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INFANTRY WEAPONS TEST METHODOLOGY STUDY: INTEGRATED OPERATIONAL TEST AND ANALYSIS PROCEDURES FOR SMALL ARMS WEAPONS SYSTEMS EVALUATION

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FOREWORD

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INTEGRATED TEST AND ANALYSIS PROCEDURES FOR SMALL ARMS WEAPON SYSTEMS EVALUATION

1. INTRODUCTION

1.1 Purpose

The purpose of this document is to summarize the findings of the Small Arms Methodology Study in terms of a working format for weapon system evaluation using the three small arms test facilities. Section 1 discusses ~~is a discussion of~~ the major parameters of the integrated test procedure. Section 2 describes procedures for training and scheduling test soldiers through the facilities taking into account the two major test variables, weapons and modes of fire. In addition, rationale is provided for the recommended sample size estimation and test soldier selection techniques. Section 3 describes the analytical procedure to be used on the field-generated data. The data are used for two purposes: selection of the most suitable combat weapon system and optimization of weapon system performance. The procedure described emphasizes the selection of the superior weapon at the earliest possible point, consistent with a thorough evaluation of operational performance, in order to maximize the time available for improving the selected weapon's performance.

1.2 Analytical Techniques

The analytical techniques required for the comparison of weapon performance and for searching for areas in which a potential for improved performance exists are quite different. Hence, the earlier the weapon comparative analysis is completed, the more time will be available for analysis of other factors. For example, data can be massaged to determine if sight alighment problems exist, if there is a degradation in long range hit probability, if the weapon has poor point firing characteristics, if ammunition consumption in a prolonged attack would approach the critical point, and so on. Further, the data base has the potential to answer operational questions such as: what is the effective range of the weapon, which range should be used to open fire, and which mode should be used in the attack, defense, or quickfire situation. This analytical approach permits the maximum utilization of the available data base which, in turn, should result in the selection of the weapon system with greatest operational effectiveness. Further, the operational characteristics of the weapon will have been defined to the extent possible within the limitations of the available data.

1.3 The Testing Situation

1.3.1 Operational performance testing is designed to yield estimates of combat effectiveness. Other factors such as weapon signature and safety are not treated formally since these characteristics are evaluated during the engineering test phase. The operational test employs three general combat missions: attack, defense, and movement security. The attack facility attempts to duplicate such combat actions as fire and movement, close combat, and frontal attack. The Small Arms Methodology Review performed by USAIB personnel found that these three combat actions contained the essential elements of all combat actions associated with attack situations. To perform these combat actions several specific tasks must be performed by the rifleman. The test facility is designed to cause the test soldier to perform these tasks in a manner similar to that required in combat. The critical combat tasks for the attack situation are:

a. Long range fire - unsupported

b. Medium range fire increasing in volume - unsupported

c. Intense, accurate fire - medium to close range

d. Rapid movement

e. Rapid magazine change

f. Rapid displacement

1.3.2 The quickfire facility attempts to duplicate the following combat actions: advance to contact, combat in cities, search and clear, combat patrol, and reconnaissance patrol. The critical combat tasks that are required of the test soldier are:

a. Intense accurate fire, medium to close range

b. Violent, quick-reaction fire

c. Alert movement

d. Rapid reaction

e. Immediate initiation of return fire

f. Deliberate, methodical movement w/detailed observation

g. Anticipated short and medium range enemy contact

1.3.3 Finally, the defense facility evaluates such combat actions as retrograde operations, deliberate defense, hasty defense, sniper, and area or position security. The critical combat tasks required of the test soldier are:

a. Long range precision fire

b. Medium range precision fire

c. Short range precision fire

d. Minimum exposure

e. Sustained combat action

f. Rapid magazine change

g. Rapid reduction of malfunctions

1.3.4 The validity of the test results produced in operational testing is directly dependent on how well the test facilities succeed in duplicating the combat actions and tasks. The target presentation scenarios must be as realistic as possible; the targets must behave as much like enemy soldiers as possible. The scenarios must be sufficiently long to tax sustainability of the weapon system; this time factor is an important consideration in the fire fight. To insure that combat realism is part of each scenario, optimized target presentation scenarios have been prepared for the defense facility and planned for the quickfire and attack facility. These should be used whenever applicable for the operational test. Special scenarios may be written and used as required. For instance, the testing of a new sniper scope may dictate a special target presentation scenario that emphasizes presentation of long range stationary and moving targets. The testing of quartermaster equipment, such as CB overgarments, may require emphasis on target acquisition which, in turn, may require a special target presentation scenario.

1.3.5 The procedures for conducting operational tests are discussed in Section 2. Techniques are described for selection of the sample of test soldiers, the assignment of test weapons, training, and scheduling. These procedures should be followed as closely as possible for each operational service test.

1.4 Criteria

The criteria for the evaluation of weapon system performance on the test facilities fall into four classes: accuracy, sustainability, responsiveness, and, to the extent possible, reliability. Within these classes several measures of effectiveness (MOE) are used.

1.4.1 Accuracy - The accuracy MOE that are available for analysis of weapon performance are:

a. Number of hits

b. Hit probability per trigger pull

c. First round hit probability

d. Engagement hit probability

e. Distribution of near misses

1.4.2 Sustainability - The primary sustainability MOE is the number of hits per pound. A secondary sustainability MOE considered in this analysis is hits per basic load. The number of rounds in the basic load of the weapon system multiplied by the hit probability equals total potential lethality in each technical situation.

1.4.3 Responsiveness - The responsiveness MOE are primarily associated with the quickfire facility and are particularly useful in pinpointing weapon handling systems. These include:

a. Time to first round

b. Time to first hit

c. Time between rounds

d. Time to shift fire

1.4.4 Reliability - Three MOE are used as a measure of weapon system reliability: number of malfunctions, number of rounds between malfunctions, and time to clear malfunctions. These MOE are of limited usefulness since most weapons that reach the operational testing phase of the test cycle have passed many engineering reliability tests. Further, the duration of the operational test is relatively short - each weapon system fires only a few hundred rounds. This small sample size increases the difficulty of estimating reliability. However, these data are available and should be analyzed to determine if potential problems exist.

1.5 Analysis

A step by step procedure for the comparative analyses of weapon system performance appears in Section 3. These steps are designed to act as a guide for the analyst, describing a path through the labyrinth of variables. The procedure describes the order of importance of combinations of variables and MOE with emphasis on specific decision nodes. The plan is only a guide; deviations from the plan should be made if the indicators in the data base pinpoint areas of interest and importance that were unforseen at the time this plan was prepared. The analysis is a multistage analysis which probes the data base until one weapon system proves superior to the other. The point in the analysis at which superiority is shown is not constant but depends on the performance characteristics of weapon systems. For weapons with widely different firing characteristics superiority may be shown in the initial phase of the analysis. For closely competing weapons, the analysis moves to increasing depths in the data basis. It is terminated when the weapons are found to have no operationally important performance differences. At the point at which superiority is found, regardless of the level of the depth of the analysis, emphasis is shifted to the task of optimizing weapon system performance. If no differences are found, the data are used to optimize the standard weapon's performance, assuming that the standard weapon will be selected as the superior weapon if no meaningful differences occur. (There are no additional costs associated with selection of the standard weapon.)

2. FIELD TEST PROCEDURES

This selection treats the six major factors which are associated with field testing: test soldier selection, sample size, weapon assignment, training, scheduling, and implementation of the test.

2.1 Selection

Test soldiers will normally be supplied from Fort Benning units, currently the 197th Infantry Brigade. The normal procedure is to select either a random sample or a stratified random sample. Using stratified random sampling, personnel records are reviewed and normally the extreme cases are removed. For example, soldiers with exceptional high or low IQ's, aptitudes, height, or weight are removed from the sample population. The remainder are then stratified into subgroups based on such physical characteristics as right or left handedness or visual acuity. Soldiers are then selected by chance from the subgroups to form the groups of test soldiers. The proportion of soldiers with specific characteristics in each test group should be similar to the general population so that each test group is a microcosm of the population of Infantrymen as a whole. Using random sampling, individuals, fire teams, or squads are simply selected by chance from the parent unit in groups of n soldiers each. The sample size is discussed in the following section.

2.2 Sample Size

2.2.1 The knowledge acquired thus far during the methodology study has contributed immeasurably to the problem of sample size estimation. Given a specific test criteria and the selection of appropriate MOE, the required sample size can be estimated reliably. However, a full scale operational evaluation of weapon performance will entail the use of all test facilities and data will be collected for all small arms MOE. This requires a sample large enough for the worst cases out of several hundred possible combinations of variables. For instance, one combination of variables might be the comparison of rifle performance in the semiautomatic mode on the attack facility at 360 meters using time to first hit. Since the number of hits achieved at this long range would be extremely small, a large number of trials and test soldiers would be required. Consequently, it would not be cost effective to plan for the worst case.

Another method must be used.

2.2.2 Evaluation of the results of the three major field experiments of the methodology study indicate that adequate information can be collected with 96 soldier/rifle systems of each type being tested. This number will provide sufficient replications for each major cell condiction (i.e. combination of variables) for most measures of effectiveness (MOE). This suggested sample size is based on an analysis of the requirements for the most important MOE, number of hits. (Selection of number, of hits as the most important MOE is discussed in Section 3). The rationale for the recommended sample of 96 soldier/rifle systems of each type is described in paragrepgh 2.2.3.

2.2.3. The sample size required to conduct an experiment depends on several considerations. For example the sample size required to place confidence intervals is determined differently than the sample size required to test a given hypotheses. The sample size formula used herein was selected because of its revelence to a test of hypothesis that $\mu_1 = \mu_2$. The formula from Steel and Torre is:

$$r \geq \frac{2(t_o + t_1)^2 S^2}{\delta^2}$$

Where:

r = The sample size per test weapon

t_o = The t value associated with the desired probability of making a Type I error

t_1 = The t value associated with the probability $2(1-P)$ where P is the required probability of detecting a difference of size δ if such a difference exists. The t associated with a Type II error

S^2 = The variance estimate

δ = The difference to be detected

In order to supply t_o and t_1 values to the formula a guess as to what sample size would be required is necessary. A first guess of 60 was made. The desired probabilities of making a Type I and Type II error must also be established. The probability of a Type I error was chosen as .05. This means that when the hypothesis ($\mu_1 = \mu_2$) is true it is desired to have only a .05 probability of rejecting that hypothesis. The probability of a Type II error was chosen as .10. This means that if the difference between μ_1 and μ_2 is as large as δ then the probability of accepting the hypothesis ($\mu_1 = \mu_2$) is .10. The values for t_o and t_1 were thus determined to be 2.0 and 1.296 respectively.

