled, switching tactics to converged sheaf fire improves performance by another factor of two.

     - Improving weapon precision to a feasible degree offers the possibility of reducing by one or two the number of volleys required to destroy targets. This improvement is practically independent of TLE and bias errors, so it becomes significant only when these errors are well controlled.

     - Improving munitions lethal radius from 25 m to 35 m enhances effectiveness by about 45%.

5. Aimed fire against moving targets in Zone IIa.

   - Cannon system accuracy and range are both insufficient to provide useful levels of performance. Terminal homing is essential. Rocket systems appear to offer better prospects than does tube artillery.

b. Rocket Systems

1. Area Fire

   - Projected GSRS capabilities are adequate to saturate one kilometer areas.

2. Aimed fire against fixed targets.

   - For TLE less than 50 m, the effectiveness of rockets can be improved by a factor of 3 to 5 by introduction of accurate inertial guidance.

   - A further factor of 2 in cost savings can be attained through use of follower guidance techniques on all but one rocket in a salvo.

   - If terminal homing devices are used with free rockets, acquisition areas in excess of one kilometer diameter will be required at 30 km range.

3. Aimed fire against moving hard targets.

   - Target agility establishes requirements for near real-time fire control.

   - TLE less than 50 m at launch time is required.

   - Two mil accuracy of midcourse guidance systems is required.

   - Terminal homing munitions are mandatory.

The factors outlined here provide a basis for preliminary evaluation of Technology Base work units, and it is with these points in mind that the following section should be read. The technologies required to provide effective fire support are largely available. System integration and cost effectiveness are larger issues than technical capability, except for terminal homing munitions where effective concepts have not been demonstrated.

4.0 TECHNOLOGY BASE EFFORTS IN FIRE SUPPORT

4.1 Distribution by Problem Areas

The previous section discussed the potential for improvements to combat effectiveness of fire support elements in terms of those parameters which can be affected by technology. Let us now examine the R&D work units, their objectives, and funding distribution. The primary data source here is Ref. 1, which identifies work units and FY77 and 78 funding with their operational objectives. A summary of work unit funding by broad problem area is given in Table III.

TABLE III

R&D FUNDING DISTRIBUTION BY PROBLEM AREA

Problem Area	$K FY77	FY78
Precision and Bias Factors (ex. met)	9,135	10,760
Meteorology	1,804	1,055
Target Acquisition	2,251	3,675
Tube Artillery Projectiles	8,706	8,441
Rockets	6,256	7,391
Guidance	3,258	4,969
Terminal Homing	2,842	5,478
Designators and Range Finders	1,613	2,133
EW and ECCM	1,391	2,085
Protection	273	313
Logistics	314	259
Totals	37,843	46,559

In view of the analysis of the previous section, Table III indicates a reasonably well-balanced program, but much more cannot be said without a more detailed look at the content of the research efforts within these problem areas. We turn, then, to this closer examination.

TABLE IV

PRECISION AND BIAS FACTORS VS. FUNDING

Topic	$K FY77	FY78	Number of Work Units
Mortar operations and concepts	100	450	2
Propellants	295	1,272	5
Projectile and component design	421	505	8
Aero- and flight-dynamics	800	840	9
Guns, wear, recoil	1,262	1,620	9
Closed loop fire direction and control	2,265	2,435	13
Fuzes	3,212	2,788	31
Production of firing tables	780	850	1
Totals	9,135	10,760	78

Table IV outlines by groups of work units the research thrusts and funding pertaining to bias and precision of tube weapons. The natural question is whether the funding is adequate to the needs and justified by the potential for improvement. The proper answer to this question should come from examination of a program plan for each area, but such documents have not been written. As noted earlier, however, there is in general an adequate scientific basis on which to build the requisite technology advances. Properly planned programs would not only make it easier to judge the worth of Technology Base efforts, but would also speed the adoption of successfully developed ideas. The absence of program plans is flagged as a widespread shortcoming of the Technology Base.

Nevertheless, some judgments can be made on the basis of Table IV:

- *The production of firing tables is not an R&D issue.*
- *There is a great proliferation of work units on fuzes representing 25% of the total effort. Relatively, this is too large.*
- *The balance between the remaining items is in accord with their relative potential to contribute to combat effectiveness.*

Unfortunately, there is no ready way to assess the progress being made on any of these topics, but many of the work units are known to have been in existence for several years. The lack of suitable measures of progress is another shortcoming of Technology Base activity which could be improved by the adoption of a program planning system.

The discussion of Section 3 emphasizes the importance of reducing bias errors in Fire Support systems. The largest single contributor to bias errors is the inaccuracy of meteorological data used in predicted fire, so it is worth examining the individual work units listed in Table V.

TABLE V

METEOROLOGICAL WORK UNITS

Topic	$K FY77	FY78
FAMAS	1,175	-
Automatic met system	156	225
Long-range wind sensor		100
Wind profile system	228	645
Wind structure	60	60
Temp-density tables for W. Europe	85	125
Totals	1,704	1,155

The majority of the dollars in FY77 are devoted to the Field Artillery Meteorological Acquisition System (FAMAS). FAMAS will provide a semi-automated and accurate system of generating met messages which will doubtless be more convenient than the current method. As presently envisioned, FAMAS will provide updated information every four to six hours, and only one unit will be assigned per division. Thus, even when FAMAS becomes operational, met information will still be, on the average, stale and pertain to regions many kilometers from the trajectories being fired. FAMAS does not appear to be the ultimate answer to the artilleryman's meteorological problem, and further R&D efforts are indicated in this area. For example, the FAALS target acquisition system offers some hope, as it can provide current meteorological information in the target region, but we do not know as yet how much this may help the situation.

Ideally, a method of correcting for atmospheric parameters on a round-by-round basis along each trajectory is what is needed to achieve the full potential benefits indicated in Figure 1. Table V does not show a systematic attack on this most important and high payoff area.

- *A planned and coordinated Technology Base program in applied meteorology research should be encouraged. Successful correction of meteorological errors could ultimately reduce, by as much as one-half, the number of artillery rounds required in predicted fire missions.*

The Science and Technology Objectives Guide (STOG)(9) contains paragraphs 78-2.5 and 78-4.6 which call for effective target acquisition systems for artillery. Table VI shows by title all of the work units listed in Ref. 1 which are justified by reference to these STOG paragraphs. Perusal of this list makes apparent the fragmented nature of the R&D efforts which appear to be almost completely oriented to electronic devices. Individually, these efforts may have merit, but they do not add up to an effective program to provide adequate targeting information to combat elements.

- *Work on reduction of TLE should be restructured.*
- *Exploratory systems studies are required to evaluate components and address interface problems.*
- *Closer ties with target acquisition efforts in the other military services should be established.*
- *The importance and large potential payoff of TLE reduction merit a major effort in planning and structuring a program.*

TABLE VI

TARGET ACQUISITION WORK UNITS

Topic	$K FY77	FY78
Fourier transform device	156	150
Mm and microwave devices	152	150
Hybrid microcircuit qualification	69	110
Diode devices	75	-
High gain RF keying	85	-
Repetitive series interrupter	23	80
Modulator technology	126	65
Laser return from artillery effluents	69	70
Microwave integrated circuits	176	185
Transistors and diodes	246	281
Low-cost microcircuits	52	90
Solid-state KU band amplifiers	60	35
Surface wave devices	152	104
Laser triangulation system	50	-
Radial beam traveling wave tube	10	82
Floating deck modulator	105	-
Sound ranging error reduction	100	118
Passive Artillery Location System (optical)	-	705
Support of DARPA HOWLS	475	1,500
Totals	2,181	3,725

Table VII shows by groups the technology base efforts pertaining to tube artillery projectiles.

TABLE VII

R&D ON PROJECTILES

Topic	$K FY77	$K FY78	Number of Work Units
Extended range projectiles	2,679	2,657	4
Explosives	650	500	2
Hard target penetrators	550	525	7
Submunitions	100	890	7
Fragmenting munitions	606	536	6
Smoke and obscurants	-	500	5
Chemical munitions (ex. smoke)	4,121	2,833	23
Totals	8,706	8,441	5

Examination of this table and the more detailed listings in Ref. 1 provides the basis for some observations:

- *There is a proliferation of uncoordinated small efforts.*
- *The work units on extended range projectiles are backed up by only a single $100 K work unit on extended range cannon design.*
- *If artillery can be made more accurate, an increased emphasis on hard target penetrators would be advantageous.*
- *The increasing effort in submunitions is well warranted by the potential operational payoff of ICM, but the total appears small.*
- *Basic research in fracture mechanics is necessary to assure the reliability of fragmentation rounds. A breakthrough is required in this field, so minor efforts are unlikely to be productive.*

- *FY78 work on smoke and obscurants begins with yet unstructured concept and definition studies.*
- *Considering the likely relative use rates of incapacitating chemical agents, work in chemical munitions appears overfunded. The reason for the large difference between FY77 and 78 is not apparent; changes are distributed over many work units.*

Twenty-one work units account for the $6-7 M worth of R&D on rockets shown in Table III. These efforts address propulsion, structures, and aerodynamic aspects of rocketry, including the Long-Range Guided Missile (LRGM) and General Support Rocket System (GSRS) programs. The work, as detailed in the Army Missile Plan,(10) appears to be making substantive progress; most of the individual work units are expected to be completed with technology demonstrations within the next three years. The existence of an overall plan of action for this area of technology has apparently resulted in a very sound and productive program.

Technology Base efforts on guidance and terminal homing are displayed in Table VIII. In view of the potentially huge return on investment in these areas, the funding may be too light, although the activity appears to be idea-limited at present. New concepts, especially for detecting and homing on armored vehicles, are needed and an active theoretical and experimental program should continue to be pursued. Current approaches included RF, IR, and magnetic sensor technology, but calculations do not yet show that this technology area is well in hand.

TABLE VIII

R&D ON GUIDANCE AND TERMINAL HOMING

	$K	
Topic	FY77	FY78
Guidance		
Inertial	2,128	3,330
DME	500	791
Laser beam rider	380	588
Fluidic actuators	140	160
Homing		
CHAMP	-	1,500
High acceleration terminal homing	278	-
Designator seeking munition	550	578
Target seeking munitions	290	870
Submissile deployment	-	300
Passive IR Seeker	1,000	1,400
Radome materials	191	235
Submillimeter wave research	400	420
Atmospheric optics	78	90
IR reflectance	35	55
Laser induced lumenescence	20	30
Totals	5,990	10,347

Missing in Ref. 1 is the program for the Sense and Destroy Armor (SADARM) munition. Ref. 11 identifies combined funding of $1.72 M for SADARM and the Canard Homing Artillery Modular Projectile (CHAMP). CHAMP requires $1.5 M, so SADARM is only $250 K. These two programs promise a real improvement of indirect fire against moving targets and should be virorously pursued. There are questions relating to the SADARM sensor which has detected tanks at a range of only 200 m which is not enough for operational utility. In view of the severity of operational problems in this area, it is disturbing that CHAMP was unfunded in FY77.

- *Efforts like SADARM and CHAMP should be intensified. Both programs are several years old, but funding levels are still uneven.*

R&D on laser range finders and designators accounts for about $2 M per year, as shown in Table II, and is comprised of a needed effort on a CLGP training device ($200 K) and some 19 individual efforts in laser technology at various wavelengths and configurations. Serious efforts in laser development are badly needed, for the current GLLD program is limited by the industrial production base capacity to build laser with sufficient power output and long life. Power output directly affects the range at which CLGP rounds can be designated (currently only about 3 k), and there is some doubt that a reliable GLLD can be provided in time to meet the COPPERHEAD IOC date. Also, the evident potential for GLLD-like devices to provide rapid survey for siting batteries and individual weapons was demonstrated in the HELBAT tests and should be pursued with vigor. The existing collection of apparently uncoordinated laser device efforts, however, does not seem to offer much assurance that these real needs will be met in a timely fashion.

The EW and ECCM work referred to in Table III is directly addressing problems of effective use of missiles and precision guided munitions. Ten work units are represented here; this appears to represent a reasonable level of exploratory effort, well-timed and keyed to munition developments.

Efforts in protection and logistics account for a very small portion of Technology Base Fire Support activity, as indicated in Table III. The low rate of funding probably indicates a general lack of enthusiasm within the Army laboratory community. Yet, these problems are important in the field. Unless crews are well protected, artillery fire can be suppressed, denying the high rates of fire essential in rapid combat situations. It is probable that successful resolution of this problem hinges more on engineering design than on actual research.

- *Evaluation of current crew protection effectiveness and a plan for improvement should be instigated.*

With respect to logistics, although the three work units address reasonable problems of ammunition handling, no substantial thought is being given to the greater problem of proliferation of projectiles and fuzes which becomes more vexing each year. Here, again, some new ideas and serious operations analysis are required before the problem gets yet further out of hand. Typically, a weapon crew today must cope with a dozen different types of projectiles and fuzes, often keeping track of them by lot number in order to achieve consistent results. The large number of fuze development efforts mentioned earlier is likely to add to the problem rather than diminish it.

- *Logistics systems should be analyzed and new doctrine established to provide a viable guide for developments in this area.*

4.2 Fiscal Budgets and Error Budgets

An informative alternate way of viewing Technology Base activity is in terms of the error budgets of typical weapons. While this approach to the Technology Base does not cover all of the work units involved, some new insights can nevertheless be gained.