2.2.4 Observations were taken from Defense I Experiment on the number of hits obtained by test soldiers during the entire exercise. An estimate of the variance was calculated and found to be 158. Using this and applying an equation for sample size estimation recommended by Steel and Torre, the sample size is estimated as

$$r = \frac{2(2.0 + 1.289)^2 \, 158.}{(6)^2}$$

$$r = 95.01 \text{ or } 96.00$$

when it is desirable to be able to detect a difference of 6 hits between two rifle systems, which represents approximately 25 percent superiority on the defense facility. The difference observed between the two rifles during Defense Experiment I was six hits per 14-minute trial. Therefore, 96 observations for each rifle should be sufficient for detecting differences as small as 6 hits between competing weapon systems. This sample size is considered the minimum size for a full-scale comparative test. Larger sample sizes will yield increasingly more usable information concerning wepon performance if the resources are available.

2.2.5 Figure 1 gives sample size requirements for different values of ' and three different probabilities of Type II error. A second iteration of the process can be performed using the sample size of the first iteration to look up new values of t_0 and t_1. It was not done here due to the small changes in t values when sample sizes of this magnitude are under consideration.

2.3 <u>Weapon Assignment</u>

2.3.1 In most tests where the performance of people performing a given task with different machines is the subject of evaluation, the best procedure is to rotate the people in such a manner that each person uses each machine. This eliminates many experimental design problems and insures that groups are balanced with respect to the machines. In small arms testing, people performance is not the subject of investigation: the primary interest is the performance of the man/weapon system. The rotation of test personnel from one weapon to another may be a serious source of bias due to unfamiliarity or negative transfer between weapons. That is, if the design of one weapon is more familiar to the test soldier, he may perform extremely well. When rotated to another weapon of different design, he may attempt to use the weapon wrongly or he may use it poorly simply because he is less familiar with its design. If the performance of the soldier were being evaluated, rotation would insure an equal chance for all. However, when performance of the entire system is of primary interest, rotation can introduce a bias.

2.3.2 The method recommended is to divide the entire test group into two subgroups of equal capability. The method used to divide the groups can be a random method, which does not insure equal groups, but minimizes the chances of unequal groups. Another procedure is to use a specifically defined procedure. The recommended method is to measure the soldier's general shooting ability when he fires the standard weapon on a 25-meter range. Performance is measured by determining the mean spread of the shot group of each soldier when he fires at the Canadian bulls-eye. Select the two best shot groups and flip a coin to assign one test soldier to each weapon system. Follow the same procedure for the next two best shot groups, continuing until all test soldiers have been assigned. Other means of assigning weapons may be used. However, this system has been tried three times and in each case statistical tests were run on performance data and no significant differences were found between groups with respect to accuracy of fire on a known distance range.

2.4 Training

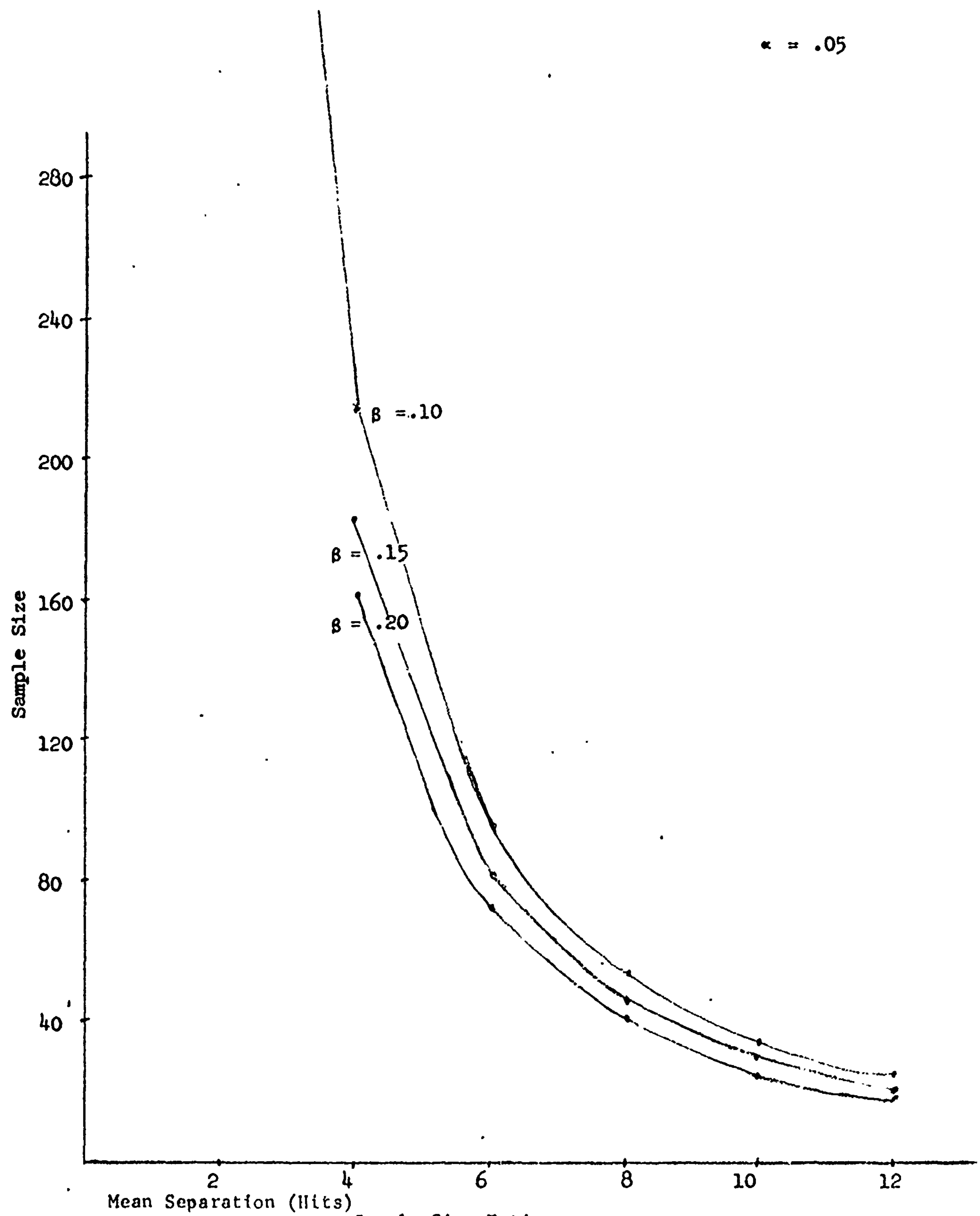
This variable was found to be a significant source of bias in weapon system evaluation. Accelerated training classes of up to three days were held to insure that the test soldier was familiar with the new weapon. In analyzing the results, bias favoring the standard weapon was found. In the time allotted it was not possible to achieve a level of familiarity between the soldier and new weapon that was comparable to the level of familiarity with the standard weapon. The basic Infantry combat training and subsequent experience with the weapon could not be matched for the new weapon in a 3-day training cycle. Indications were that a 2-week intensified course with several hundred live rounds would be required before the bias could be eliminated. This procedure is recommended in future operational evaluations.

2.5 Scheduling

2.5.1 After the soldiers have been selected, assigned to their respective weapon systems, and trained, they must participate in the test by firing on each of the three test facilities. The optimum method of accomplishing the firing is to allow one third of the groups to fire on the defense facility first, then on the attack facility, and finally on the quickfire facility. Another third of the group should begin with the attack facility, and the last third should begin with the quickfire facility. The entire schedule would be:

Test Group

	A	B	C
ATT	1	3	2
QF	2	1	3
DEF	3	2	1

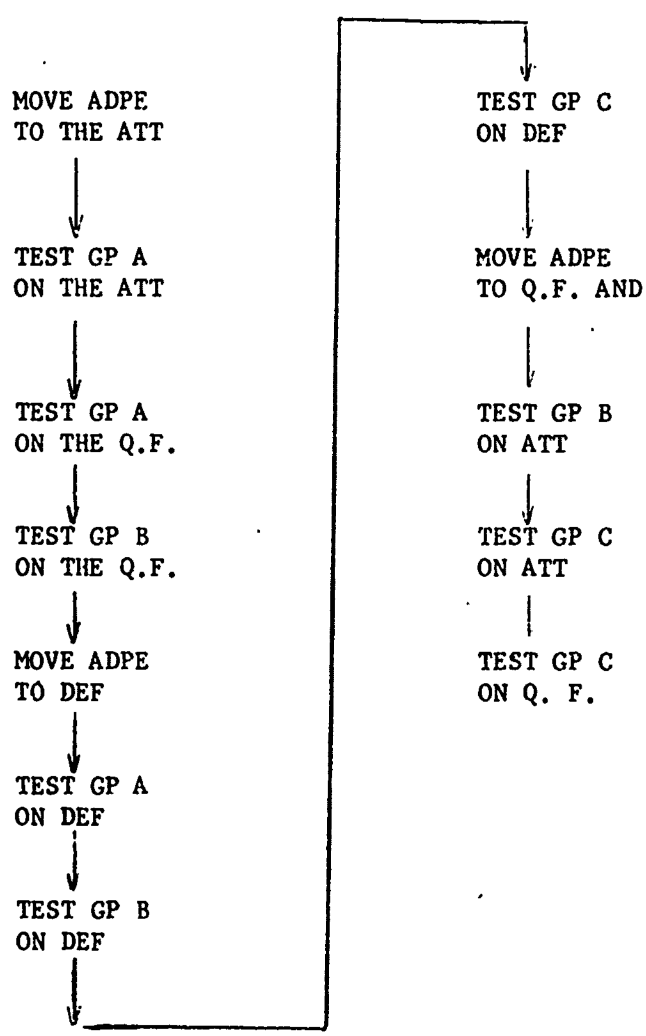


Sam^le Size Estimates
Figure 1

Each third (A, B, and C) fires in a different sequence. Each group contains equal numbers of each weapon system. This design balances the effects of test facility and allows comparisons of performance from one facility to another if desired. The method has definite drawbacks from a practical standpoint since it would require movement of the ADPE three times. See Figure 2.

2.5.2 The alternate method would be to test all soldiers on one facility and then move to the next which would require only one additional move. It is possible that with this procedure each test soldier would improve in performance slightly as he becomes more familiar with the targets and cues of the facilities and hence gathers increasing confidence. If performance on the last facility should markedly improve, for instance, the improvement could not be attributed to the facility's characteristics or the combat situation because of the confounding of the learning factor. Comparisons between facilities using such measures as time to first round would be risky because of the unbalanced design.

2.5.3 Assuming, then, that the former method will be employed, still further balance is required. If two or more modes of fire are used, these must also be balanced in the design. For example in a two weapon-two mode test, group A would consist of one third of the entire group of the 192 test soldiers (using the minimum recommended sample size). Of the 64 members, 32 will be equipped with weapon X and 32 with weapon Y. Each test soldier will fire twice on each test facility, once in each of the two modes (e.g. semi automatic and controlled burst). The schedule for the quickfire facility is shown in Figure 3. The same schedule would be repeated for group members 33-64 and would be repeated again changing the mode of fire for each individual. This same procedure would be used for each of the three groups of 64 test soldiers as they are rotated among the three facilities. A total of 192 trials would be run on the quickfire facility for each weapon type. Figure 4 shows the schedule for the attack facility. The schedule would be repeated for each group of eight soldiers in the 64-man test group.