For cannon artillery, a representative error budget can be constructed by abridgement of the detailed information for a 155 mm howitzer in Ref. 7. This weapon is selected here because of its familiarity and widespread use, but its relative distribution of error components is typical.

In Table IX, error components are shown along with those portions of Technology Base funding which may be reasonably ascribed as relevant to those components. Comparisons must be made judiciously, however. Allocation of R&D dollars should be in proportion to the payoff of success and to the difficulty of the tasks. Payoff is related to the potential for improvement and not necessarily to the absolute value of a given error. In the absence of formal program planning to achieve stated objectives, it is very difficult to make sound judgments on the appropriateness of budget distributions. Nevertheless, the comparison of fiscal and error budgets can provide a rough idea of equitability and identify gap areas.

TABLE IX

TYPICAL TUBE ARTILLERY ERROR BUDGET* VS. R&D FUNDING
(155 mm Howitzer, Range = 15,000 m)

				$K	
Precision Errors**	%***	Range	Deflection	FY77	FY78
Propellant variations	5	36	-	745	1,572
Projectile variations	7	42	-	2,187	2,480
Weapon tolerances & wear	7	37	18	1,262	1,620
RMS		67	18		
Bias Errors**					
Survey related	1	10	10	50	-
Met: temp., density, wind	46	95	50	1,804	1,055
Crew related	33	(76)	(52)	1,260	1,595
Powder temp. est.		52	-		
Muzzle vel. est.		29	-		
Aiming and laying		32	47		
Registration		35	17		
Technical fire control	1	15	15	1,005	660
RMS		123	73		
			Totals	8,313	8,982

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*This table includes the major effects. A more detailed analysis of error components is given in Vol. III or Ref. 7.

**Error components are given in meters of standard deviation.

***Percentage contribution of variance to CEP.

Error reductions of the order of 50 percent may be feasible and would offer a substantial improvement in performance. On this basis, and by reference to the program details in Ref. 1, we can draw some conclusions. We see, for example, that work units relevant to projectiles and propellants are mainly concerned with improving materials and aerodynamic stability, however,

- *There is no Technology Base effort specifically directed at assuring uniformity of munitions in the field.*

Work units on crack growth, wear, erosion, etc., are addressing reasonable facets of the weapon life problem, but:

- *There is no long-life weapon design project.*

While survey related errors are small, speed of response is an important factor. The potential of laser rangers and designators to cut weapon emplacement time is very good. There is one technology project on this topic, but no evident thrust towards applications.

- *Rapid survey techniques and devices should be pursued more vigorously.*

As discussed in Section 3:

- *Planned work in meteorology will not lead to the effective control of atmospherically driven bias errors.*

The remaining error categories are being effectively addressed in the Human Engineering Laboratory Battalion Artillery Test (HELBAT) series. In HELBAT many advances have been proposed and demonstrated to improve accuracy and speed of response, but the operational sphere is but little affected as yet; although, this widely known and excellent work has been widely briefed in the community.

- *HELBAT related efforts would benefit from the preparation of a consolidated R&D program plan and a closer association with the engineering development community.*

Precision guided munitions and terminal homing may be considered as means of sidestepping the problems exemplified by artillery systems error budgets. This topic was discussed in the previous section, but we may note here that, while much of the technology is common to both cannon and rocket systems, it is difficult to sense much interaction between work units for these different systems.

Turn now to consideration of rocket system error budgets. Table X, taken from the Rapid Fire Area Saturation System (RFASS) Study,(8) shows the error budget for a six-inch diameter GSRS. The data are drawn from theoretical calculations, test data, and experience with the HONEST JOHN and LITTLE JOHN rockets, and appear to be representative. Individual errors for larger rockets, eight- or ten-inch diameters, differ in detail, but the overall picture is unchanged. The data are for a range of 30 km. Dollar figures are drawn from the Army Missile Plan.(10) Parentheses indicate work relevant to reduction of more than one error component.

TABLE X

GSRS ERROR BUDGET VS. R&D FUNDING

				$K	
Precision*	**%***	**Range**	**Deflection**	**FY77**	**FY78**
Total impulse	5	94	0	634	575
Malaim	1	4	29	(2,515)	(1,835)
Ballistic coefficient	8	123	0	2,610	1,965
Fuze	.3	22	0	-	-
Angle**	39	29	271	2,515	1,835
RMS		159	272		
Bias*					
Malaim	1	4	29	(2,515)	(1,835)
Density	14	166	0	-	-
Ballistic wind	28	180	147	(340)	(320)
Surface wind	4	5	87	340	320
RMS		245	173		
			Totals	6,099	4,695

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[*] Error components are given in meters of standard deviation.

[**] Includes mallaunch, dynamic unbalance, thrust malalignment.

[***] Percentage contribution of variance to CEP.

Ref. 10 makes a good case for the appropriateness of the funding distribution. No outstanding gaps are evident except for the meteorological R&D noted earlier. Fuzes are not addressed in the Army Missile Plan, but an adequate capability for fuze development exists elsewhere. Review of the rocket and missile work units in Ref. 1 indicates a well-balanced program. We may note, however, that precision error contributions associated with impulse, ballistic coefficient, and "angle" depend in a large part on manufacturing technology and achieved tolerances. MIRADCOM has no specific program in this area and, perhaps, could benefit from a closer association with ordnance makers. If rockets come into their own, these error sources will demand tight control at the manufacturing level.

5.0 MANAGEMENT ISSUES

5.1 User Perceptions of Technology Base Efforts

The interests of DRCBSI are concerned with improving the user-developer dialogue as well as ensuring battlefield effectiveness. It is appropriate then to provide here some observations relevant to that problem. Ref. 1 identifies the TRADOC proponent for each Technology Base work unit. These proponents have reviewed the efforts and assigned priority designators according to the following scheme:

A - Critical
B - Essential
C - Required
D - No Specific Interest

The results of this evaluation are interesting and illuminating. One infers that, in the user's view, the Technology Base efforts are largely misdirected, for among the more than 2,000 work units reported, only 12 are rated as critical, and 181 are rated essential. The vast majority (two-thirds) of the work units receive a C grade, while nearly one-fourth are graded D. Table XI shows this result as broken down by Army Mission Areas.

The figures indicate a broad consistency of opinion among the various TRADOC elements which reviewed the work units. In an attempt to understand the details of this evaluation, and because the focus of interest in this report is the First Support Mission Area,

TABLE XI

ANALYSIS OF USER PROPONENT ASSIGNED PRIORITIES BY NUMBER OF WORK UNITS AND ARMY MISSION AREA

	Priority Ratings					
Mission Area	A	B	C	D	Totals	GPA*
Close Combat	6 (1%)	33 (6%)	308 (57%)	197 (36%)	544	1.72
Other Combat Support		26 (9%)	214 (73%)	54 (18%)	294	1.90
Combat Service Support		20 (6%)	229 (65%)	101 (29%)	350	1.77
Fire Support	1 (.5%)	27 (12%)	121 (56%)	68 (31%)	217	1.82
Air Defense	2 (1%)	32 (21%)	108 (70%)	12 (8%)	154	2.16
ISTA	3 (2%)	36 (20%)	114 (63%)	29 (16%)	182	2.07
Command Systems		7 (3%)	174 (90%)	13 (6%)	194	1.97
Program-Wide Support			51 (100%)		51	2.00
Other Logistics			19 (80%)	5 (20%)	24	1.79
Ballistic Missile Defense			30 (100%)		30	2.00
Totals	12 (.6%)	181 (9%)	1368 (67%)	479 (23%)	2040	1.87
Approximate Fiscal Equivalents	$2M	$24M	$184M	$64M	$274M	

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*GPA indicates "Grade Point Average" computed on the basis of A = 4, B = 3, C = 2, D = 1.

the priorities assigned by TRADOC in Fire Support were further broken down by DARCOM laboratory. It should be noted that within this mission area, 80 percent of the priorities were assigned by the Field Artillery School (FAS). No consistent differences between FAS and the other raters are discernible, however. Table XII shows the TRADOC priorities assigned to various DARCOM organizations, in terms of the FY77 funding levels.

One trend is evident in Table XII. It is that those work units graded "critical" or "essential" cost more. They average $270K each, vice $155K for units prioritized C and D. Presuming that the implicit priorities of DARCOM laboratory directors are reflected in funding levels, the trend noted here indicates at least a rough agreement between DARCOM and TRADOC as to the relative importance of many of the technology base work units.

A somewhat surprising result of Table XII is the below average rating of MIRADCOM. The Army Missile Command has an excellent reputation, a well-respected laboratory director, a good record of technical achievement, a modern outlook, and appears to be organizationally responsive. Why, then, the low rating? In an effort to understand this, a more detailed look at the MIRADCOM projects was undertaken.

An independent evaluation of the MIRADCOM work units was made, attempting to assign priority ratings based on the potential contribution to combat effectiveness of each of the efforts. This

TABLE XII

ANALYSIS OF USER PROPONENT ASSIGNED PRIORITIES BY $K (FY77) WITHIN VARIOUS DARCOM ORGANIZATIONS; FIRE SUPPORT MISSION AREA

	Priority Ratings						
DARCOM Organization	A	B	C	D	Total $K	Number of Work Units	GPA
MIRADCOM		2,061	6,739	3,301	12,101	53	1.90
LCWSL	250	817	4,534	1,407	7,008	37	2.02
EWA			3,301	802	4,121	24	1.80
BRL		310	1,750	625	2,685	19	1.89
HDL		285	1,160	1,087	2,532	26	1.68
ARRADCOM		246	1,776	238	2,260	18	2.02
ASL		1,250	484		1,734	5	2.72
EWL		1,141	395		1,536	9	2.74
SCWSL		747	280		1,027	8	2.73
AMMRC			546	109	655	10	1.83
HEL		493	100		593	2	2.83
MERADCOM			375		375	2	2.00
NARADCOM			160		160	1	2.00
CS&TA				155	155	3	1.00
Totals by $K	250	7,350	21,600	7,724	36,942		2.00*
Totals by Work Unit	1**	27	121	68		217	

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*The grand grade point average here is computed on the basis of budget allocation, rather than by number of work units as reported in the preceeding table.

**The sole work unit rated "Critical" is titled, "Closed Loop Fire Support Systems, Region II."

evaluation resulted in an overall rating of 2.8, corresponding to a priority of B, the "essential" category. It is probable that many of the differences between the two evaluations are based on differing perceptions of the meaning of the rating terms. In general, however, the SPIDER Charts tend to report lower assigned priorities to work units which are more theoretical in nature or have payoff in the more distant future. In any event, it would be wise to assure that the full potential of scientific work is considered before it is deleted because of lack of apparent user interest.

These differences are, perhaps, not unexpected, given the professional proclivities of all the raters, but they do point up the need for better communication and mutual understanding between users and developers. The motivational and perceptual differences between these two groups are at the heart of the problem of ensuring a smooth transition between research on the one hand and operational adoption on the other.

It would be highly simplistic to categorize the R&D community as "blue sky" or the operational community as lacking vision. What is really needed is a better appreciation by each of the other's problems. One obvious suggestion is for laboratory directors to review carefully the priority ratings assigned by TRADOC proponents and establish more personal contacts in the user community, both to explain their R&D motivations and rationale and to discover at firsthand the problems of field operation. On the other side of the coin, the operational community should be encouraged to take a more scientific, less pragmatic, approach to their problems, enlisting, where possible, the services of the Army laboratories. The HELBAT exercises are a well-known example of the type of profitable interactions which can arise from such an approach.

In this same spirit, it would be interesting and valuable to collect the opinions of DARCOM Program Managers on Technology Base efforts. This could provide a useful retrospective view of the laboratories, as well as some guidance for future exploratory development work. The ensuing dialog could do much to strengthen the bridge between the 6.3a and the 6.3b-6.4 budgets and ensure that the relatively small technology base budget has its proper impact on the Army's $15B, RD%&E and procurement budgets.

5.2 Structure of Technology Base Efforts

Analysis of the DARCOM SPIDER Charts(1) provides many interesting insights and some causes for concern. The theme of user-developer communications (and the apparent lack thereof) was introduced in an earlier report,* where it was observed that, for

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*Technology Base Activities Relevant to RSTA Systems Problems, MITRE Working Paper, WP-12231, 25 March 1977.

the Reconnaissance, Surveillance, and Target Acquisition (RSTA) Mission Area, there seems to be little in the way of formal program organization to resolve Army problems. This same general observation can be made in the Fire Support Mission Area. Examination of work units in the context of systems, subsystems, and operational capability requirements provided by Ref. 1 yields several perceptions:

- Considered individually, work units are of clear potential military relevance.
- Planning and program organization to remove operational deficiencies are not evident.
- A progression of efforts from 6.1 through 6.3 is not apparent. (The next edition of Ref. 1 will show a five-year funding pattern which will be helpful in this respect.)
- Science and Technology Objectives Guides provide justification for all work units, regardless of their apparent importance.

The general lack of structured program planning is subjectively apparent, but also turns out to be real, although there are notable exceptions. AARADCOM apparently has come to the same conclusions: Their FY78 Technological Base Plan(9), published in April 1977, lists as new objectives:

- Restructure existing programs to reconcile with the "new way of doing business."
- Achieve early exploitation of existing technology, proof of feasibility of technology concepts, and transfer to 6.3a.

- Establish the basis for continual flow of new science (6.1) and technology (6.2) with preplanned transfer.
- Establish a comprehensive, continuing systems engineering program to provide for most effective allocation of resources and comparative evaluation of concepts.

In discussing AARADCOM's Artillery Systems Study project, the same document says:

> "The basic objective is to make up for lost time in identifying the real needs of artillery so that technology base efforts can be applied to provide major improvements in artillery weapons systems. To do this we need to develop a hierarchy of models to conduct various levels of systems studies; these models should also be suitable for development decisions on artillery weapons on a continuing basis. Meeting the objective may also require us to plan, coordinate, conduct, analyze, and support experimental studies pertinent to artillery systems performance."

Such sentiments indicate a laudable, if somewhat tardy, trend toward identifying R&D efforts with their potential contributions to combat effectiveness and structuring programs to be maximally useful.

A comprehensive planning document relevant to fire support is to be the Army Missile Plan (AMP)(10) prepared by MIRADCOM as a management tool and overall planning guide for the Command. This document covers over $100M of laboratory efforts, showing clearly and convincingly where individual programs are heading and why and how. AMP describes weapon system concepts under development, analyzes their deficiencies, and structures technical responses to these deficiencies. System priorities are established and related to Army and JCS goals and priorities, and tasks are ranked accordingly. R&D is clearly keyed to the development cycle, and the contribution of fundamental work units to multiple developments is made clear. Basic research (6.1) is rationalized and justified in a convincing manner. The relationships between work units, projects, and programs are made apparent. Latest technology availability dates are included, so that one can estimate when weapon concepts can transition to advanced or engineering development. AMP also contains a section evaluating itself, which identifies some deficiencies and proposes improvements for the next edition. Altogether, the Army Missile Plan is a thorough, helpful, and above all, a convincing document which provides a basis for the management of Army R&D within its sphere. MIRADCOM and its products can easily be measured through the AMP, which also provides a suitable background for zero-base budgeting and Congressional testimony.

The particular format adopted by the AMP is not important, although it could provide guidance to other laboratories developing parallel plans. Indeed, due to its modular construction, AMP is occasionally frustrating. Its information content is uncommonly high, however, and DARCOM would do well to assure that similar documentation is available throughout the Technology Base community. The effort so expended would be amply repaid by the increased relevance of R&D work units and their eventual contributions to combat effectiveness.

5.3 Science and Technology Objectives Guide

As the Science and Technology Objectives Guide (STOG)(9) is emerging as a major document of reference for the motivation and justification of Technology Base programs, it is worthwhile to devote some attention here to the STOG response in the Fire Support Mission Area. As was noted above, it seems to be excessively easy to justify work units by reference to a particular STOG paragraph, but this is not the only shortcoming. Many of the STOG entries provide excellent statements of appropriate technology base work, neither overly constraining nor excessively general. Unfortunately, however, the numerical prioritization system adopted is somewhat confusing, so it is difficult to gain an appreciation of the contribution to combat effectiveness of successful prosecution of a particular STOG paragraph. Developer proponents are, however, required to reorder their programs around STOG guidance and provide analyses of feasibility and planned technological solutions. This planning activity, if well done, will add a new and useful dimension to the assessment of ultimate utility of Technology Base work.

Within the fire support area, a few of the STOG 78 paragraphs call for system developments which are mainly of an engineering nature. Basically, such guidance may be misdirected to the Technology Base community. Examples include:

78-4.1	New Medium Mortar System
78-4.5a	New SP Artillery Weapon
78-4.5e	Crew Protection
78-4.7	Packaging and Handling Equipment

78-4.8 New Armored Self-propelled Field Artillery Weapon

78-4.9 Increased Survivability of Non-armored Systems

The needs expressed here are very real and could be satisfied by establishing directed programs. Such efforts could distract, however, from the future-oriented work which should be the main focus of the Technology Base. This is not to say, of course, that the Technology Base should not contribute to these programs, but the primary responsibility might better lie elsewhere. It is worth noting that the laboratories do not respond vigorously to STOGs of this type; three of the six items mentioned above are completely unfunded, while the other three account for only some $300 K in FY77.

STOG 78-4.2h is curious. It calls for automatic alignment and loading systems for a sustained rate of fire of eight rounds per minute. Note, however, that M6-40, "Field Artillery Cannon Gunnery,"(13) states that the sustained rate of fire for 155 mm weapons is one per minute and, for eight-inch howitzers, is one per two minutes. These figures are based on thermal limits of the tubes and represent many years of experience. Apparently, more than alignment and loading systems will be required to achieve high rates of fire.

R&D guidance in the Fire Support Mission Area is consolidated in STOG 78-4. Table XIII shows the response to STOG 78 by percent of total fire support technology base funding.

Perusal of this table indicates that more than 80 percent of the available funding is indeed being spent on the most important problem areas of range and accuracy. The most notable underfunded area is 4.21, anti-radiation missiles, where a concerted effort should be encouraged. (It should be noted, however, that some relevant work is to be found under STOG 78-4.2a.)

STOGs 78-4.2a and 78-4.2b justify nearly half of the total fire support technology base budget, and this is entirely appropriate in view of the Army's increased emphasis on the Zone II problem, which depends heavily on indirect and unobserved fire techniques. Presuming technological success in this area, the issue of when to cease firing will surely become more important, and we find neither STOG guidance nor research on this problem.

- *It is recommended that the question of battle damage assessment in the Zone II context be studied and that a STOG paragraph be devoted to this.*

The present "tactical constraint" criteria, as used in the BATTLEKING Report,(12) is essentially to devote three minutes worth of battalion fire to high worth targets and three minutes of battery fire to low worth targets. These criteria may lead to either insufficient or excessive response in many cases. The issue here is not so much one of conserving ammunition (although that is important), but of utilizing fire units efficiently so that the rate of target engagement can be maximized. Only in this manner can the Army compensate for its numerical disadvantage.

TABLE XIII

DISTRIBUTION OF FIRE SUPPORT FUNDING BY STOG 78-4 CATEGORY

STOG 78 Paragraph	Topic	% of Funds Allocated
4.1	New Medium Mortar	<2
4.2a	Passive Seekers, CLGP, ECM	24
4.2b	Multiple Rocket Systems	22
4.2c	New Munitions Concepts	17
4.2d	High Fragmentation Casings	2
4.2e	1:1000 Survey	0
4.2f	Near Real-Time Met	5
4.2g	Muzzle Velocity Correction	0
4.2h	Auto Alignment and Loading	<1
4.2i	Common Projectile From Air and Ground	<1
4.2k	Improved Smoke Munitions	1
4.2l	Anti-radiation Missile	0
4.3	Increased Range	8
4.4	Rapid Response Fire Support	11
4.5a	Mobile SP Artillery	0
4.5b	Howitzer Reliability	0
4.5c	Soft Recoil	2
4.5d	Tube Wear	<1
4.5e	Crew Survivability	<1
4.5f	Reduced Muzzle Signature	0
4.6	Target Acquisition	4
4.7	Ammunition Packaging, Handling	<1
4.8	Armored SP Artillery Weapon	0
4.9	Survivability of Non-armored Systems	0
4.10	Earth Penetrator Warhead	<1

This battle damage assessment problem, with its vast operational and fiscal implications, is a good example of the importance of soundly constructed R&D efforts and the multiplier effect of R&D funds. In early combat stages, a division is expected to expend some $4.5M worth of 155 mm HE ammunition per day (12,000 rounds @ $375 each). If funding equivalent to a corps' single day's worth of ammunition expenditure could double the effectiveness or the number of targets successfully engaged, the impact would be enormous.

In summary, the STOG appears to be a useful document to motivate and justify technology base efforts. It is, however, as yet, far from perfect, incomplete in some areas, and possibly misdirected in others.

- *STOG would be a more useful management tool if the scientific and technical aspects were more highly stressed, and this could probably be achieved by involving the laboratories themselves in the construction of the document.*

APPENDIX I

PARAMETRIC VARIATIONS ON AMMUNITION RATES REQUIRED TO KILL REPRESENTATIVE TARGETS

1.0 INTRODUCTION

Section 3 of this report contains examples of the ammunition costs that would be required to destroy a representative fixed soft target in Zone IIa by a howitzer and by rockets. In this Appendix some parametric variations are presented which amplify the earlier discussion.

A thorough analysis of combat effectiveness would require extensive simulation and war gaming which is well beyond the scope of this report. The elementary analysis used here (which is described mathematically in Appendix II) is a shortcut method of estimating effectiveness. It neglects the interaction of weapons but focuses on those parameters which contribute most directly to individual weapon accuracy. Understanding the effects of varying these parameters then enables one to make comparative, if preliminary, judgments on the prospective value of R&D thrusts.

In order to avoid the proliferation of numerical results only a restricted number of target and weapon types are considered. The FORTRAN computer program described in Appendix II has wider capabilities, however, and could be used to address other problems. The parameters of the analysis are:

Munition lethal radius

Weapon precision, expressed in standard deviations of the dispersion pattern about MPI

Bias errors, input as absolute distances in range and deflection

Target location errors, expressed as standard deviation of the target location system

Number of weapons firing simultaneously

Individual weapon aim points.

The first four of these items are technology driven, while the last two are primarily matters of doctrine. The focus of this report being on technological matters, the first four parameters are of primary interest and various modes of fire are investigated only to assure that the conclusions on technology remain valid for different tactical situations. While most artillery fire is done in a parallel sheaf mode, calculations are included here for converged sheaf and area fire doctrines also. The results of these calculations show differing effectiveness, of course, but the main trends persist so far as technology development is concerned. While the percentage differences between effectiveness in various modes of fire are relatively small with current values of target location error, the calculations suggest that if TLE is reduced, it may be worthwhile to change doctrine and seek more effective modes of using weapons. The application of new technology for automating weapon laying and computing special corrections will make it feasible to adopt more efficient techniques in the field.

2.0 EXAMPLES OF CANNON FIRE

2.1 Effect of Firing Doctrine for Different Bias Errors

Figure 1 of Section 3 shows the ammunition cost to kill a representative soft fixed target by parallel sheaf fire as a function of TLE and bias error. To fix ideas, the munition lethal radius is 25 m, and the weapons are spaced in a "lazy W" formation 200 m wide and 60 m deep. HE rounds costing $375 each are assumed. For range and deflection bias errors of 120 m and 70 m respectively (chosen to be representative of a 10 kt. wind at 45° to the trajectory), it can be observed in Figure 1 that the ammunition expenditure increases slightly as target location errors approach zero. This is because an accurately located target (small σ_T) has a low probability of actually being far from its designated position. Thus, when bias errors are large, only the tail of the projectile impact distribution function covers the likely target position so that few of the rounds fired will be effective. A less precisely located target, on the other hand, has a larger probability of actually being closer to the biased mean point of impact so that, on the average, more of the rounds fired will land in the target vicinity. When bias errors are small and when a finite radius of lethality is taken into account the effect becomes numerically insignificant as indicated by the lower two curves of Figure 1.

However, the effect is much more severe in the case of converged sheaf fire, as might be imagined. Figure I-1 compares the costs

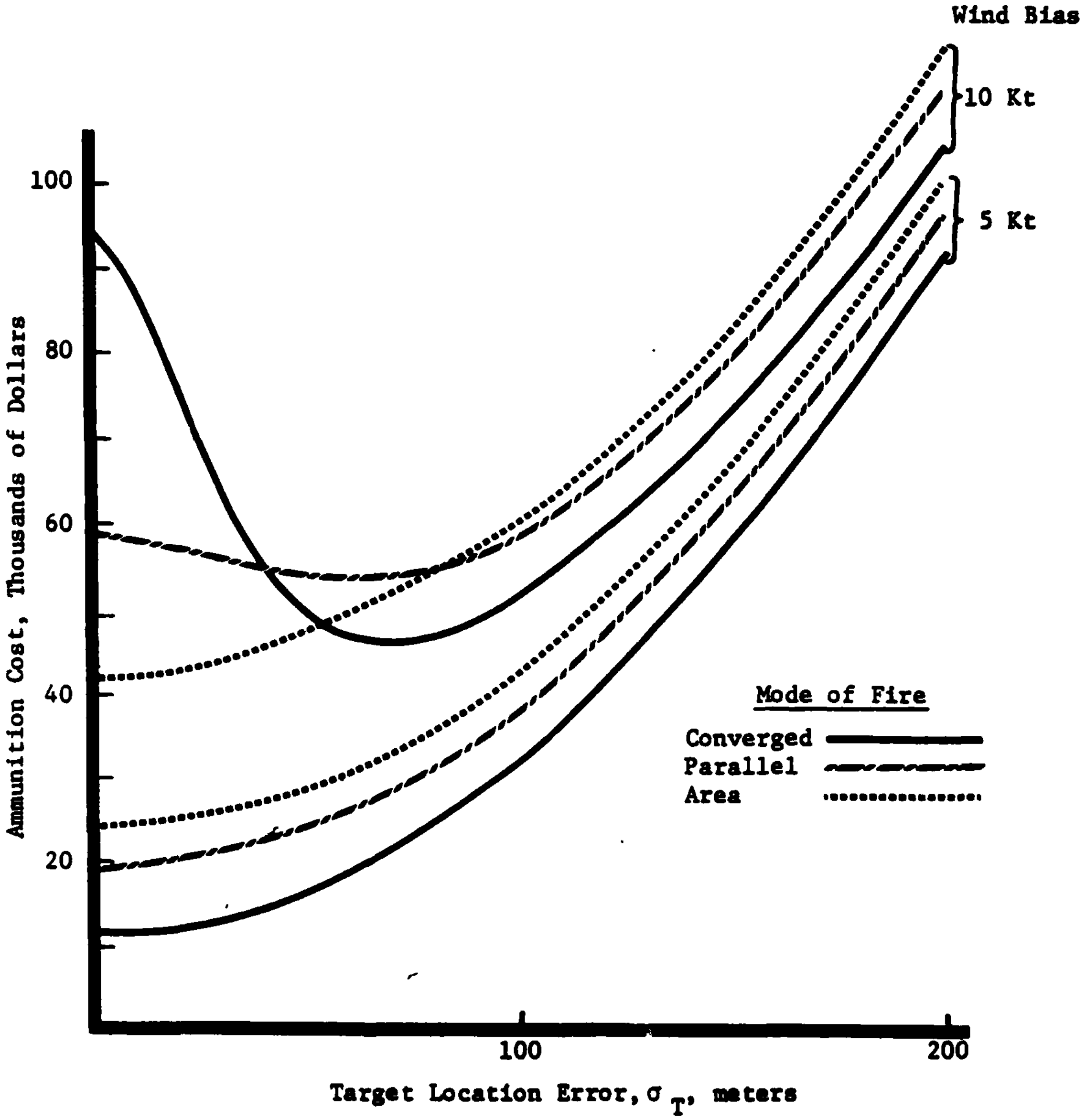

FIGURE I-1
EFFECTS OF FIRING DOCTRINE AND BIAS ERROR

associated with parallel sheaf, converged sheaf, and area fire when addressing the example soft fixed target described above. Area fire is simulated by a group of five parallel sheaf volleys spaced 50 m apart. Large biases are very damaging to the effectiveness of converged sheaf fire, but this tactic is always the most effective for small biases. When adjusted fire techniques are available (generally not in Zone II) the inhibiting effects of large bias errors can, of course, be eliminated. This highlights the desirability of a method to observe impacts and damage inflicted in Zone II.