Schedule of Events Using Balanced Design

Figure 2

TRIAL	GROUP MEMBER	MODE	TRIAL	GROUP MEMBER	MODE
1	X1	S	17	X5	S
2	Y1	S	18	Y5	S
3	X2	S	19	X6	S
4	Y2	S	20	Y6	S
5	X3	S	21	X7	S
6	Y3	S	22	Y7	S
7	X4	S	23	X8	S
8	Y4	S	24	Y8	S
9	X5	CB	25	X1	CB
10	Y5	CB	26	Y1	CB
11	X6	CB	27	X2	CB
12	Y6	CB	28	Y2	CB
13	X7	CB	29	X3	CB
14	Y7	CB	30	Y3	CB
15	X8	CB	31	X4	CB
16	Y8	CB	32	Y4	CB

Legend:

X,Y - Weapon
S - Semiautomatic
CB - Controlled Burst

Quickfire Schedule

Figure 3

TRIAL*	GROUP MEMBERS	MODE
1	X1, X2, X3, X4	S
2	Y1, Y2, Y3, Y4	S
3	X5, X6, X7, X8	CB
4	Y5, Y6, Y7, Y8	CB
5	Y1, Y2, Y3, Y4	CB
6	X1, X2, X3, X4	CB
7	Y5, Y6, Y7, Y8	S
8	X5, X6, X7, X8	S

*Trial - One 4-member fire team per trial

ATTACK SCHEDULE

Figure 4

2.5.4 The schedule shown in Figure 4 can also be used for the defense facility if four firers are to be used. Adjustments in firing group size can be made using up to 10 firers at a time. The same scheduling technique should be employed when scheduling firing groups of different sizes.

3. ANALYTICAL PROCEDURE

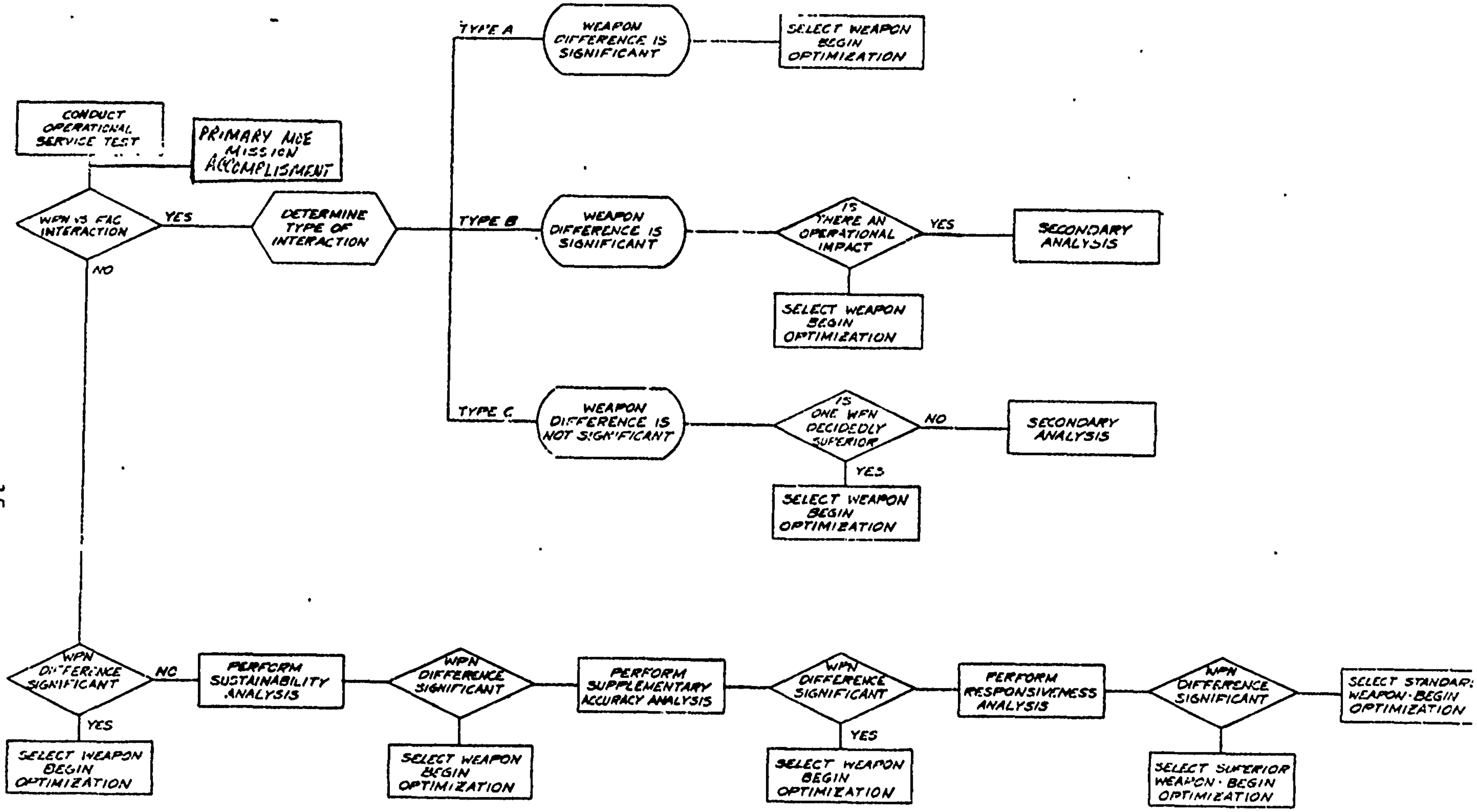
3.1 General Description

3.1.1 This section describes the recommended procedure for analyzing performance using data generated on the Infantry Board's three small arms test facilities. The multi-step process is outlined and described in the following subsections. The flow chart in Figure 5 briefly describes the decision nodes and the resulting analytical steps. The paragraphs that follow provide a general description of the various steps in this procedure.

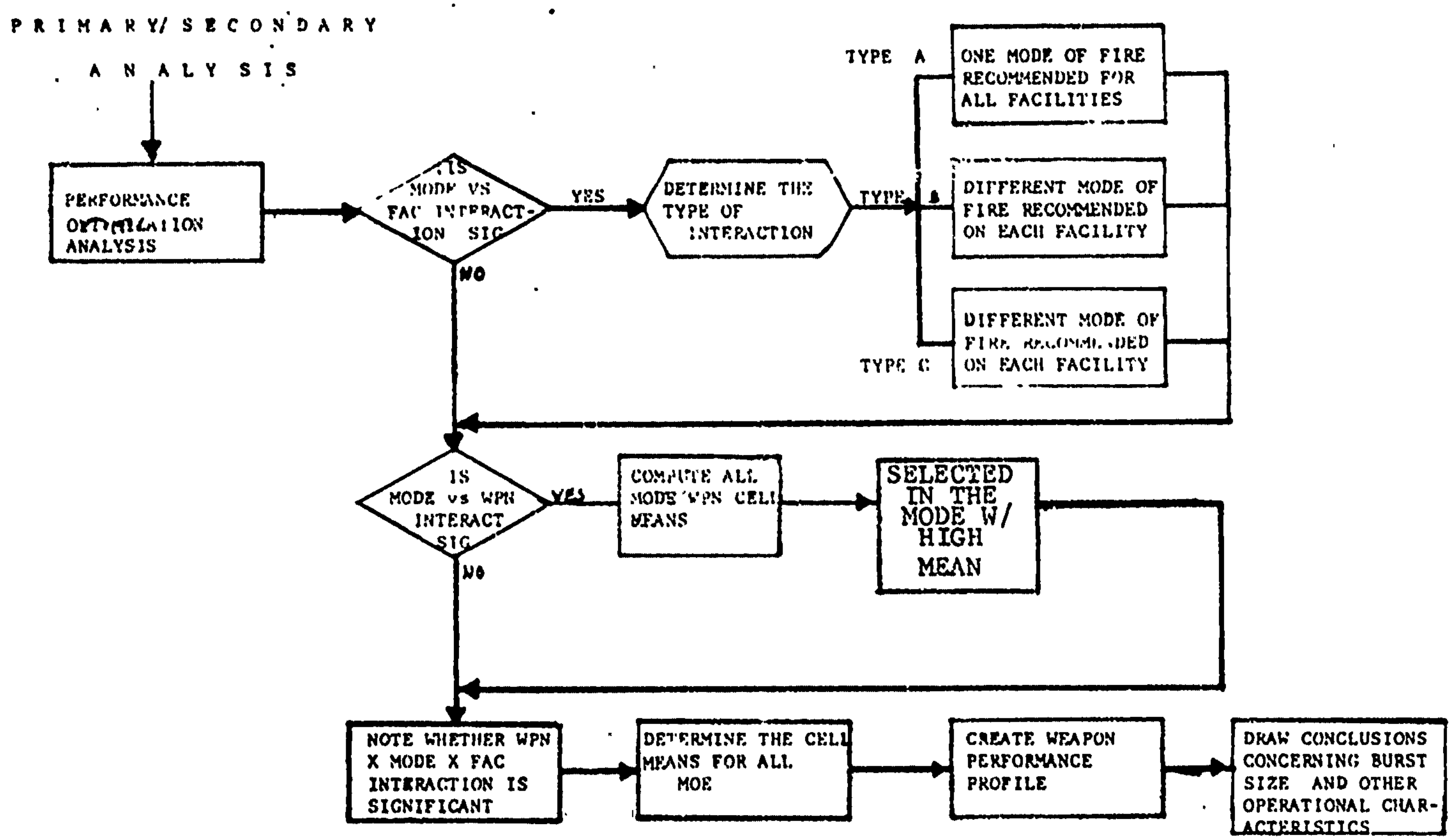
3.1.2 The initial step, the primary analysis, is to determine whether there is a significant interaction between weapons and facilities using the measure target hits. If no interaction exists as determined by an analysis of variance, the analyst then determines whether one weapon system was significantly superior on all test facilities. If one weapon is superior, the analyst proceeds directly to the optimization analyses, which is described in paragraph 3.4. If weapons were not significantly different, the analyst proceeds to the secondary analysis, which is described in section 3.3. The secondary analysis is designed to identify small differences between closely competing weapons.

3.1.3 If an interaction was found during the initial step, the primary analysis must be continued until the interaction is explained or justified. An interaction occurs when the difference between two weapon systems does not remain consistent from one facility to the next. The detailed procedures for this analysis are described in section 3.3.