2.2 Effect of Weapon Precision

To investigate the potential benefits of technological advances which may make the weapons themselves more precise, we calculate the costs required to kill a target for several values of weapon preciion. In order to provide a ready basis of comparison with the other calculations, a base case problem is selected and variations in weapon precision are considered relative to that. The conditions of the base case problem are:

Range: 15 km
Target: Fixed; soft
Munition: HE rounds, at $375 each
Lethal Radius: 25 m
Weapons: Six gun battery of 155 mm howitzers
Doctrine: Converged sheaf; fire repeatedly until a cumulative kill probability of .8 is achieved
Weapon Precision: Standard deviations of 75 m and 38 m in range and deflection respectively
Bias Errors: 60 m in range, 35 m in deflection

These conditions are representative of current practice. The bias errors represent the effects of a 5 kt uncompensated wind blowing at 45° to the trajectory. Refs. 7 and 8 show that these values correspond to one standard deviation of bias error due to two-hour staleness of met information. The weapon precision figures are in accord with values given in Refs. 2, 7, and 12 which indicate a characteristic 2:1 elliptical scatter pattern about a mean point of impact.

Figure I-2 shows the results of calculations for various values of weapon precision. In all cases shown, the 2:1 ratio of range to deflection precision has been retained, although the results are not very sensitive to this. From the calculations we may conclude that 25 m improvements in range precision are worth approximately $3K, or slightly in excess of one volley fired. (The curves should really proceed by $2.25K steps, as partial volleys would not be fired in practice. For the purposes intended here, the difference is academic.) The worth of better precision is nearly independent of TLE except in the lower ranges, where it becomes negligible due to the controlling influence of the bias errors assumed. Indeed, for very precise weapons and target locations, we see that the bias completely destroys the system effectiveness. Area fire techniques, which can be thought of as artificially increasing dispersion, recoup some of this loss when TLE is small, but are otherwise not advantageous as was indicated in the preceding figure. Comparing

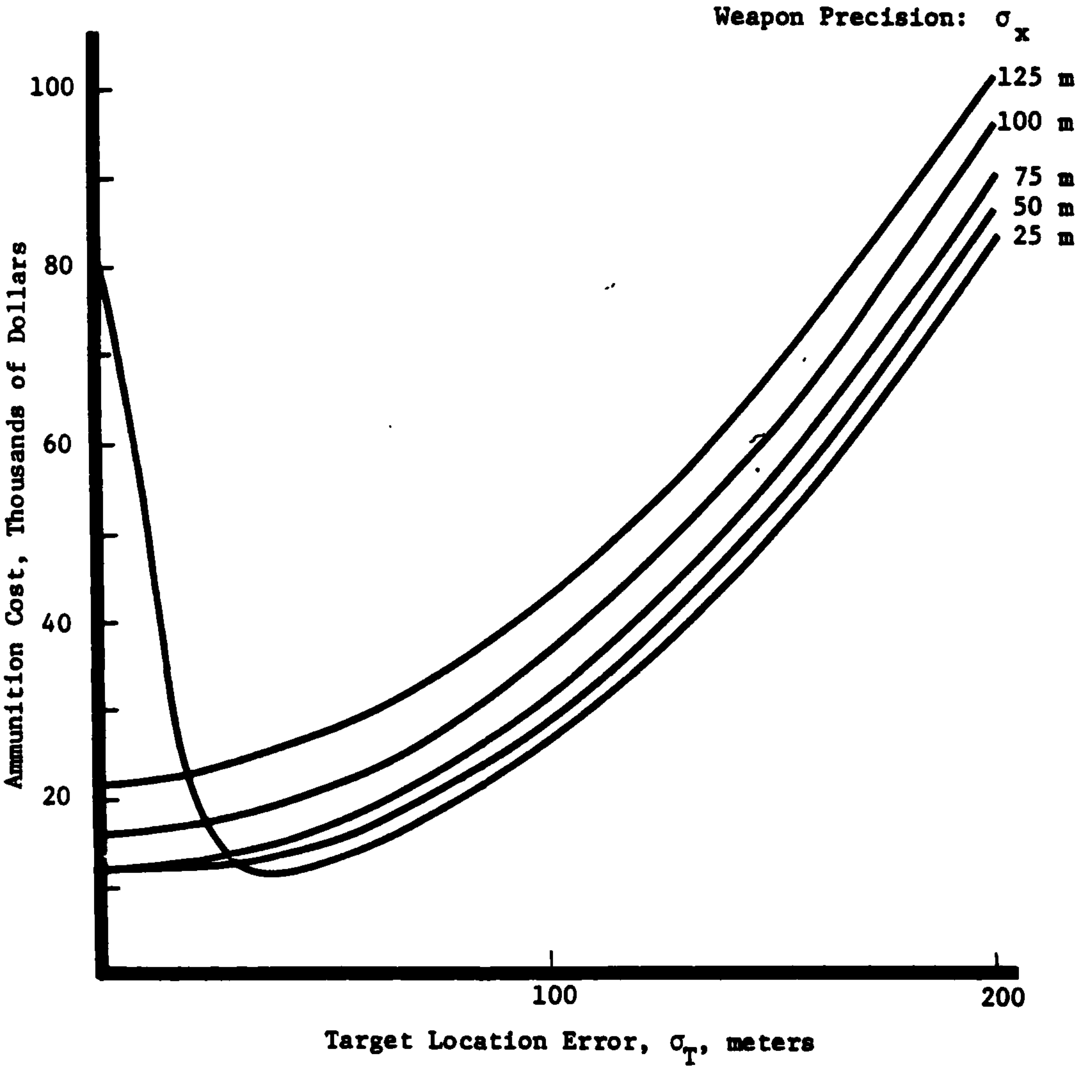

FIGURE I-2
EFFECTS OF WEAPON PRECISION

Figures 1, I-1 and I-2 we can conclude that the worth of improved precision is vastly less than that of improved TLE or bias errors. Open sheaf or area fire techniques obliterate the differences due to weapon precision for the range of parameters considered here.

2.3 Effect of Lethal Radius

Lethal radius, of course, depends on both target hardness and the projectile itself. Figure I-3 shows the effect of variations of this parameter relative to the same base case assumed previously. The value of improved conventional munitions (ICM) is clear, as is the high cost of shooting at hard targets. The number of rounds required is almost inversely proportional to the lethal area for the range of TLE investigated.

2.4 Effect of RAP Rounds

Rocket assisted projectiles (RAP) offer two useful advantages. Because they require a smaller propellant charge to achieve a given range, their use at shorter ranges is less stressful to the weapons themselves. This fact has a real influence on tube life and is an important consideration. The analysis used here is not detailed enough to include tube wear factors, but the utility of RAP rounds in extending range can be modeled to a degree.

To perform cost calculations for RAP rounds, the base case has been altered in two respects: the cost per round is taken to be \$545, and the weapon precision factors are increased by one-third to account for the increase in range from 15 to 20 km. (Weapon precision is almost linearly dependent on range.)