3.1.4 Both the primary and secondary analyses are terminated when the superior weapon has been identified. At this point, the analysis shifts from a comparative analysis to a performance optimization analysis, as shown in the flow diagram in Figure 6. The objective of the performance optimization analysis is to determine, using the data generated during the service test, the best mode of fire for each tactical situation (e.g. assault, quickfire), the optimum burst size for the automatic mode engagement, maximum effective range, and other pertinent operating characteristics. The data base can be used to pinpoint strengths and weaknesses of the weapon system and, hence, will form the basis for recommendations concerning employment of the weapon system and future improvements. The optimization analytical procedure is described in Section 3.4.



ANALYTICAL PROCEDURE FOR SELECTION OF WEAPONS
FIGURE 5



OPTIMIZATION ANALYSIS
FIGURE 6

3.2 Primary Analysis

3.2.1 Selection of MOE

3.2.1.1 At this initial stage of the analysis, the objective is to determine if an appreciable difference exists between weapon systems. If such a difference exists, the data base and available time can be used to optimize weapon system performance rather than using additional time comparing weapon performance. The earlier in the analysis that the superior weapon system can be identified, the more time can be made available to improve weapon system performance.

3.2.1.2 The primary analysis employs a single measure of effectiveness. The most valid single combat measure is the ratio of friendly to enemy kills. Since the number of friendly kills is a function of the effectiveness of enemy weapons and the ability of the enemy to locate friendly soldiers, this factor can be considered a constant providing one candidate weapon does not require more exposure on the part of the user or have a more identifiable signature than other candidate weapons. The manner in which hand held rifles are used is such that no appreciable differences in exposure have occurred to date. Further, weapon signature is carefully evaluated during engineering tests to insure that excessive blast, smoke, or flash are minimal.

3.2.1.3 Consequently, one primary measure of combat effectiveness is the number of enemy casualties. This type of measure is known as a measure of mission accomplishment where the mission is to close with and defeat the enemy. The small arms test facilities are designed and constructed to represent a slice of life; they simulate, to the extent possible, real combat situations. The facilities require the test soldier to perform the same combat tasks (e.g. long range aimed fire, quick reaction short range fire) required in combat. Because of these factors, the mission accomplishment measure can be equated to the number of targets hit. As long as target presentation scenarios provide realistic presentations and cues, the validity of the relationship between enemy casualties and target "casualties" will remain high.

3.2.1.4 There are many advantages to using a mission accomplishment measure. Almost all MOE are implicitly included in the mission accomplishment measure with respective weighting similar to their relationship to real combat measures. For instance, targets presented in a realistic manner at all ranges consistent with the tactical situation will insure that accuracy measures such as hit probability are appropriately accounted for in the mission accomplishment measure. Realistic scenario length will insure that sustainability is appropriately weighted on the mission accomplishment measure. Weapons that are unresponsive and are difficult to handle due to such problems as poor pointing characteristics or excessive recoil will achieve fewer hits on realistic targets and hence will impact on mission accomplishment.

Since some specific operating characteristics such as optimum burst size are not yet known, the new weapon will be at a slight disadvantage. Most probably, the new weapon will be fired in a manner similar to that used with the standard weapon, which may not be optimum for the new weapon. A burst analysis is recommended regardless of the test outcome to determine whether a significant bias exists. If the burst analysis shows a significant bias, that portion of the service test affected (i.e. the situation which uses automatic fire) must be repeated.

3.2.1.5 There are other advantages to using a mission accomplishment measure. Weapons of grossly different characteristics can be compared directly. For instance, a high rate of fire, multiple projectile, controlled burst rifle could be compared directly to a conventional bolt action rifle using the most valuable single index of performance: the amount of damage inflicted on the enemy. Also, the data are more suitable for use by other agencies in such studies as vulnerability or two sided combat simulation analyses.

3.2.1.6 Mission accomplishment (MA) is defined to be the number of targets hit in a given tactical scenario. This measure is an encompassing measure and has buried within it the effects of most of the measures now considered important. Table summarizes the measures of effectiveness (MOE) and indicates either their inclusion or exclusion from MA. The rationale for the relationship between MA and MOE is given by MOE in subsequent paragraphs.

(1) Distribution of near misses. This MOE is not related to MA as defined above.

(2) Hit probabilities per trigger pull -- semiautomatic mode

(3) Hit probabilities per trigger pull -- automatic mode

$MA \approx^{*} \sum$ [(Trigger Pulls at Range I) x (Ph at Range i) - Duplicate Target Hits]

(4) Engagement hit probabilities.

$MA \approx^{*} \sum$ [(Engagement at Range i) x (Engagement H_p at Range i) x (Average number of targets hit per engagement)]

*The "approximately equal to" is caused by the existence of time constraints on target exposure.

(5) Time to first hit (Targets react to hits). If two weapon systems under test have different time to first hits, i.e., $\mu_a > \mu_b$ where μ_a and μ_b are the average time to first hits per system, then MA is affected because of the limited target exposure time. Consider a distribution of time to first hit for weapon A as depicted in Figure 7 and a distribution of time to first hit as depicted in Figure 8.

Table I

MOE	Attack	Quick Fire	Defense	MA
Distribution of near misses	0	0	0	0
Hit probabilities per trigger pull--semiautomatic	X	X	X	X
Hit probabilities per trigger pull--automatic mode	X	X	X	X
Engagement hit probabilities	X	X	X	X
Time to first hit	X	X	X	X
Time to first round	X	X	X	X
Time between rounds	X	X	X	X
Time between bursts	X	X	X	X
Time between hits	X	X	X	X
Time to shift fire	X	X	X	X
Number of rounds to first hit	X	X	X	X
Hits per pound	X	0	X	X
Time to change magazine	X	X	X	X
Time to recharge magazines	0	0	0	0
Time to clear malfunctions	X	X	X	X
Time between malfunctions	X	0	X	X
Movement times	X	0	0	X
Compatibility with other equipment	X	X	0	X
Ease of handling in the assault role	X	0	0	X
Sound level recording (blast)	0	0	0	0
Light reduction (smoke and haze)	X	0	X	X
Visual light emission (flash)	0	0	X	X
Ejection patterns	X	0	X	X

Figure 7

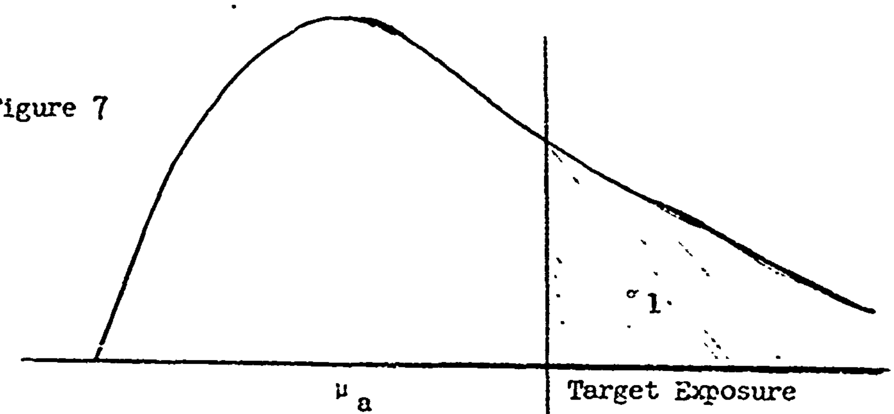
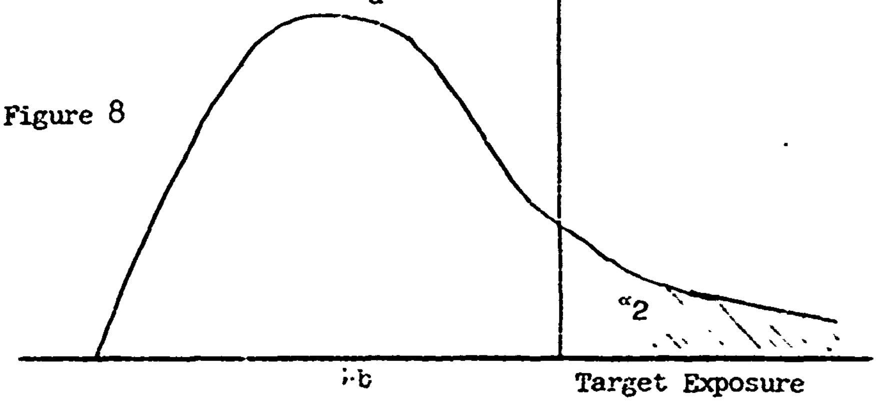


Figure 8



Assuming roughly the same standard deviation for both distribution it is evident from Figures 7 and 8 that the curve in Figure 7 has more area to the right of the target exposure time and as a consequence fewer hits would be achieved resulting in a lower MA.

(6) Time to first round. This MOE is related to MA in the sense that time to first round is correlated with time to first hit. The correlation was found to be approximately .65 in the quickfire experiment 1.

(7) Time between rounds. This MOE is related to MA to the extent that a long time between rounds for one weapon system would indicate interface problems and a failure to get rounds down range decreases the value of MA. Given that each round has a potential contribution to MA, any increase in TBR will reduce MA. The quickfire experiment showed a minus correlation between total rounds fired and time between rounds; total rounds fired had a high positive correlation with effectiveness as defined by the discriminant function.

(8) Time between burst. Same as 7.

(9) Time between hits. Since targets are normally exposed for a selected period, an increase in time between hits will decrease mission effectiveness. The logic follows that described for MOE number 7, above.

(10) Time to shift fire. This MOE is a good indicator of man/weapon interface problems. A weapon system that performs poorly with respect to this variable would decrease MA, because a soldier is not placing fire on new targets as soon as he could.

(11) Number of rounds to first hit. Related to item number 5, above.

(12) Hits per pound. This is a measure of total potential weapon system lethality expressed as a function of total system weight. It is part of the mission accomplishment measure to the extent that the test scenarios are of realistic length. If scenarios are patterned after realistic defensive and attack actions, this measure will affect the mission accomplishment measure. As ammunition begins to run low, the test soldier will reduce his firing rate to conserve ammunition. As the rate is reduced or if the test soldier expects all of his basic load, the number of targets hit will be reduced thus an impacting is felt on the mission accomplishment measure.

(13) Time to change magazines. If magazine change time takes longer for one weapon and the scenario is sufficiently taxing then this shortcoming would be reflected in MA for that weapon.

(14) Time to recharge magazines. Not related to MA due to the manner by which this MOE is collected.

(15) Time to clear malfunctions. An undesirable weapon performance on anyone of MOE 15 or 16 has the effect of taking the weapon of action thus causing a reduction in MA.

(16) Number of rounds between malfunctions. See item 15.

(17) Movement times. Any weapon characteristic that effects movement time, ease of handling in the assault and perhaps compatibility with other equipment would cause a degradation in MA on the attack facility. A slight problem reflected by these MOE would probably be non-detectable by MA.

(18) Compatibility with other equipment. See item 17.

(19) Ease of handling in the assault role.

(20) Sound level recording. Not part of MA.