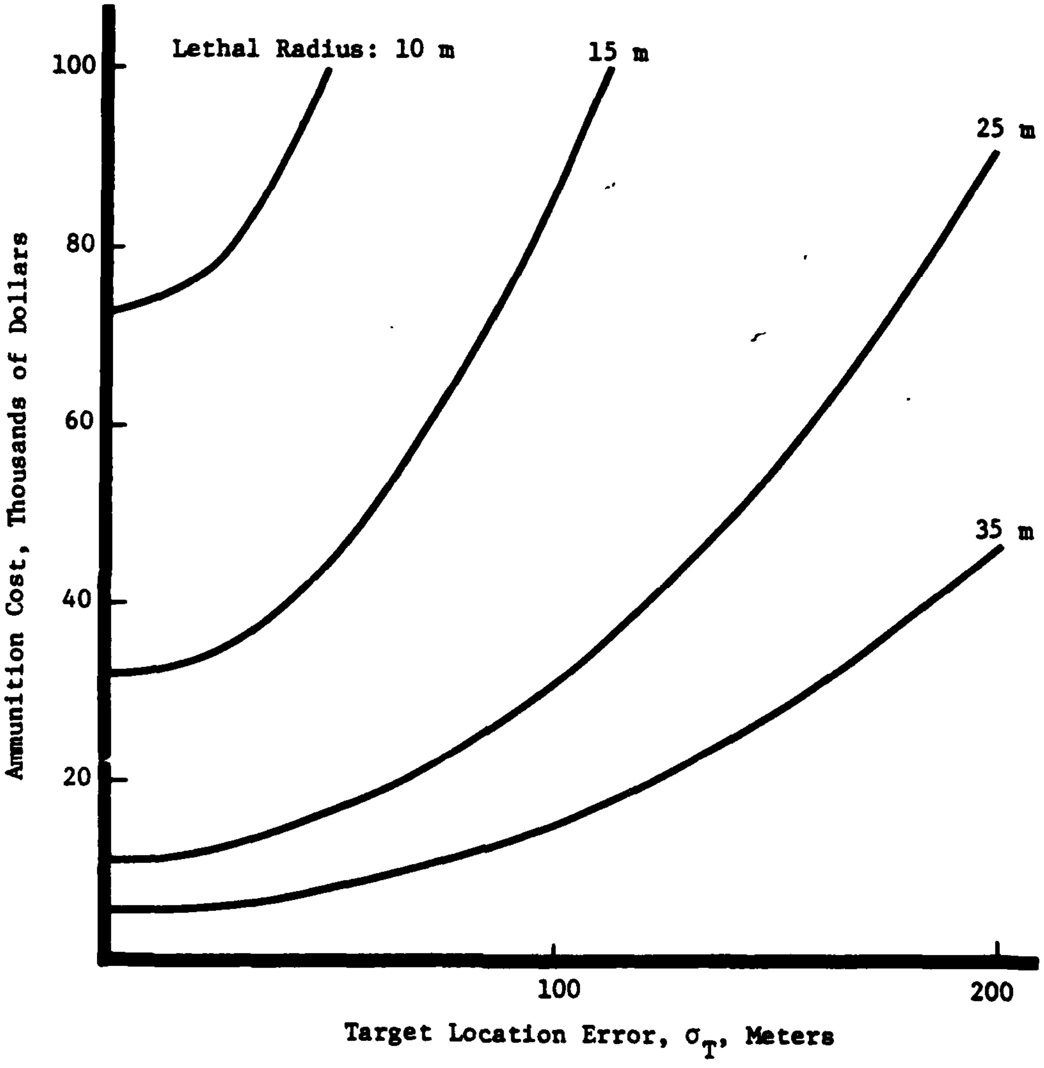

FIGURE I-3
EFFECTS OF LETHAL RADIUS

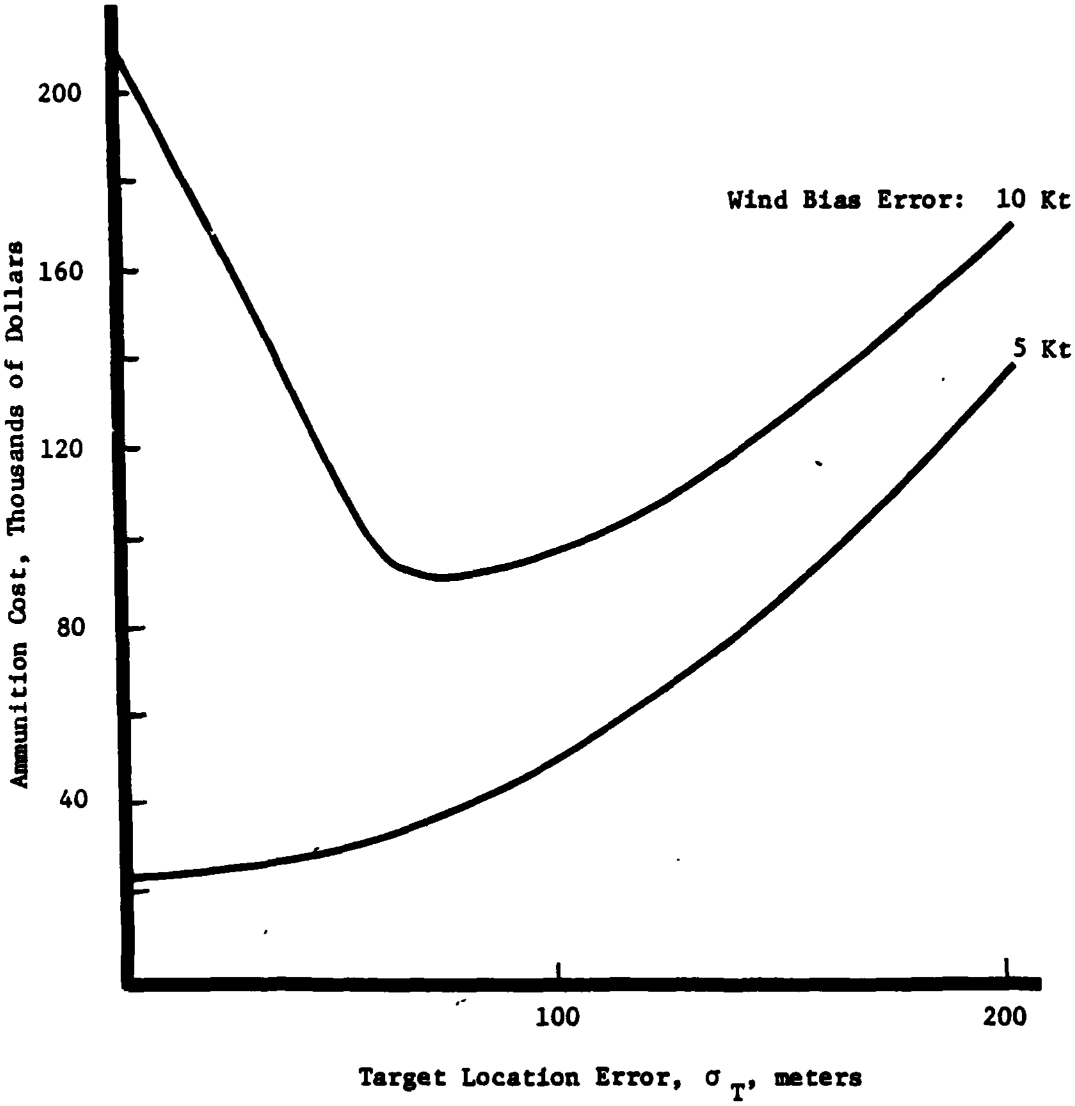

FIGURE I-4
AMMUNITION COST TO KILL BY RAP ROUNDS

The results are shown in Figure I-4, and are not really surprising. The central conclusion is that fire at greater ranges is much more costly; up by about a factor of two from the base case. Zone II combat is going to be expensive by any measure. Again, the bad effect of large bias errors is evident, although as before, area fire is helpful in recovering part of the losses.

2.5 Effect of Moving Hard Targets

The effectiveness model used here can give only an indication of the difficulty of addressing targets such as tanks. As variations from the base case to convert it to a tank target simulation, let the lethal radius be 5 m and the range and deflection bias errors each be 100 m. These bias errors can be interpreted as representative of the motion of the target (at 10 kmph) during the time of flight of the projectile over a 15 km range. That is, we make the implicit very favorable assumption of instant battery response when the target has been located. TLE is assumed to be only 30 m, and an improved gun with 50 m standard deviation in range dispersion is postulated.

Even with these highly optimistic assumptions on system performance, the calculated single volley kill probability is only 10^{-4}. Thus, even if the target always remained within a 150 m radius of its originally located position, about 2500 volleys or \$5.5M worth of ammunition would be required to achieve an 80 percent assurance of kill. If an area fire technique is adopted, the average single volley kill probability improves, but by less than a factor of 10, and over

100 volleys are still required. Noting that this represents about two hours of fire by a single battery, the ineffectiveness of cannon artillery against tanks is evident. Any resolution of this problem will have to be in terms of terminal homing munitions.

3.0 EXAMPLES OF ROCKET FIRE

3.1 Effects of Bias, Precision, and Lethal Radius

Table X gives an error budget representative of GSRS, and the performance of this system has been indicated in Figure 2. It is scarcely worthwhile to display graphically the effects of varying the parameters of the calculation for they can be reduced to a few simple rules. Summarizing the results of a series of calculations, it can be said that:

- Halving the bias errors halves the cost to destroy the base case target, independent of TLE, in the range shown in Figure 2.
- Halving both the precision and bias errors improves the cost effectiveness by a factor of about 2.5.
- Halving only the precision error reduces cost effectiveness for small TLE, and barely influences costs for TLE in excess of 100 m (the same general effect as illustrated for cannon artillery in Figure I-2).
- Doubling lethal radius doubles the cost effectiveness over the whole range of TLE.

The general behavior of rockets and cannons is thus seen to be very similar, despite the apparent wide divergence of their accuracy parameters.

3.2 Comparison of Cannons and Rockets

It is of some interest to compare the performance of cannons and rockets at a range at which the two systems can compete. Figure I-5 shows the costs to address the base case target at a range of 15 km using HE rounds, RAP rounds, and both free and guided rockets. Rocket

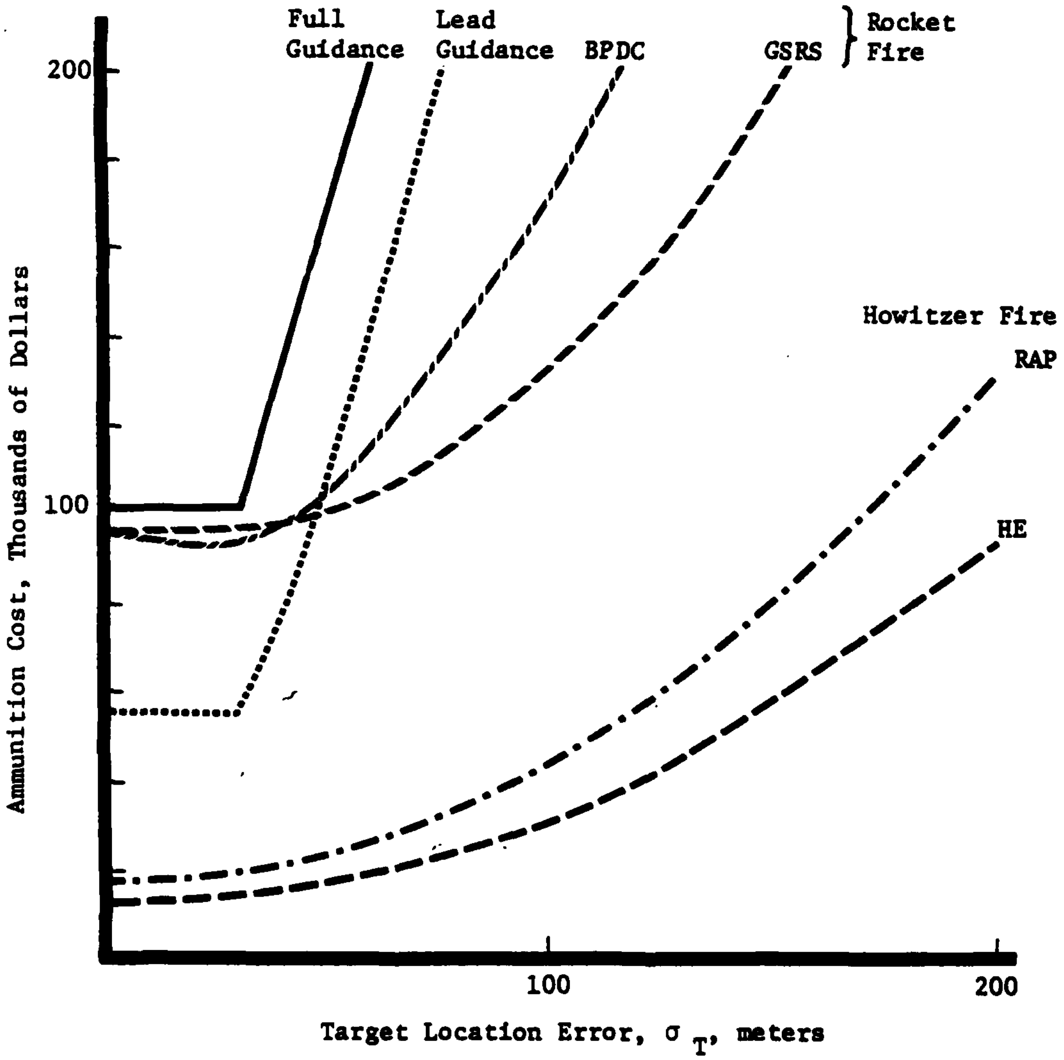

FIGURE I-5
COMPARISON OF CANNON AND ROCKET PERFORMANCES

accuracy parameters are taken from Ref. 8. Rocket costs, per salvo of ten, are $10 K for free rockets, $20 K for boost phase direction control (BPDC) rockets, $100 K for fully guided rockets, and $55 K for full guidance on the lead rocket only with follower guidance on the remainder of the salvo. As described in the main text, two mil accuracy is assumed for the intertially guided systems. HE rounds and RAP rounds are again costed at $375 and $545 each. This comparison is not quite fair to the RAP, however, as no allowance is made for the increased tube life which RAP may give. In all of these calculations, the lethal radius is taken as 25 m, and the characteristic 5 kt wind is presumed to be acting.

On the basis of the results shown in Figure I-5, there is not much of an argument for the use of rockets at ranges attainable by cannon artillery. However, if costs of guided rockets can be reduced and small TLE is achieved, they may play a viable role at shorter ranges because of their relative mobility.

4.0 AREA TARGETS

As indicated in Appendix II, the analytical problem of addressing area targets is much more complex than that of point targets. Moreover, the results exhibit the same general trends, so that it is valid to draw inferences, at least for the purpose of judging the Technology Base, on the basis of the results already presented for point targets. Nevertheless, it is of interest to examine some numerical results for the case of cannon fire against a representative area target.

The case chosen for analysis is shown in Figure I-6, which depicts an air defense battery being addressed by three batteries of 155 mm howitzers at a range of 15 km. Within the target complex there are four missile transporter-erector launchers (TEL) and a directing radar vehicle. Each of these elements is of itself a relatively soft target for which a lethal radius of 25 m is appropriate for base case

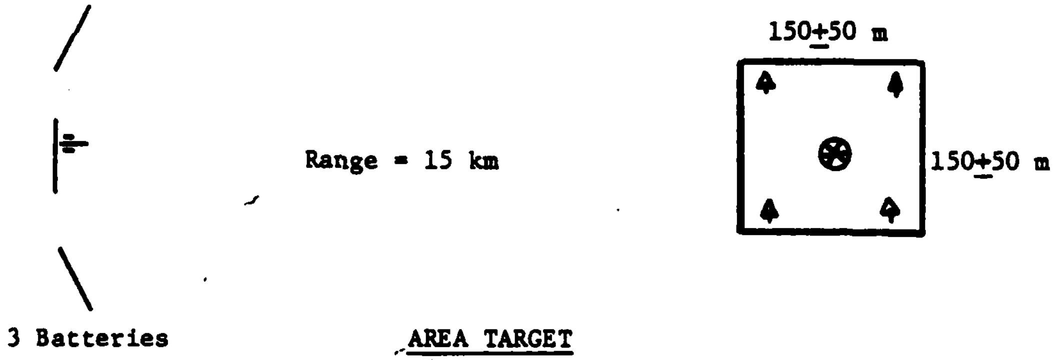

FIGURE I-6
REPRESENTATIVE AREA TARGET

calculations. The artillery batteries are presumed to fire in unison at a given time-on-target command. Their mode of fire is by parallel sheaf of width 250 m, and battery aim point centroids are displaced from each other by 50 m so as to cover the target area effectively. The target complex is supposed to be located by RF means, i.e., the emitting radar is located. It is representative of actual practice to take the four TELS as symmetrically disposed with respect to the radar. Weapon precision, bias errors, TLE, and projectile lethality are taken to be the same for all weapons firing, and calculations were made for various values of these parameters.

The cost of ammunition to service this target is shown in Figure I-7. The kill criterion on which these costs is based is an 80 percent assurance of destroying two of the five target elements. The costs are lower than indicated in the previous examples of cannon gunnery, primarily because of this less stringent kill requirement.

Examination of the figure indicates that the dependence on target location accuracy and wind bias error is qualitatively the same as for point targets, although the effect of a five-knot wind is somewhat less debilitating than for a point target. It should be noted that the curves of Figure I-7 should actually proceed by \$6.75 K steps (the cost of one battalion volley). The data shown are smoothed between steps for clarity. Overall, a factor of three improvement in performance can be obtained by control of meteorological and target location errors. It is again emphasized, however, that

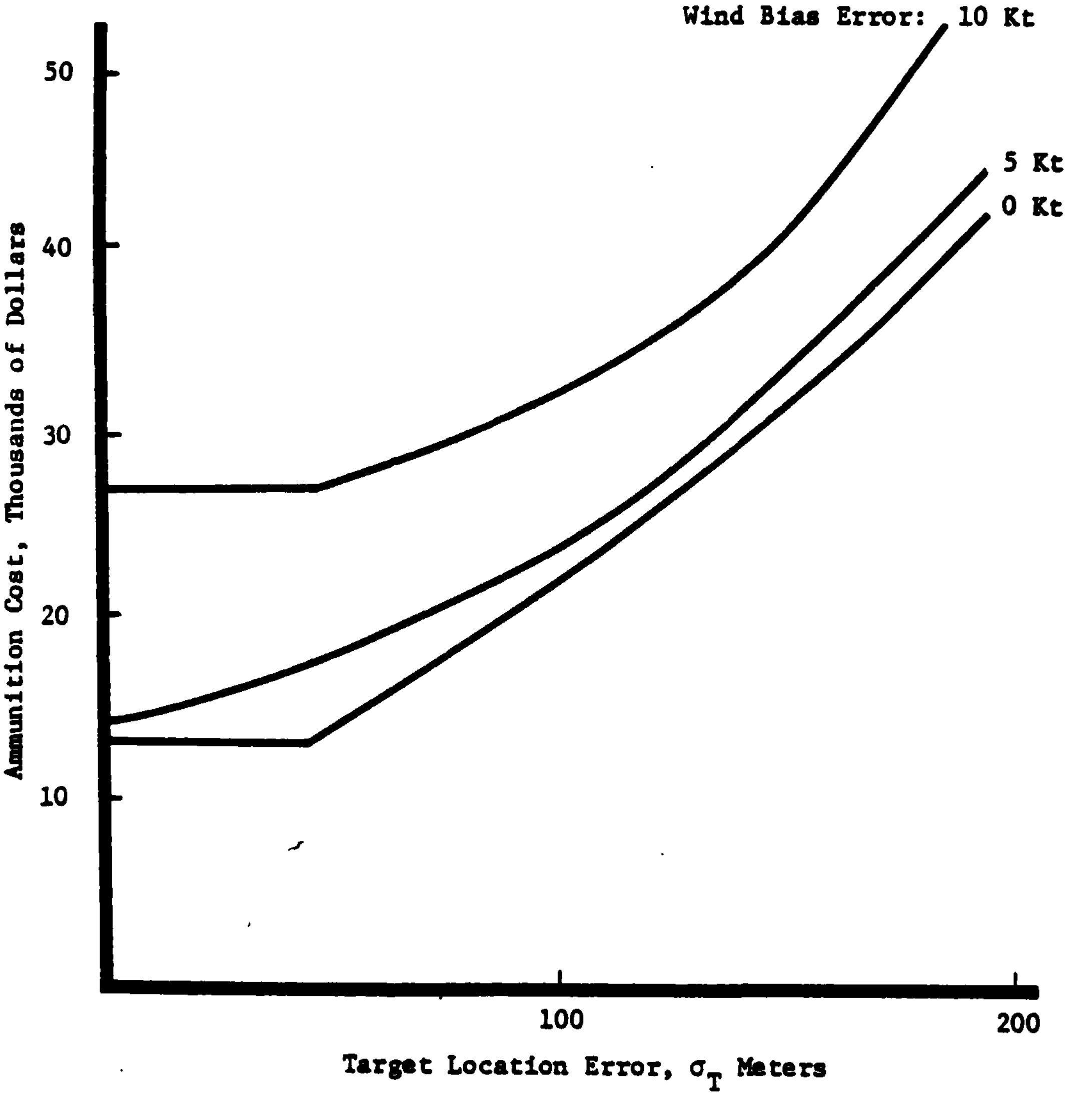

FIGURE I-7
EFFECTS OF BIAS ERROR FOR AREA TARGETS

both of these errors must be controlled at once or the full benefit if either cannot be achieved.

In this example, the range precision error of the howitzers was taken to be 75 m. This is a realistic value for 155 MM weapons and is in accord with the calculations done for point targets. Recomputing the data of Figure I-7 with the weapon precision error reduced to 50 m results in no discernable differences. That is, for fire at area targets, an improved weapon precision would not be valuable.

Additional calculations, made for lethal radii of 15 m and 35 m, confirm the result obtained earlier for point targets--that effectiveness is, to a good approximation, proportional to the square of the lethal radius.

APPENDIX II

MATHEMATICAL EXPRESSION OF FIRE SUPPORT EFFECTIVENESS

1.0 INTRODUCTION

The Fire Support Effectiveness Model described here gives a method of calculating single shot and single volley kill probabilities against typical targets as described in the Joint Munitions Effectiveness Manuals (JMEM). These kill probabilities (P_k) can then be used to calculate the number of rounds (or volleys) required to neutralize a target with a desired level of assurance.

The P_k is computed as the integral over the target field of the kill probability density function, p_k:

$$P_k = \iint_{-\infty}^{\infty} p_k \, dydx \qquad 1.1$$

where the density p_k is taken to be

$$p_k = p_I \cdot P_{T,a} \qquad 1.2$$

and p_I is the probability density of a round impacting at the point (x,y), while $P_{T,a}$ is the probability of a target being within a lethal radius, a_L, of the point (x,y). Allowance is made for parametric representation of the lethal radius, weapon accuracy, target location system accuracy, bias due to systematic errors, and a firing doctrine which aims weapons at different points in the target field. The model is kept as simple as possible while retaining these important parameters in order to investigate in a quantitative way the value of technological changes in terms of combat effectiveness.

2.0 THE COORDINATE SYSTEM AND TARGET LOCATION

2.1 Circular Normal Error Distributions

No X

Cartesian coordinates (x,y) are established, where the x axis is in the direction of fire (range direction) and the y axis is transverse to the direction of fire (deflection direction). Without loss of generality, it is assumed that a target location system is operating which reports a target at the point $x = 0$, $y = 0$.

Certain target location systems such as acoustic locators, ground surveillance radars, etc., have characteristic error distributions which can be well represented by the circular normal density function. I.e., the probability density of the actual target position being at (x,y) when the target is reported at (0,0) is given by

$$p_T(x,y) = (2\pi\sigma_T^2)^{-1} \exp - \frac{x^2+y^2}{2\sigma_T^2} \qquad 2.1$$

Thus, the probability of a target being within an infinitesimal rectangle dxdy, centered at (x,y) is $p_T dxdy$.

A target will be destroyed if a weapon warhead detonates at a distance less than or equal to one lethal radius, a_L, of the target position. Thus, it is necessary to compute the probability, not that a target is at point (x,y), but that a target is within a radius a_L of the point (x,y). The probability of this occurrence is denoted by $P_{T,a}$, and is given by the integral of p_T over the circular patch of radius a_L centered on (x,y). I.e.:

$$P_{T,a} = \frac{1}{2\pi\sigma_T^2} \int_{y-a}^{y+a} \int_{u_1}^{u_2} \exp - \frac{u^2+v^2}{2\sigma_T^2} \, dudv \qquad 2.2$$

where

$$u_1, u_2 = x \mp \sqrt{a_L^2 - (v-y)^2} \qquad 2.3$$

In the interesting limiting case $\sigma_T \to 0$, it is easy to show that

$$P_{T,a} \begin{aligned} &= 1 \quad \text{for } x^2 + y^2 < a \\ &= 0 \quad \text{for } x^2 + y^2 > a \end{aligned} \qquad 2.9$$

2.2 Other Error Distribution Functions

While important, the normal error distribution is not the only one encountered in practice. As an example of an alternative of practical importance, consider the case of a side looking airborne radar system which is able to report only that a target is within a certain finite range-azimuth bin, say of width $2L_R$ in the range direction and width $2L_A$ in the azimuth direction. Imagine this rectangular bin to be centered on the origin and oriented as shown in Figure II-1.

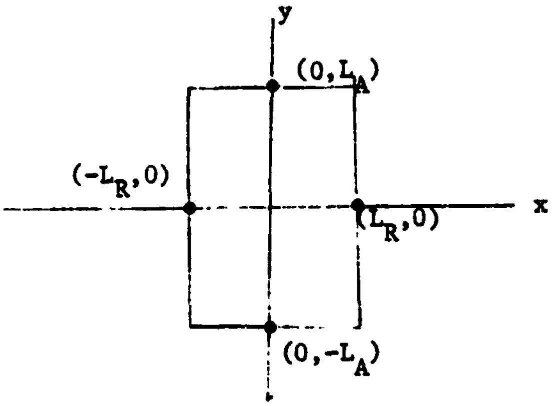

FIGURE II-1
RANGE—AZIMUTH BIN

While other assumptions are possible, we postulate here the not unreasonable density distribution:

$$p_T(x,y) = \frac{1}{4L_AL_R} \qquad \text{for } |x|<L_R \text{ and } |y|<L_A$$

$$= 0 \quad \text{otherwise} \qquad 2.10$$

The probability that a point $x = \xi$, $y = \eta$ lying within the range-azimuth bin is within a distance a_L of a warhead impact point (x,y) is given by

$$P_{T,a} = \iint p_T \, dydx \qquad 2.11$$

where the integration is over the patch of radius a_L centered at (x,y). Geometrically, this integral can be interpreted as $(4L_AL_R)^{-1}$ times the shaded area indicated in Figure A-2.

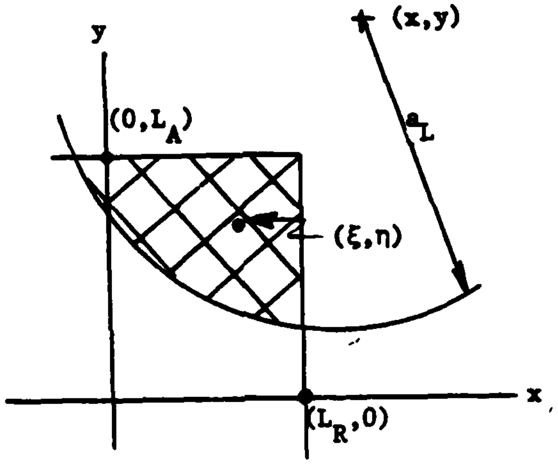

FIGURE II-2
MONTE CARLO INTEGRATION

While closed form expressions for $P_{T,a}$ in terms of elementary functions can be constructed, they are rather complicated. For computational purposes, it is probably as simple to use the Monte Carlo process sketched below to calculate this quantity.

The Monte Carlo method proceeds through a sequence of N trials, each of which has a result R which is equal to zero or one. For the $j^{\underline{th}}$ trial, select random numbers, ξ_j, η_j, such that

$$|\xi_j|<L_R \text{ and } |\eta_j|<L_A \qquad 2.12$$

Then calculate $\rho_j^2 = (x-\xi_j)^2 + (y-\eta_j)^2$, and

assign
$$\begin{aligned} R_j &= 1 \quad \text{if } \rho_j^2 < a_L^2 \\ &= 0 \quad \text{otherwise} \end{aligned} \qquad 2.13$$

Then,

$$P_{T,a} = \lim_{N\to\infty} \frac{1}{N} \sum_{j=1}^{N} R_j \qquad 2.14$$

It is easy to see that if the disk of radius a_L lies wholly within the range-azimuth bin, $P_{T,a} = \pi a_L^2/4L_A L_B$; if the disk covers the entire range azimuth bin, $P_{T,a} = 1$; and if no part of the disk overlaps the bin, $P_{T,a} = 0$. These limiting cases are useful for sample calculations.

3.0 THE WEAPON(S)

3.1 Warhead Lethality

As mentioned in the foregoing, a lethal radius parameter, denoted by a_L, is used to provide a kill criterion. While other formulations are possible, the "cookie cutter" concept is adopted here; i.e., a target will be presumed to be killed if a single warhead round impacts within distance a_L of the target position, but the target is presumed to be undamaged if the miss distance is greater than a_L. Alternatively, one could specify some degree of damage as a function of miss distance, but all such models could be reduced to an equivalent cookie cutter concept for damage greater than or equal to some specified degree of damage. Thus, no great generality is lost, while a large computational advantage is achieved by the simple model selected here.

Warhead lethality as measured by a_L is, of course, dependent on both the target type and the warhead type. Tabulated values of lethal area A_L as a function of weapon, projectile, target, and field conditions are to be found in the various JMEM publications. For almost all cases it is reasonable to convert from lethal area to lethal radius by the obvious relation $A_L = \pi a_L^2$.

3.2 Weapon Precision

A large number of rounds fired by a weapon are empirically observed to impact in a scatter pattern about a mean point of impact (MPI). The difference between the MPI and the weapon aim point will be referred to in the sequal as a <u>bias</u>, while the scatter about the MPI is

AD-A091 610   MITRE CORP MCLEAN VA METREK DIV   F/G 15/7
SURVEY OF U.S. ARMY TECHNOLOGY BASE R&D IN THE FIRE SUPPORT MIS--ETC(U)
AUG 77 F W NIEDENFUHR   F19628-76-C-0001
UNCLASSIFIED MTR-7637   NL

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discussed in terms of precision (or frequently, dispersion).* Factors contributing to the precision error are generally presumed to be random in nature, while bias errors are presumed to be systematic. For a full discussion of the origin of these errors, the reader is referred to the various JMEMs and the appropriate field manuals for the weapon system under consideration.