(21) Light reduction (smoke and haze). A weapon performance that in any manner obscures targets would cause a reduction in MA for that weapon.

(22) Visual light emission (flash). This could effect the MA for night test by affecting the individual's darkness adoption.

(23) Ejection Patterns. This MOE would only effect MA if the pattern caused the firer or adjacent firer any discomfort that would tend to reduce his effectiveness.

3.2.1.7 Since most of the MOE are an integral part of the primary measure, a weapon system that proves to be superior in terms of the mission accomplishment measure on all test facilities may be selected immediately. There is no need to continue the comparative analysis since the superior weapon system has been identified. Emphasis should be placed on the analysis of various MOE to determine whether performance could be improved even more. For instance, although hit probabilities will be adequate at all ranges, they should be examined to determine whether improvements are possible. Time between bursts should be examined to see if modifications could improve the soldier's ability to cope with recoil, reacquire the target, or lay the sights more quickly and effectively. Other areas where potential increases are possible are in optimizing burst size, mode of fire, and training procedures. This type of analysis which is designed to optimize weapon system performance differs from the comparative analysis of weapon system performance. Therefore, it is important to determine as quickly as possible which candidate weapon is superior in order to maintain proper orientation of the analysis: optimization vs selection.

3.2.1.8 Table 1 shows that 3 measures are not accounted for in the MA measure: round level, time to recharge magazines, and near miss distance. Engineering and safety tests normally monitor such weapon characteristics as signature effects to insure that the weapon is safe to fire. The tactical significance, however, is not accounted for objectively. Military experience must be used to evaluate the effects of differing signature characteristics as these characteristics affect the vulnerability of the individual, the probability that he will be detected by the enemy. Time to recharge magazines can easily be measured as magazines are being prepared for use in the tactical test. If significant differences are found, these differences should be noted by the test officer. The impact on the tactical situation can be estimated by requiring test soldiers to load their own magazines during the simulated fire fight on the defense facility. Finally, miss distance is not included in the MA measure since suppression is not a parameter of the test facilities; however, these data can be used in the secondary analysis as a part of the supplementary accuracy analysis.

3.2.2 Technical Approach

The technique for performing the primary analysis is a 3x2x2 factorial experiment. The factors are facilities, weapons (assuming 2 weapons) and modes of fire (assuming 2 modes). The linear model is:

$$Y_{ijkl} = u + F_i + W_j + M_k + (FW)_{ij} + (FM)_{ik} + (MW)_{jk} + (FMW)_{ijk} + e_{ijkl}$$

Where:

u = the overall mean

F_i = i^{th} facility effect

W_j = j^{th} weapon effect

M_k = k^{th} mode effect

Y_{ijkl} = observation corresponding to the l^{th} soldier using the k^{th} mode of the j^{th} weapon on the i^{th} facility

e_{ijkl} = random error corresponding to the l^{th} soldier using the k^{th} mode of the j^{th} weapon on the i^{th} facility

The analysis of variance to be performed is shown in Figure 9. The paragraphs below are referenced in Figure 6 and describe the meaning of a significant difference and the steps to be followed should the F-value for a variable or combination of variables be significant.

Source	df	ss	ms	F	Significance*
Facilities	2			A	None
Weapons	1	Sum	Mean	B	If D significant Secondary Analysis
Mode	1	Of	Squares	C	Secondary Analysis
Fac X Wpn	1	Squares		D	Primary Analysis
Fac X Mode	1			E	Secondary Analysis
Wpn X Mode	1			F	If B significant Secondary Analysis
Fac X Wpn X Mode	2			G	Primary Analysis
Error					
Total					

Primary Analysis of Variance
Using Hits on Targets

Figure 9

*Significance:

A - A significant F-value for facilities simply means that more hits are obtained on one facility when compared to the other facilities. This difference is due to the differences in number of targets exposed and time of exposure and has no meaning in terms of weapon evaluation.

B - A significant F-value for weapons states that one weapon system has overall superiority to the other weapon(s) on the facilities. This finding is based on the assumption that the facilities represent a realistic slice of life and that other factors such as weapon signature and exposure have been considered. This test also assumes that weapons submitted to operational effectiveness testing have achieved an acceptable level of reliability and durability.

C - A significant value for mode states one mode is overall superior to another on the test facilities and initially indicates that the weapons should be used in the superior mode at all times.

D - A significant F-value for this interaction implies that one rifle may not be consistently superior on all test facilities, i. e., one weapon may be superior under one combat condition but inferior in another. This result will require continuation of the Primary Analysis and is discussed in the next subsection, 3.2.3.

E - A significant F-Value indicates that one mode is possibly superior on one facility but inferior on another. Proceed to the secondary analysis since the results indicate the optimum mode for each facility or combat situation.

F - A significant F-value indicates that one weapon is possibly superior in one mode but inferior in the other mode. If B above was significant, the next step is to proceed to the optimization analysis. If B was not significant, the next step is to begin the secondary analysis.

G - A significant F-value here is more difficult to interpret. It indicates a significant interaction between the three variables and is known as a second order interaction. If this should occur a specific analysis will have to be undertaken to determine the cause. At times, the second order interaction may be explained in terms of the first order interactions. The exact analytic approach will depend on the first order interactions and the composition of the data base. Decisions concerning the method of reduction of the interaction effect should be made after the interaction occurs. It is not practical to try to account for all possible causes of possible second order interactions.

3.2.3 Interpretation of the Interaction

3.2.3.1 This stage of the analysis was reached because of a significant interaction between weapons and facilities as indicated by a significant F-value in the initial analysis of variance test (the F-value of the D or G analysis Figure 9). If no interaction occurred at D or G, the analyst should proceed directly to the secondary analysis, section 3.3. The interaction will have occurred if one weapon proves superior on one facility but inferior on one of the other facilities.

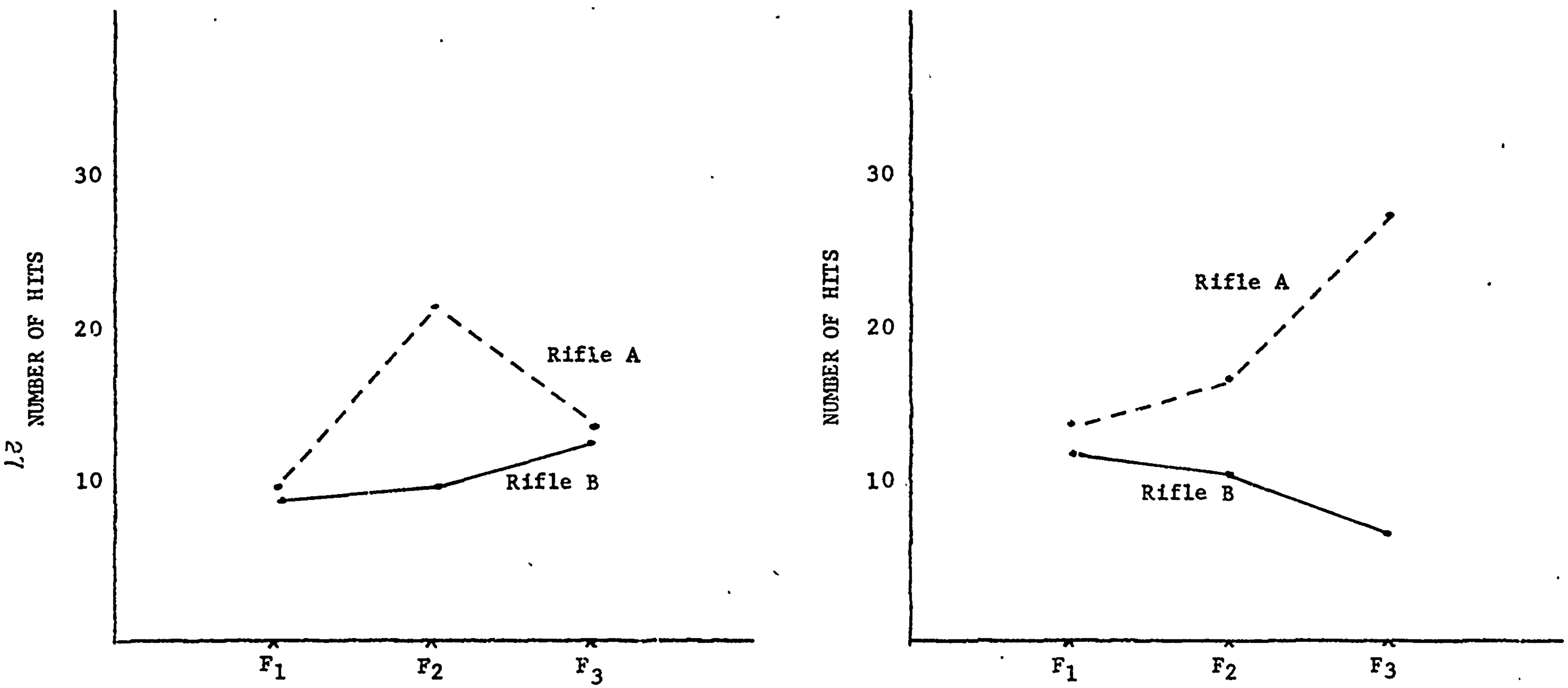
3.2.3.2 The first step in this phase of the analysis is to graph performance means using number of hits for the three test facilities. If an interaction was present, the resulting graph would be similar to one or more of the types of interactions shown in Figures 10, 11 and 12.

3.2.3.3 Figure 10 is called a Type A interaction and shows that one weapon system is consistently superior to the other weapon system. If this type of interaction occurs the analyst may proceed directly to the Optimization Analysis.

3.2.3.4 Figure 11 shows two possible Type B interactions. This type of interaction indicates that there was a significant difference in performance between the competing weapon systems, but the differences were not consistent across facilities. The analyst at this point must determine whether an explanation exists for these results. For instance, referring to the left hand graph in Figure 11, perhaps rifle A had extremely good point fire, close range effectiveness which could be expected from a shotgun or other multiple projectile weapon. The facility (F_2) would be the quickfire facility. The decisions must now be made whether the improvement in the quickfire role is operationally significant, that is, large enough to compensate for the poor performance in the attack and defense roles. Such a decision would be based on the frequency of the occurrence of the types of combat actions. Such operations as fire and movement, hasty defense, retrograde operations, and deliberate defense occur far more frequently than such quickfire operations as combat in cities. If it is felt at this time that the differences are operationally significant, the analyst must proceed to the secondary analysis. If the differences are not operationally significant, the superior weapon should be selected, and the analyst should proceed to the optimization analysis.

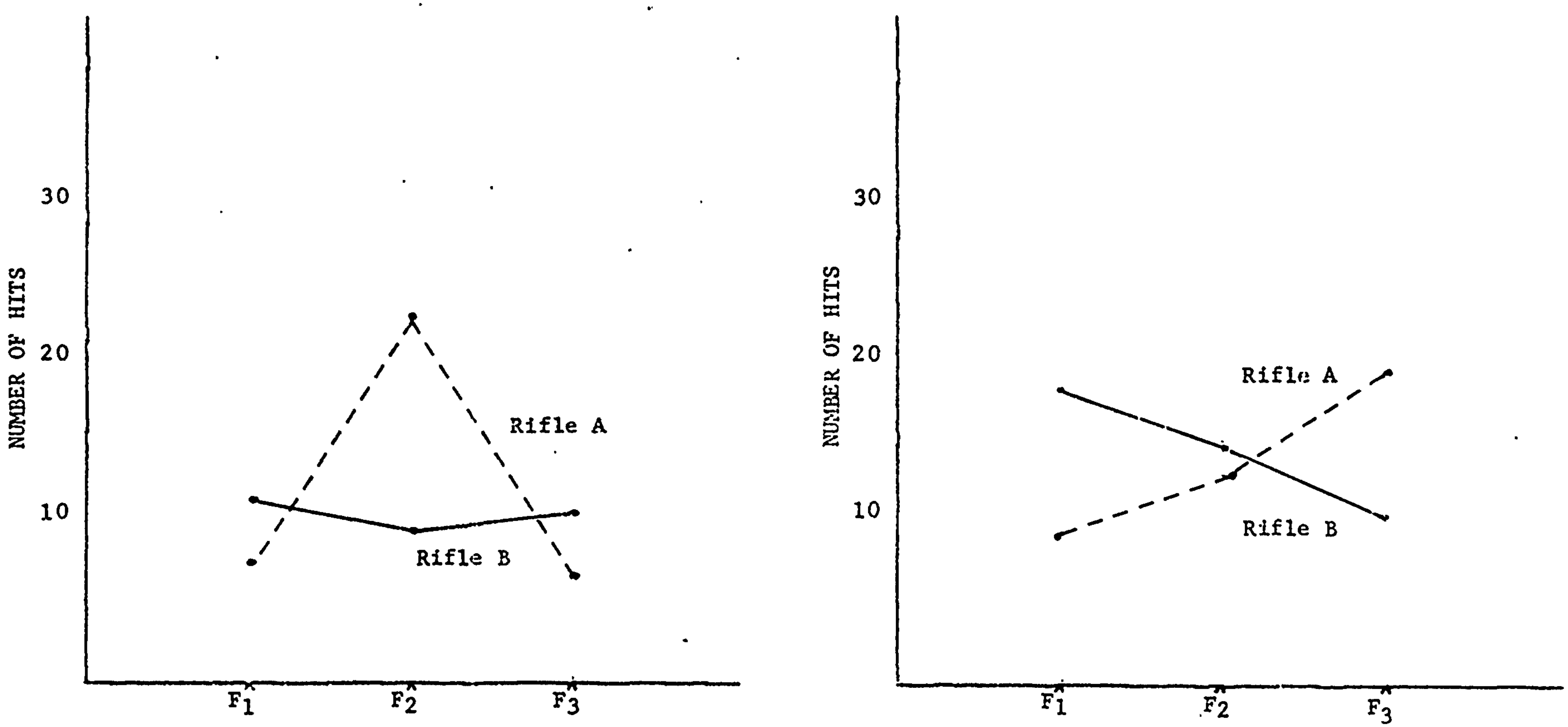
3.2.3.5 Figure 12 shows the Type C interactions. These interactions are similar to the Type B interactions, but the differences in performance are of much smaller magnitude. No significant differences were found between weapons although there was a significant interaction. Essentially the same decision must be made here as was described in the preceding paragraph. However, in this case, there should be a strong tendency to reject the new weapon system in favor of the standard weapon. If this is done, the secondary analysis may be eliminated and the optimization analysis selected.

3.2.3.6 If the graphing technique fails to explain to the source of the interaction, a second procedure is recommended. The procedure is to construct a two-way table (Figure 13) with entries equal to the sum of the observations for each weapon/facility (WF_{ij}) combination where i stands for the i^{th} weapon and j for the j^{th} facility.



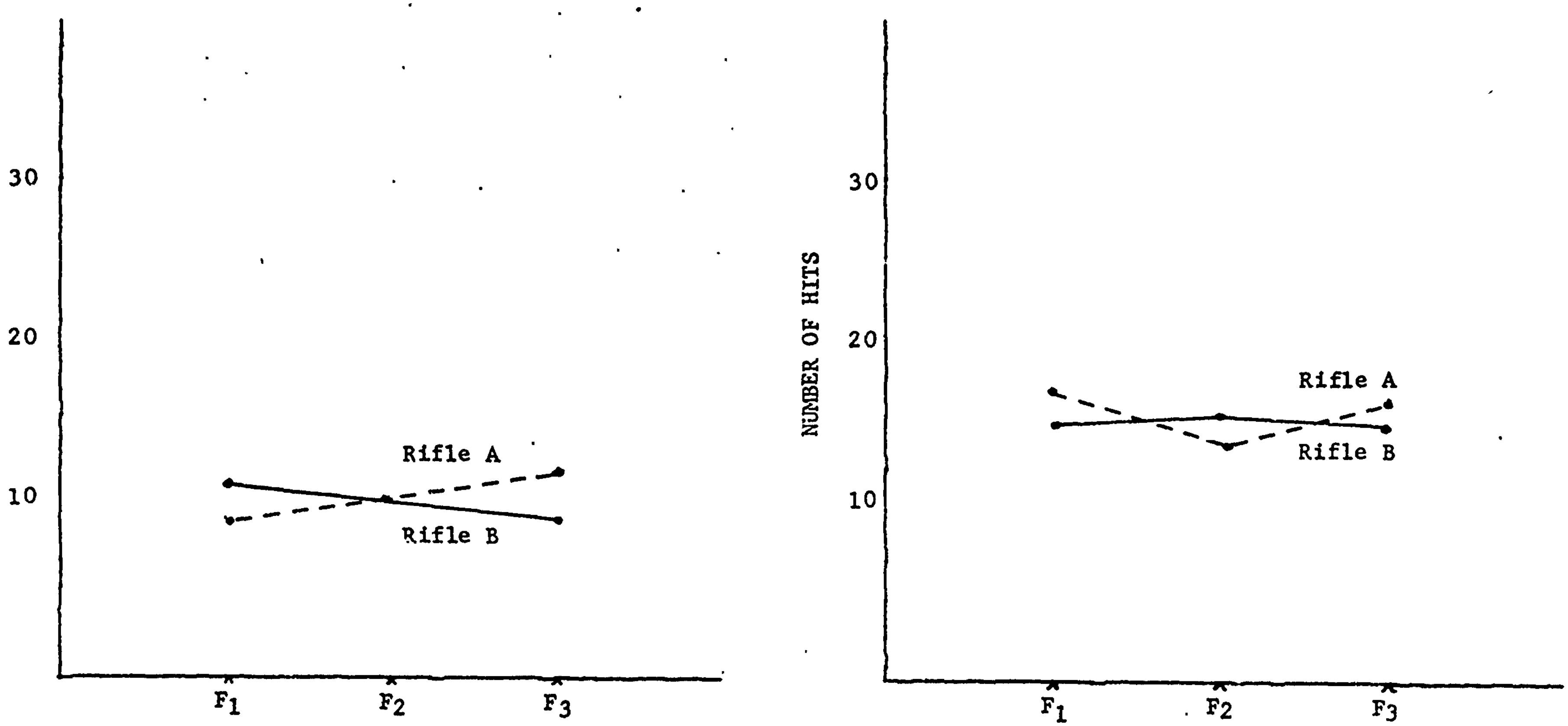
TYPE A INTERACTIONS

FIGURE 10



TYPE B INTERACTIONS

FIGURE 11



TYPE C INTERACTIONS

FIGURE 12

	Weapon		
	W_1	W_2	$W_2 - W_1$
Facility F_1	W_1F_1	W_2F_1	$W_2F_1 - W_1F_1$
F_2	W_1F_2	W_2F_2	$W_2F_2 - W_1F_2$
F_3	W_1F_3	W_2F_3	$W_2F_3 - W_1F_3$

Two-Way Table of Interactions

Figure 13

The next step is to compute the sums of squares for each sample effect. This is accomplished by using the following functional relationships:

a. Weapons with Attack Facility

$$ss = \frac{(W_2F_1 - W_1F_1)^2}{2\ r\ m}$$

b. Weapons with Quickfire Facility

$$ss = \frac{(W_2F_2 - W_1F_2)^2}{2\ r\ m}$$

c. Weapons with Defense Facility

$$ss = \frac{(W_2F_3 - W_1F_3)^2}{2\ r\ m}$$

where r is equal to the number of test soldiers in the test condition and m equals the number of firing modes used. Each of the ss values is tested for significance with the error value which appears in Figure 6 using an F-test. If no significant differences are detected, the performance of the competing weapons systems is essentially identical on all three facilities with respect to target hits. There is no justification for selecting the test weapon in terms of performance. Consequently, based on the operational testing, the standard weapons should be retained. The data base should be analyzed for possible inconsistencies in the standard weapons's performance using the optimization analysis.

3.2.3.7 If there are significant differences, the particular test will indicate where the inconsistency is, i.e., on which facility(s) the comparative performance differed. Such inconsistencies will necessitate moving to the next phase of the analysis, the secondary analysis.

3.3 Secondary Analysis

3.3.1 Selection of MOE

3.3.1.1 The second step in the analysis occurs when the performance of competing weapon systems is found to be very close. For example, this will occur if one weapon system is found to be superior in the defensive situation and inferior in the attack situation with no logical explanation for the interaction effect. Several selected MOE are analyzed in a series of analytical steps (see Figure 5).

3.3.1.2 The initial step is the sustainability analysis which provides an estimate of the staying power of the weapon system in addition to that which is built into the primary MOE via the target presentation scenario. Several MOE could be selected including number of trigger pulls, hits per pound, hits per basic load, number of trigger pulls per basic load, and the number of combat minutes per basic load. From these, the measure hits per pound has been selected as the most meaningful measure since it incorporates two weapon characteristics, weight and accuracy. A soldier's combat effectiveness consists primarily of what he can carry into combat; the lethality per pound of resource becomes the most meaningful measure and permits direct comparison of varied ammunition types in terms that are meaningful in the combat environment. A second measure has been added as a final check, the number of potential hits per basic load. Ordinarily the hits per pound measure will provide the information required. However, if the weapon component of the man/weapon systems being compared differ markedly in weight, the difference will normally be accounted for in terms of the weight of ammunition carried. Therefore, it is necessary to know the number of pounds carried in the basic load. A more descriptive method of treating this variable is to express it in terms of potential hits per basic load. If the lethality of the ammunition varies between weapons, the kill-given-a-hit probability will have to be added to make the measure even more meaningful. The measure then becomes kills per basic load.