For a single weapon firing at a fixed aim point, experience indicates that the density distribution of the probability density for a warhead impacting at (x,y) when the MPI is at (0,0) is given by

$$p_I = \frac{1}{2\pi\sigma_x\sigma_y} \exp - \frac{1}{2}\left[\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2\right] \qquad 3.1$$

This bivariate normal distribution is well authenticated by an accumulation of data over many years; this fact is, indeed, the source of the conviction that the individual errors here are of a random nature. The parameters σ_x and σ_y which characterize the precision of an individual weapon are the standard deviations of the distribution.** Here σ_x is in the range direction, while σ_y refers to the transverse direction.

3.3 Groups of Weapons

Consider a group of identical weapons firing in concert (volley fire) for example, a cannon artillery battery, or a group of rockets

---

[*] Army parlance favors the term "precision," while Navy terminology is "dispersion."

[**] It should be noted that with cannon artillery weapons it is more conventional to speak in terms of "standard errors," S, rather than standard deviations, σ. A range of ±1 standard error includes half of the events, as does a range of ±.675 standard deviations, thus, $S \approx .675\sigma$.

fired from a launcher. In the model under development here, each weapon is permitted to fire at a different aim point. For the i$\underline{\text{th}}$ weapon, the aim point coordinates are taken to be (x_i, y_i). Then the probability of a round from the i$\underline{\text{th}}$ weapon impacting within a small area dA surrounding the point (x,y) is

$$dP_I = dA(2\pi\sigma_x\sigma_y)^{-1}\exp -\frac{1}{2}\left[\left(\frac{x-x_i}{\sigma_x}\right)^2 + \left(\frac{y-y_i}{\sigma_y}\right)^2\right] \qquad 3.2$$

$$= p_I dA$$

It should be noted that the parameters (x_i, y_i) are at the disposal of the analyst using the model, and can be selected in various ways. If $x_i = y_i = 0$ for $i = 1,2,\ldots,N$, all weapons are aimed at the same point. Rudimentary variations on this simple firing doctrine can be accomplished by selecting one or several additional aim points.

4.0 SYSTEMATIC ERRORS

Various systematic errors act within the weapons system and the environment, tending to displace the mean point of impact from the intended aim point. Chief among these errors are the meteorological effects including air density and the winds which tend to blow projectiles away from their intended course. The condition of particular weapons with respect to wear, alignment, adjustment, etc. is another contributor to systematic error or bias, as are crew proficiency and survey accuracy.*

For the purposes of the Fire Support Effectiveness Model being developed here, all of these effects are viewed as removing the mean point of impact from the aim point by introducing a bias with components $(-x_B, -y_B)$. As the main purpose here is not to examine the difference between individual weapons, the same components of bias error are applied to all weapons in a group. This is a realistic representation for wind drift or survey errors, for example, and may be taken to represent an average bias resulting from systematic error in individual weapons.

Analytically, then, the bias components $(-x_B, -y_B)$ are introduced as aim point offsets. Thus, the term p_I in Equation 3.2 becomes

$$p_I = (2\pi\sigma_x\sigma_y)^{-1} \exp -\frac{1}{2}\left[\left(\frac{x-x_i+x_B}{\sigma_x}\right)^2 + \left(\frac{y-y_i+y_B}{\sigma_x}\right)^2\right] \qquad 4.1$$

---

*Detailed discussions of error sources and associated corrections are given in the Field Manuals for various weapons systems.

5.0 CALCULATION OF SINGLE SHOT AND VOLLEY KILL PROBABILITIES

The term single shot kill probability (SSP_k) is used here to represent the probability that a single round destroys a target whose reported position is at the point x=y=0. Destruction is defined to occur when a round impacts within one lethal radius, a_L, of the target position.

As obtained in Section 2.0, this appendix, the probability of a target being within a distance a_L of the point (x,y) is denoted by $P_{T,a}$. From Appendix II, Section 3.0, the probability density of a warhead impacting at the point (x,y) is p_I. As these terms refer to independent events, the probability density of their simultaneous occurrence is given by their product, p_k.

$$p_k = p_I P_{T,a} \qquad 5.1$$

p_k is the probability density of a kill occurring at the point (x,y); the probability of a kill occurring anywhere in the field is thus the integral over the entire x-y plane of this density:

$$SSP_k = \iint_{-\infty}^{\infty} p_I P_{T,a} \, dydx \qquad 5.2$$

When the target location system has a circular normal error distribution, $P_{T,a}$ is taken from Equation 2.2 In that case, two of the four integrations required for SSP_k can be accomplished in terms of elementary functions; the third can be expressed in terms of the complementary error function Erfc(x) and the final integration must be done numerically. Thus, after some reduction, Equation 5.2 becomes:

$$SSP_k = \frac{1}{4\sqrt{\Pi}} \int_{x_i - x_B + a_L}^{x_i - x_B + a_L} \left[\mathrm{Erfc}\left(\frac{y_i - y_B - \sqrt{a_L^2 - (t - x_i + x_B)^2}}{\bar{\sigma}_y} \right) - \mathrm{Erfc}\left(\frac{y_i - y_B + \sqrt{a_L^2 - (t - x_i + x_B)^2}}{\bar{\sigma}_y} \right) \right] \exp - \left(\frac{t}{\bar{\sigma}_x} \right)^2 d\left(\frac{t}{\bar{\sigma}_x} \right) \qquad 5.3$$

where $\bar{\sigma}_x^{\,2} = 2(\sigma_x^{\,2} + \sigma_T^{\,2})$ and $\bar{\sigma}_y^{\,2} = 2(\sigma_y^{\,2} + \sigma_T^{\,2})$.

Volley kill probability is then

$$VP_k = 1 - \prod_{i-1}^{N} \left[1 - SSP_k(i) \right] \qquad 5.4$$

and when all guns in the group fire at the same aim point,

$$VP_k = 1 - \left[1 - SSP_k \right]^N \qquad 5.5$$

To recapitulate, kill probabilities as functions of the parameters listed below can be calculated by direct evaluation of Equations 5.3, 5.4, and 5.5.

a_L: Lethal radius of a warhead. a_L depends both on the projectile and the target type.

σ_T: A measure of TLE. σ_T is the standard deviation of the target location system error distribution function.

σ_x, σ_y: The range and deflection standard deviation, respectively, of the dispersion pattern for an individual weapon. Assumed to be the same for all weapons firing as a group.

x_i, y_i: Aim point coordinates for the $i^{\underline{th}}$ weapon in a group. $i = 1, 2, \cdots, N$.

N: Number of weapons in a group.

x_B, y_B: Components of bias error such as survey error or wind induced projectile drift.

Altogether there are $7 + 2N$ parameters which must be selected before computing P_k.

6.0 ASSURANCE

The result of a single round (or volley) is either a "success" (with probability P_k) or a "failure" (with probability $(1-P_k)$). A sequence of such trials, the outcomes of which are statistically independent, leads to a geometric distribution of probability of a success after j failures, i.e., the probability of a successful trial after exactly j failures is $P_k(1-P_k)^j$.

Assurance is defined as the cumulative probability of success after the $n^{\underline{th}}$ trial (e.g., a kill by the time the $n^{\underline{th}}$ volley has been fired). Mathematically, then,

$$A_n = \sum_{j=o}^{n-1} P_k(1-P_k)^j$$

$$= 1 - (1-P_k)^n \qquad 6.1$$

If the assurance, A_n, is given, and the number of trials to achieve this assurance is desired, we have, on solving Equation 6.1 for n,

$$n = \frac{\ln(1-A_n)}{\ln(1-P_k)} \qquad 6.2$$

This result requires that the P_ks be the same for each trial, of course. If A_n is arbitrarily selected, Equation 6.2 will not in general lead to an integral value of n, in which case the number of trials required is the next larger integer (which therefore corresponds to a slightly larger assurance than was originally selected).

For small values of P_k, Equation 6.2 can be reduced to a convenient "rule of thumb." Expanding in a Taylor series:

$$\ln(1-P_k) = -\left[P_k + \frac{1}{2}P_k^2 + \frac{1}{3}P_k^3 + \cdots\right] \qquad 6.3$$

If the second and subsequent terms are negligible, $\ln(1-P_k) \approx -P_k$. Further

$$\begin{aligned} -\ln(1-A_n) &= 1 \text{ for } A_n \approx .63 \\ &= 2 \text{ for } A_n \approx .86 \\ &= 3 \text{ for } A_n \approx .95 \end{aligned}$$

Thus:

For small P_k, $\frac{1}{P_k}$ shots (volleys) will result in a kill 63% of the time, $\frac{2}{P_k}$ shots will result in a kill 86% of the time, and $\frac{3}{P_k}$ shots will result in a kill 95% of the time.

The concept of assurance thus leads to a measure of the cost of killing a target. (Graphs of assurance as a function of P_k and number of trials are given in Section 2-45 of Army Field Manual 6-40, "Field Artillery Cannon Gunnery," for example.)

7.0 FIRE AGAINST AREA TARGETS

The problem of destroying area targets can be phrased in terms of destruction of a number of individual point targets distributed over a given geographical area. For each point target, one can use the methodology outlined in the earlier sections of this appendix to calculate the probability of kill and, thus, develop the set of kill probabilities p_i, $i = 1, 2, \ldots, N$, that each of N targets has been destroyed by a given action. (An action consists of firing a single volley with aim points distributed over a given area.) After a number, j, of actions have been taken, the probability that the $i^{\underline{th}}$ target has been killed is

$$ {}_jp_i = 1 - (1-p_i)^j \tag{7.1} $$

provided that all actions are the same.

The probability that exactly M of the individual point targets within the given area target have been killed after the $j^{\underline{th}}$ action is

$$ {}_jP_M = \underbrace{\sum_{k=1}^{N}\sum_{m>k}^{N}\sum_{n>m}^{N}\cdots}_{M\ \text{sums}} \; \underbrace{f_k f_m f_n \cdots}_{M\ \text{factors}} \prod_{i=1}^{N} (1-{}_jp_i) \tag{7.2} $$

where $\quad f_i = {}_jp_i/(1-{}_jp_i)$.

The probability that M or more of the individual point target elements have been killed after the $j^{\underline{th}}$ action is

$$ {}_j\tilde{P}_M = 1 - \sum_{K=o}^{M-1} {}_jP_K . \tag{7.3} $$

Commands for fire against area targets are given in terms of the factor ${}_j\tilde{P}_M$. For example, a commander may wish to achieve an 80 percent assurance that 30 percent of the individual elements of an area target have been destroyed. In this case ${}_j\tilde{P}_M = .8$, with $M = [.3N]$ where "[.3N]" connotes the greatest integer in .3N. The problem, then, is to find j, the number of volleys required to achieve the given assurance, as a function of the parameters which affect the set p_i which defines the result of the first action.

For computation, the p_i are first obtained by using the basic algorithm which yields the single volley kill probabilities, p_i. Then the factors ${}_j\tilde{P}_M$ are calculated for various values of j and given target hardness, TLE, bias error, etc. Then, those values of j which yield a sufficient assurance of destruction of M or more target elements can be determined.

The process is very much simplified if the p_i are all equal to the same constant value, p. In this special case,

$$ {}_jP_M = \frac{{}_jp^M}{M!} \frac{\partial^M}{\partial {}_jq^M} {}_jq^N \qquad 7.4 $$

where ${}_jp + {}_jq = 1$. Consider, for example, a counter battery case, where the commander wants an assurance of .8 that two or more of the six guns in an opposing battery have been killed. The single volley kill probabilities for each target element (opposing gun) will be the same if (but <u>only</u> if) the area covered by the action is much larger than the area of the target complex. In this case, Eqs. 7.3 and 7.4 yield:

$$ {}_{j}\tilde{P}_{2} = 1 + 5X^{6} + 6X^{5} \qquad 7.5 $$

where $X = q^{j}$, and $q = 1-p$. Setting ${}_{j}\tilde{P}_{2}$ equal to .8, the desired assurance, we find $X = .576$, so that if $p = .1$, say, $j = 5.24$, or in excess of five volleys are required.

Such calculations are not valid if the target area and the area covered by the aim points of the action are of the same general extent, for then, the p_i are not all the same. The problem is then dominated by the "edge effects" which in most practical cases induce a large variation among the p_i. Thus, for most applications, it is necessary to use Eq. 7.2 in its general form.

8.0 FORTRAN PROGRAM

The Fire Support Effectiveness Model FORTRAN Program is written for interactive operation from a terminal under Conversational Monitor System (CMS) environment of an IBM 370/148 VM computer. The logic of the program is straightforward. It first requests the user to provide parametric inputs, including the number of different lethal radii to be used for computation and their values (A_L); the weapon error (σ_x, σ_y) and systematic (bias) errors (X_B, Y_B); and the number of weapons to be fired as a group and their aiming coordinates (X_i, Y_i for the ith gun). The inputs are given in free format, i.e., user can separate the inputs by a comma or a blank space. Maximum number of A_L, σ_T, and weapons to be fired for each cycle of computation is ten. However, by changing the dimension statement in the program, this limitation can be modified.

Upon receipt of all the inputs, the probability of kill (P_k) is computed using equations 5.3, 5.4, and 5.5 for each combination of A_Ls and σ_Ts. The increment of the integral is 1/100th of two A_L (i.e., $(2 \times A_L)/100$). The output is tabulated in the form of σ_T versus P_k.

Once the output is presented, the program asks the user whether more runs are required. A "no" response causes the program to stop; a "yes" response allows the user to alter the value of inputs and to compute the P_k based on the new values.

A sample problem and the program listing are included here for reference.