3.3.1.3 The next step is an accuracy analysis. This has been accomplished to a large extent during the initial analysis using the primary MOE. However, in the case of close competing weapons, it is necessary to insure that effectiveness is consistent over a broad spectrum of range distances. If the scenarios are poorly designed, it would be possible to get an overkill on targets at close ranges which would inflate the number of hits per trial or per pound in the sustainability analysis. An effective all-purpose weapon must provide effectiveness at all ranges associated with Infantry combat. The measure used in this supplementary accuracy analysis is hit probability per trigger pull, which permits a direct comparison of weapon performances which is independent of the number of projectiles per round, the number of rounds per burst, and so on. A given weapon system with its basic load has n number of trigger pulls. The number of trigger pulls multiplied by the hit probability equals the expected number of kills for a given range. Comparative performance at all ranges will be the basis of the accuracy analysis.

3.3.1.4 A second measure of accuracy effectiveness is near miss distance. If performance is essentially equal in terms of target kills, the next most important item is fire suppression which can be defined as a temporary combat kill. However the parameters associated with suppression are not well understood. Thus far the analysis has based selection of weapons on the criteria, number of targets hit, because of the assumption that the realistic test facilities provide a positive relationship between target hits and the number of enemy soldiers that would be hit in similar combat situations. There is no known method for equating near misses or fire suppression to the survival probability of enemy or friendly troops. Therefore, suppression (or near misses) is not recommended as a criteria for weapon selection at this time. The near miss data are recommended for use during the optimization analysis as an indicator of weapon accuracy. This measure of dispersion should be useful in isolating interface problems such as difficulty in achieving a fine sight picture.

3.3.1.5 Should comparative performance remain very close between competing weapons, it is necessary to proceed to the next analytic step, the responsiveness analysis. Responsiveness is primarily measured on the quickfire facility and is used to determine handling characteristics of the weapon. As mentioned in Section 1, several measures are available. The measures selected are time to first round, time to first hit, time to shift fire, and time between trigger pulls. Each provides an estimate of man weapon performance in terms of the man/weapon interface. The first measures ease of alignment and accuracy; the second measures ease of target reacquisition and realignment; the third measures how well the soldier copes with recoil and target obscuration, especially in the automatic mode.

3.3.1.6 At this stage of the analysis, if no performance differences are found on which justification for weapon selection can be made, the weapons can be assumed to be equally effective in combat. If no other rationale exists such as reliability, cost, or safety for weapon selection, the standard weapon becomes the "superior" weapon simply because it is already available and in the inventory without the tremendous costs associated with the procurement of a new weapon system. Although not shown on the flow chart, reliability is measured by the number of rounds between malfunctions. These data do not enter into the decision criteria because of lack of sample size. Reliability, number of rounds between failures (NRBF) will be measured far more accurately during the engineering test phase and other phases of the service test. Consequently, it is assumed that a reliable weapon would not have reached the operational test phase. However, a reliability analysis should be done with NRBF to insure that an operational reliability problem has not been overlooked. Any reliability problem that occurs with this relatively small sample of live fire should receive major consideration and should be resolved before any decision is made to select a superior rifle system based on operational performance.

3.3.2 Technical Approach

3.3.2.1 Sustainability Analysis

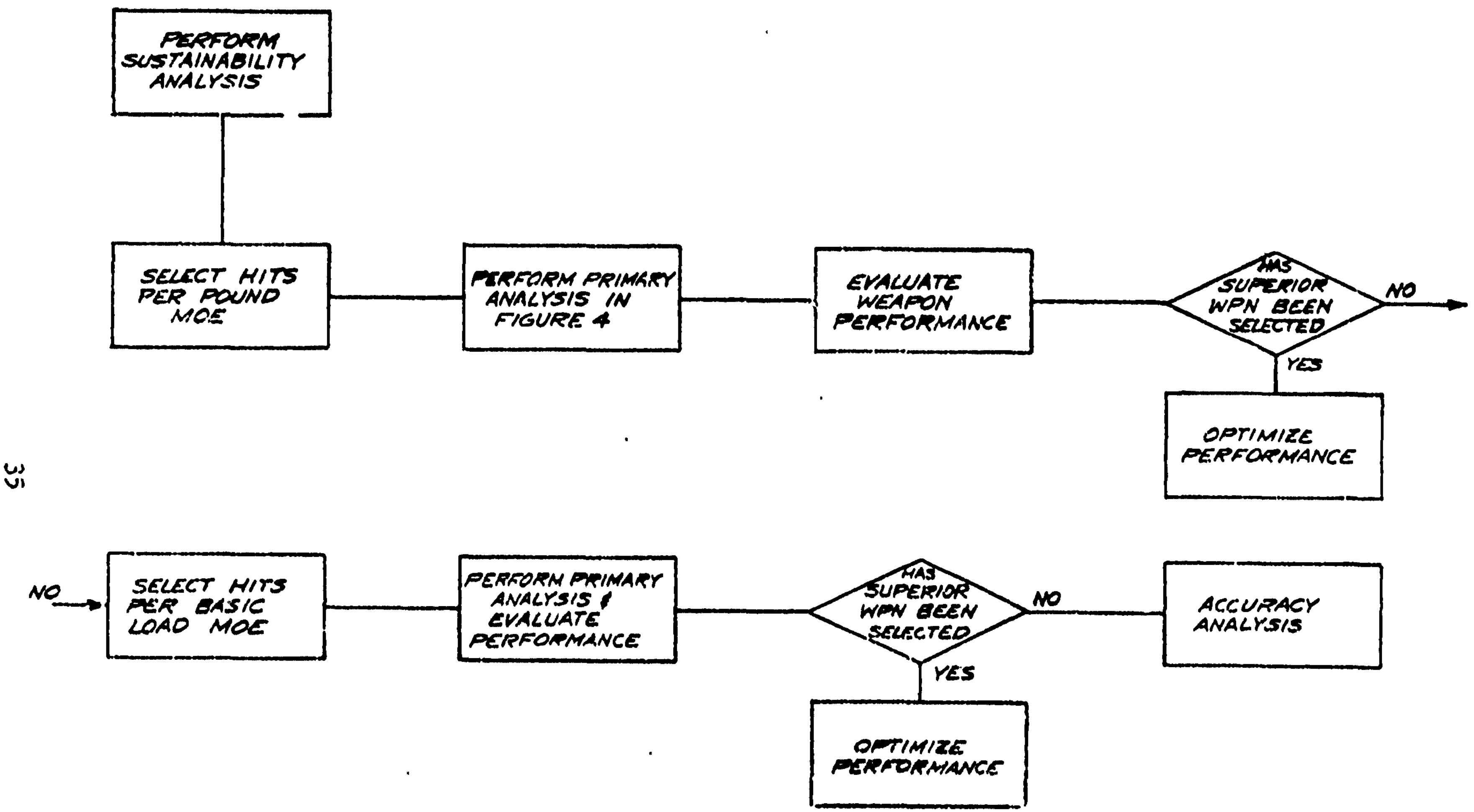
Since one test weapon failed to establish a clear superiority over the competing weapon(s), the next effort is to move to more detailed analyses using other MOE. With no difference in hits, the number of potential hits that a soldier can carry into combat becomes an important criterion. In the case of sustained fire fights or in situations where resupply becomes difficult or costly, sustainability assumes increasing importance. Therefore, although there were no differences using target hits on the three test facilities even though the trials were sufficiently long to duplicate combat fire fights, there is some desirability and utility value in having a good ammunition supply.

Figure 14 is a summary flow chart of the sustainability analysis. The initial test is to compute the number of hits per pound of ammunition. The analysis of variance statistical test that is shown in Figure 5 is used. The entire 2x2x3 factorial analysis is repeated. If the analysis still fails to show a clear superiority, a comparison of rifle hits per basic load is made again repeating the entire statistical procedure. Hits per basic load yields the number of potential hits in the basic load and weights the outcome in favor of the largest basic load. All other factors such as lethality are assumed to be equal. If lethality is not equal but known from laboratory tests, the number of potential kills per basic load can be estimated and used instead of hits per basic load. The equation below can be used to determine the kills per basic load for each man. The analysis proceeds as in the primary analysis previously outlined.

$$\text{Kills} = P_h \times \text{lethality} \times \text{basic load}$$

$$\text{where lethality} = \frac{\text{Number of kills}}{\text{Number of hits}}$$

If at the conclusion of the sustainability analysis, no clear cut difference between weapons has been determined, the next step is to proceed to the supplementary accuracy analysis.