SAMPLE PROBLEM INPUT

```
THE FIRE SUPPORT EFFECTIVENESS MODEL

A METHOD OF CALCULATING SINGLE SHOT AND SINGLE VOLLEY
KILL PROBABILITIES AGAINST TYPICAL TARGETS .
---DEVELOPED BY MITRE/METREK, 1977


LETHAL RADIUS
-------------
INPUT NUMBER OF AL'S AND THEIER VALUES
?
1,25


TARGET LOCATION SYSTEM
----------------------
INPUT NUMBER OF SIGMAT'S AND THEIR VALUES
?
6,20,30,50,100,1540,200


WEAPON SYSTEM ERRORS
-----------------------
INPUT SIGMAX,SIGMAY,XB,YB
?
100,50,0,0


WEAPON GROUP
------------
INPUT NUMBER OF WEAPONS UP TO 10
?
10
INPUT X,Y AIMPOINTS AS X1, Y1, X2, Y2,.....
?
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

SAMPLE PROBLEM OUTPUT

```
FOR:  LETHAL RADIUS:        AL=     25.
      WEAPON PRECISION:     SIGMAX=  100. SIGMAY=   50.
      BIAS ERRORS:          XB=     0. YB=     0.
      NUMBER OF WEAPONS:    N= 10
      WEAPON AIM POINTS:  (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.)

     SIGMAT              PROB. OF KILL
     --------           ---------------
      20.                 0.431579590
      30.                 0.399730325
      50.                 0.325607002
     100.                 0.179084718
    1540.                 0.00131136179
     200.                 0.0654633045
MORE RUN? 1=YES, 0=NO
?
1
TYPE: 1 TO CHANGE ALL INPUT VALUES
      2 TO CHANGE LETHAL RADIUS ONLY
      3 TO CHANGE TARGET LOCATION SYSTEM ONLY
      4 TO CHANGE WEAPON SYSTEM ERRORS ONLY
      5 TO CHANGE WEAPON GROUP ONLY
?
4


WEAPON SYSTEM ERRORS
----------------------
INPUT SIGMAX,SIGMAY,XB,YB
?
100,50,120,71


FOR:  LETHAL RADIUS:        AL=     25.
      WEAPON PRECISION:     SIGMAX=  100. SIGMAY=   50.
      BIAS ERRORS:          XB=  120. YB=    71.
      NUMBER OF WEAPONS:    N= 10
      WEAPON AIM POINTS:  (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.) (    0.,     0.) (    0.,     0.)
                          (    0.,     0.)

     SIGMAT              PROB. OF KILL
     --------           ---------------
      20.                 0.115372121
      30.                 0.120690286
      50.                 0.126354277
     100.                 0.106543958
    1540.                 0.00130599737
     200.                 0.0537526011
MORE RUN? 1=YES, 0=NO
?
0
```

PROGRAM LISTING

```
FILE: ARTPK    FORTRAN  A                   CONVERSATIONAL MONITOR SYSTEM

      DIMENSION AL(10),SGT(10),TPK(10)
      COMMON GUNX(10),GUNY(10),IGUN
      REAL LB, MISPK
      PIE=22./7.
      WRITE (6,151)
151   FORMAT(///' THE FIRE SUPPORT EFFECTIVENESS MODEL'/
     &/' A METHOD OF CALCULATING SINGLE SHOT AND SINGLE VOLLEY'/
     &' KILL PROBABILITIES AGAINST TYPICAL TARGETS .'/
     &' ---DEVELOPED BY MITRE/METREK, 1977 ')
C
C     REQUEST FOR INPUTS
C
      ICHAGE =1
210   WRITE (6,1)
1     FORMAT(//' LETHAL RADIUS'/' -------------'
     &/' INPUT NUMBER OF AL''S AND THEIR VALUES ')
      READ (5,*) NA,(AL(I),I=1,NA)
      IF (ICHAGE-1) 215,215,20
215   WRITE (6,3)
3     FORMAT(//' TARGET LOCATION SYSTEM'/' ----------------------'
     &/' INPUT NUMBER OF SIGMAT''S AND THEIR VALUES ')
      READ (5,*) NSGT,(SGT(I),I=1,NSGT)
      DELTA=100.
      IF (ICHAGE-1)220,220,20
220   WRITE (6,2)
2     FORMAT(//' WEAPON SYSTEM ERRORS'/' ----------------------'
     &/' INPUT SIGMAX,SIGMAY,XB,YB ')
      READ(5,*) SGX,SGY,XB,YB
      IF(ICHAGE-1) 225,225,20
225   WRITE(6,4)
4     FORMAT(//' WEAPCN GROUP'/' ------------'
     &/' INPUT NUMBER OF WEAPONS UP TO 10' )
      READ (5,*) IGUN
10    WRITE(6,5)
5     FORMAT (' INPUT X,Y AIMPOINTS AS X1, Y1, X2, Y2,..... ')
      READ(5,*) (GUNX(I),GUNY(I),I=1,IGUN)
      NTIMES=100
20    DO 200 I=1,NA
      DELTAT=AL(I)*2./NTIMES
      DO 150 J=1,NSGT
      SGXMD=SQRT(2.*(SGX**2+SGT(J)**2))
      SGYMD=SQRT(2.*(SGY**2+SGT(J)**2))
      MISPK=1.
      DO 50 IG=1,IGUN
      T=GUNX(IG)-XB-AL(I)
      IF(IG-1) 55,55,30
30    IF(GUNX(IG)-GUNX(IG-1)) 55,40,55
40    IF(GUNY(IG)-GUNY(IG-1)) 55,27C,55
55    DPPK=0.
      DO 300 IT=1,NTIMES
      YIB=GUNY(IG)-YB
      ATXIBS=AL(I)**2-(T-GUNX(IG)+XB)**2
      IF(ATXIBS) 70,75,75
70    WRITE(6,71)ATXIBS
71    FORMAT(' AL**2-(T-XI+XB)**2 IS ',F12.7,' ATXIBS IS SET=0')
```

PROGRAM LISTING (Concluded)

```
      ATXIBS=0.
75    ATXIB=SQRT(ATXIBS)
      UB=(YIB+ATXIB)/SGYHD
      LB=(YIB-ATXIB)/SGYHD
      TWOERF=ERFC(LB)-ERFC(UB)
      DFPK=DFPK+EXP(-(T**2/SGXHD**2))*TWOERF*DELTAT
      T=T+DELTAT
300   CONTINUE
      DFPK=DFPK/(2.*SQRT(PIE)*SGXHD)
      IF(IGUN-1)60,60,270
270   MISPK=MISPK*(1.-DFPK)
 50   CONTINUE
      TPK(J)=1.-MISPK
      GO TO 150
60    TPK(J)=DFPK
150   CONTINUE
C
C     OUTPUT.......
C
      WRITE(6,152) AL(I),SGX,SGY,XB,YB,IGUN
152   FORMAT(//' FOR:  LETHAL RADIUS:       AL= ', F6.0 /
     &'        WEAPON PRECISION:   SIGMAX=', F6.0,' SIGMAY=',F6.0/
     &'        BIAS ERRORS:        XB=',F6.0,' YB=',F6.0/
     &'        NUMBER OF WEAPONS:  N=',I3)
160   WRITE(6,161)  (GUNX(IG),GUNY(IG),IG=1,IGUN)
161   FORMAT('        WEAPON AIM POINTS: ',3('(',F5.0,',',F5.0,')')/(
     &26X,3('(',F5.0,',',F5.0,')')))
155   WRITE(6,171)
171   FORMAT(/'       SIGMAT                PROB. OF KILL'/
     &'       --------           ----------------')
      DO 180 J=1,NSGT
      WRITE(6,181) SGT(J),TPK(J)
181   FORMAT(F10.0,15X,F15.12)
180   CONTINUE
200   CONTINUE
      WRITE(6,6)
6     FORMAT(' MORE RUN? 1=YES, 0=NO ' )
      READ(5,*) MRUN
      IF(MRUN) 250,250,260
260   WRITE(6,7)
7     FORMAT(' TYPE: 1 TO CHANGE ALL INPUT VALUES'/
     &'        2 TO CHANGE LETHAL RADIUS ONLY'/
     &'        3 TO CHANGE TARGET LOCATION SYSTEM ONLY'/
     &'        4 TO CHANGE WEAPON SYSTEM ERRORS ONLY'/
     &'        5 TO CHANGE WEAPON GROUP ONLY')
      READ(5,*) ICHAGE
      GO TO (210,210,215,220,225), ICHAGE
250   STOP
      END
```

REFERENCES

1. Base Technology Programs Related to Battlefield Systems, FY1977 and FY1978 (SPIDER Charts) (U) CONFIDENTIAL, U.S. Army Materiel Development and Readiness Command, 29 April 1977. (No document number)

   Presents over 2,000 technology base work units representing in excess of a quarter billion dollars of R&D budget at the 6.1, 6.2, 6.3a level. Work units are briefly described by title, problem addressed, funding, and Army Mission Area context. This document gives the best available overview of technology base activity.

2. Joint Munitions Effectiveness Manuals

   These books provide tabular and graphical information on weapon and munition accuracy, as well as vulnerability of selected targets. They are an invaluable source of data in ready reference form. For the Fire Support Mission Area, the following are of principal interest:

Weapon Effectiveness UNCLASSIFIED	FM101-50-1
Effectiveness Data for 155 mm Howitzer, M109 (U) CONFIDENTIAL	FM101-60-3
Effectiveness Data for 8-inch Howitzer, M110 (U) CONFIDENTIAL	FM101-60-4
Effectiveness Data for Rocket, 762 mm, M50 (U) CONFIDENTIAL	FM101-60-8
Indirect Fire Accuracy (U) CONFIDENTIAL	FM101-61-5-1
Weapons/Ammunition Characteristics (U) CONFIDENTIAL	FM101-61-2

3. Common Reference World Grid; Concept Implementation (U) SECRET MITRE Technical Report, MTR-6996, by D. Kozakoff, September 1975

   Useful basic discussion of World Grid System for navigation and position locating. Errors, accuracy, and interoperability are covered.

REFERENCES (Continued)

4. Synopsis of Some Position Location Systems and Their Coordinate References (U) CONFIDENTIAL, MITRE Working Paper, WP-10879, September 1975, by W. Lawrence

Describes ITNS, SEEK BUS, PLRS, and LORAN.

5. A Review of Selected Targeting Methods for the GPS Missile (U) SECRET, MITRE Technical Report, MTR-7131, by D. Kozakoff, April 1976

Helpful discussions of several precise targeting systems used by the Air Force

6. ISTA Mission Area Review--Final Report (U) SECRET, MITRE Technical Report, MTR-7460, by E. Famolari, et al., July 1977

7. Accuracy Analysis of Artillery Cannon Systems (AAACS)
Vol. I, Main Report, UNCLASSIFIED, BDM/CARAF-FR-75-045, 30 April 1975, AD B010585L
Vol. II, Model Documentation, UNCLASSIFIED, BDM/CARAF-FR-75-046, 30 April 1975, AD B010586L
Vol. III, Scenario & Data (U) SECRET, BDM/CARAF-FR-75-047, 30 April 1975, AD C00585L

A Herculean effort in excruciating detail, concerning error sources for tube artillery systems. Over 150 pages list individual errors in terms of standard deviations and their associated effects coefficients! A first order perturbation model is proposed and sample problems presented. FORTRAN listings are provided for the model. This report was sponsored by the Field Artillery School, Ft. Sill, which uses the perturbation model, to a limited extent, as a decision aid. The work is of greater potential utility, but does not seem to have been widely known in the community.

8. Rapid Fire Area Saturation System, AMC Report 74-002, April 1974
Vol. I, Baseline Design (U) SECRET, AD-529-745L
Vol. II, Baseline Design (Cont'd.) (U) SECRET, AD-529-746L
Vol. III, Cost Analysis (U) CONFIDENTIAL, AD-529-781L

A thorough preliminary design and costing study which examines alternatives for GSRS. A wealth of design and performance data for a family of rocket systems. Will continue for some years to be a viable document because of the fundamental approach used.

REFERENCES (Concluded)

9. Science and Technology Objectives Guide, FY78 (U) CONFIDENTIAL, HQ, DA (No document number)

   Prioritized R&D goals from the user point of view. Updated annually.

10. Army Missile Plan, Fiscal Year 1976 and 77 (U) SECRET, U.S. Army Missile Command, Redstone Arsenal, Alabama, 3 January 1976 (No document number)

    Shows the plan, funding, and rationale for work conducted at MIRADCOM. Not detailed, but a highly useful roadmap for R&D in rocketry and the connection to operational and evolving systems. Good example of R&D documentation.

11. Preview Technological Base Program, FY78 (U) SECRET, U.S. Army Armament Research and Development Command, 1 April 1977, Log No. RJE(SP)-5-S-77

    Explains the AARADCOM System and technology thrusts, giving funding and some information on accomplishments. Highly useful insights into weapon research in this command.

12. Report of Artillery System Study Group (Task Force BATTLEKING) (U) SECRET, OCRDA, HQ, DA, December 1974, CRD6200

    This comprehensive effort gives a good current picture of artillery capabilities and addresses conceptual systems, measures of effectiveness, and deficiencies. Recommendations are made for future development. Lttle is said about technology base activity per se. Despite being nearly three years old, this volume is still an excellent statement of the state of the art.

13. Field Artillery Cannon Gunnery UNCLASSIFIED, FM6-40, HQ, DA

    The basic manual for field artillery. Explains principles and practices in useful detail, providing an excellent picture of "how it is" in the field. Subsidiary manuals provide further specialized information.

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