SUSTAINABILITY ANALYSIS

FIGURE 14

3.3.2.2 Supplementary Accuracy Analysis

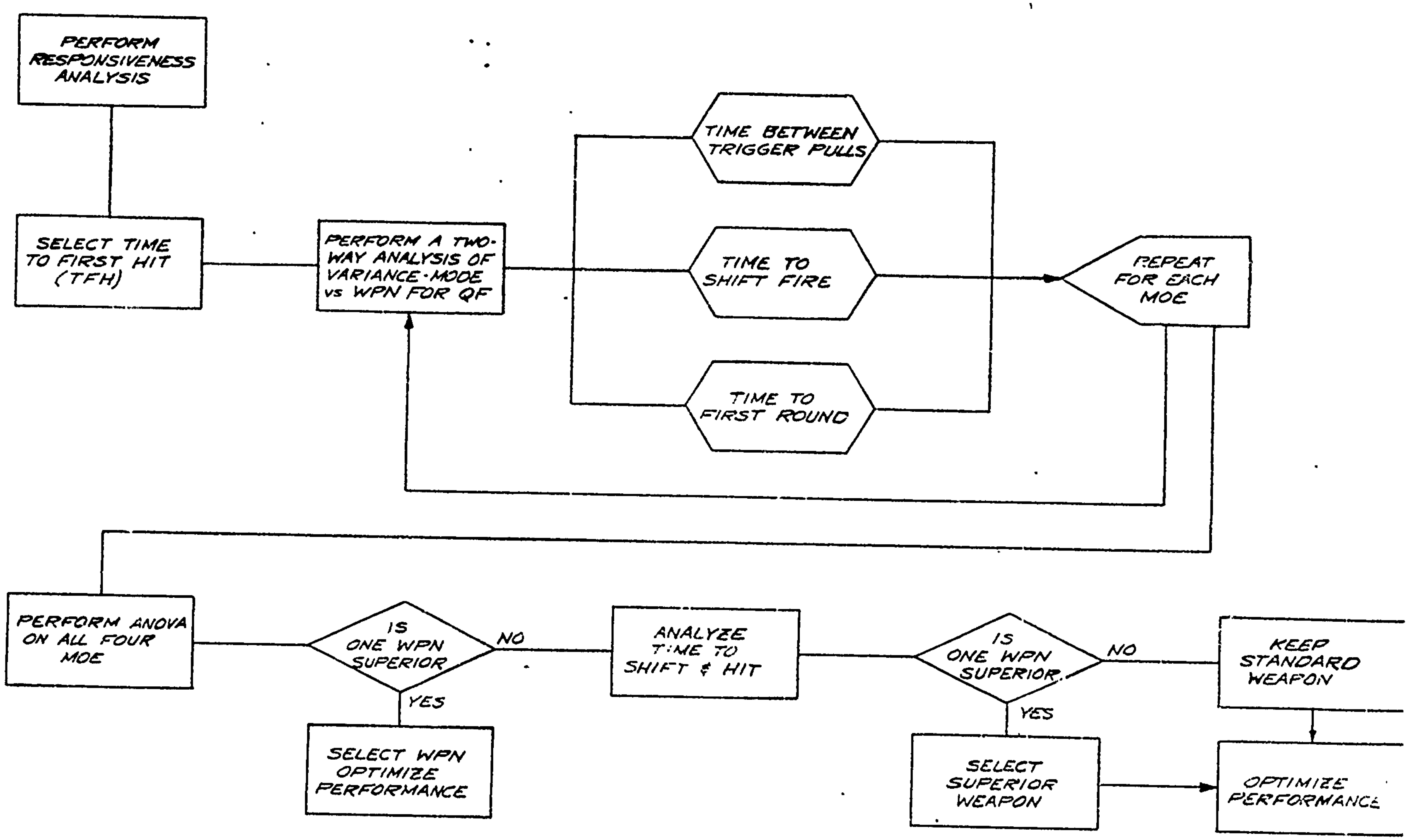
If no rifle selection has been made at the conclusion of the sustainability analysis, the next step is to repeat the primary analysis using hit probability per trigger pull. Since no differences occurred in terms of target hits, it is unlikely that significant differences will occur here. However, before proceeding further, it is desirable to insure that weapon performance is relatively equal with respect to range. If the capabilities varied significantly with respect to range, it is likely that the test officer would be aware of a potential problem before this stage in the analysis is reached. This analysis will provide a check and will yield hard data on performance with respect to range as a safeguard against a possible discrepancy. For example, such a problem could occur if a shotgun or other short range weapon were compared to a slow rate of fire, highly accurate weapon. The latter would achieve a few hits consistently over the entire range spectrum producing an exponential curve. A rapid firing shotgun could produce a large number of close range hits such that the total hits would be equal even though there is a decided difference in capability. This supplementary test will provide a picture of performance at all ranges. This output will also be referred to during the optimization analysis. If a significant difference does occur during this test, this is an indicator that the test scenario was unrealistic in terms of target exposure. Close range targets probably were allowed to remain in view too long, permitting an excessive number of hits at close range. Before proceeding, any discrepancy between the results of the targets hit analysis and the hit probability analysis will have to be explained.

3.3.2.3 Responsiveness Analysis

The responsiveness analysis is associated with the quickfire situation only, since the type of action required (quick violent response to target cues) is inherent in the attack and defense only to a limited extent. Therefore, these data would not be used as selection criteria until all other tests failed to provide a basis for weapon selection. Performance in the attack and defensive situations must be considered before responsiveness data come into consideration because of the frequency with which attack and defensive combat actions take place as compared to quickfire situations.

The responsiveness analysis consists of four iterations through a two-way analysis using responsiveness MOE (see Figure 15). If one weapon system fails to show superiority with all four MOE, data are combined to form a fifth measure, time to shift fire and achieve a second hit. This combat task requires the test soldier to hit two targets in rapid succession. This approach is based on the analysis of the quickfire 1 data which indicated that the two best discriminators were time to first hit and time to shift fire. This new measure combines both of these and should discriminate if there is any real significance between weapons.

If after proceeding through this entire secondary analysis no selection has been made, it can be safely assumed that no real operational performance differences exist. The analyst should proceed to the optimization analysis to improve the standard rifle's performance to the extent that time permits. If a selection has been made prior to reaching this point, the optimization analysis already has begun with the superior weapon system, either the standard of the test rifle.



RESPONSIVENESS ANALYSIS
FIGURE 15

3.4 Optimization Analysis

3.4.1 Selection of MOE

All available MOE are candidates for use in the optimization analysis. The analysis is designed to present as complete a picture of rifle performance as possible to insure that the operational characteristics are thoroughly understood. The analysis should indicate strengths and weaknesses of the weapon system. The MOE recommended for use are summarized below:

3.4.1.1 Attack Facility MOE

a. All hit probabilities

b. Miss distance

c. Time between rounds

d. Time between hits

e. Time to first hit

f. Movement times

g. Time to shift fire

h. Time to change magazine

i. Number of rounds to first hit

j. Ease of handling in assault role

k. Compatibility with other equipment

3.4.1.2 Defense Facility MOE

a. All hit probabilities

b. Miss distance

c. Time to shift fire

d. Time to change magazines

e. Time to recharge magazines

f. Time to clear malfunctions

g. Number of rounds between malfunctions

h. Sound level

i. Light reduction

j. Visual light emission

k. Ejection pattern

3.4.1.3 Quickfire Facility

a. Time to first round

b. Time to first hit

c. Hit probability - semi-automatic

d. Hit probability -automatic

d. Time between trigger pulls

f. Time to shift fire

g. Rounds fired

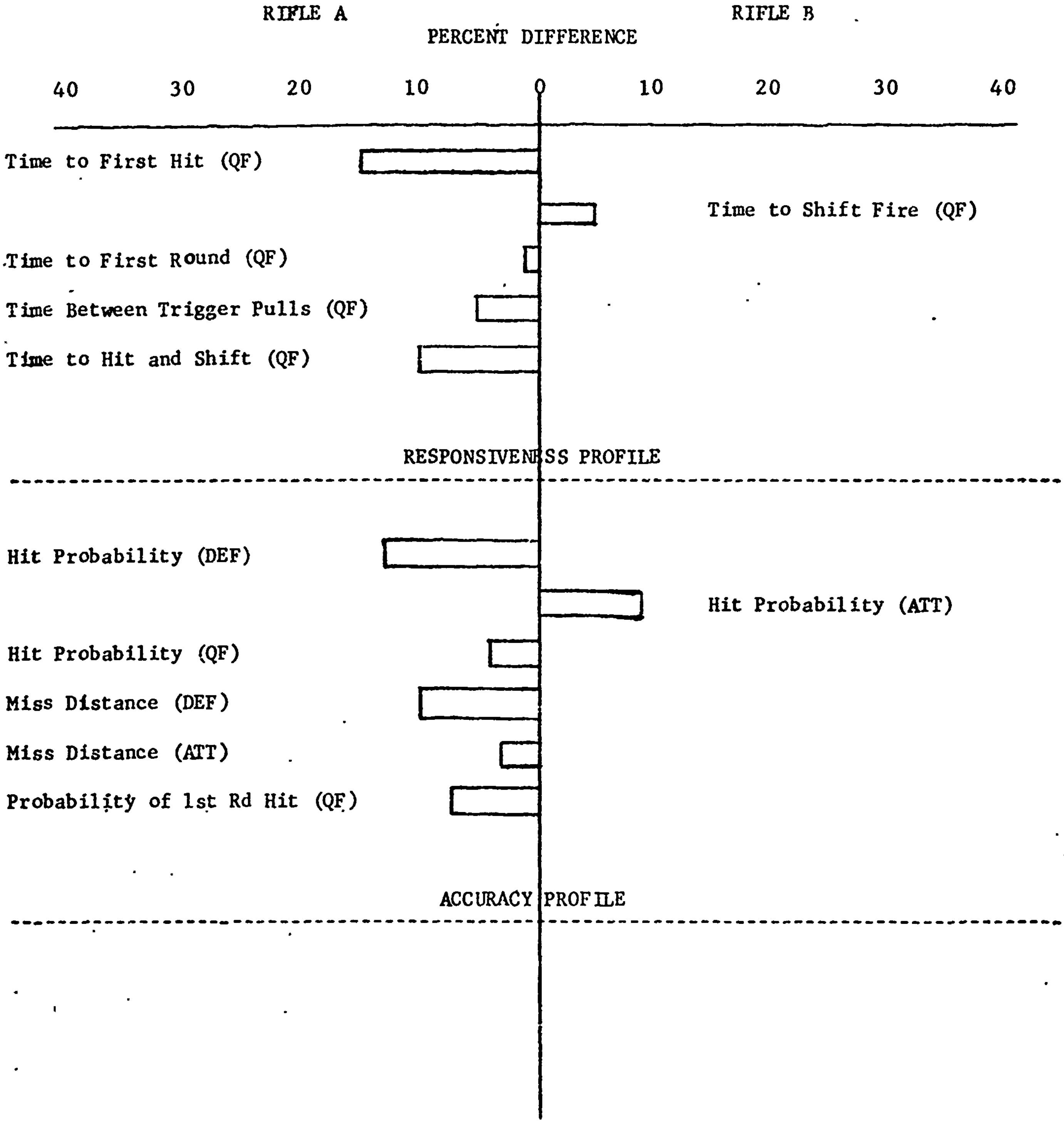
h. Miss distance

3.4.2 Technical Approach

3.4.2.1 Introduction - The technical approach assumes that in any comparative test between rifles, the rifle which is not selected as the superior weapon system will produce data which are valuable in comparing the relative strengths and weaknesses of the two weapon systems. In fact, the "inferior" rifle may exceed the selected rifle in performance with some MOE. The comparing of performance, then, is a useful method of determining operating characteristics which could possibly be improved. For example, in Figure 6, a performance profile is shown for two weapons. The X-axis is the percent difference between the weapons and the Y-axis contains a set of selected MOE. The graph shows that the selected weapon is generally superior with the exceptions in time to shift fire and burst hit probability. These would be indicators that possibly some characteristics from the inferior rifle could be transferred to the selected weapon to improve its responsiveness capability. The following paragraphs describe several useful techniques which are available for isolating meaningful differences in close competing weapon systems using quantitative MOE. The more qualitative MOE (visual light emission, ejection patterns) must be analyzed subjectively and are not included in this analysis.

3.4.2.2 Pictorial Analysis - The first analytical technique for optimizing weapon system performance is to prepare graphs showing weapon system performance as a function of weapon, mode, range, and facility using a variety of MOE. The analyst must search for anomalies in the data base, which will appear as extreme changes in curve shape or extreme fluctuation from point to point. As performance is examined as a function of range, for instance, the analyst should note the characteristics of the curve. Is it smooth? Does it reach the x-axis prematurely indicating poor performance at extreme ranges? Does performance change appreciably from one test facility to another? For instance, a longer time between rounds on the quickfire facility might indicate difficulty in handling the weapon when used in the off-hand position. Potential problems noted by the test officer are another indicator of where to look in the data base for performance problems. Further, side-by-side plots of performance curves for the two weapons systems are often useful in isolating particular problems.

3.4.2.3 Effectiveness Analysis - Another useful technique is to segregate engagements by some criterion such as effectiveness. For example, define effectiveness as the ability to achieve a hit on a target and designate these engagements as successful. Divide all engagements on a particular facility into two categories: successful and unsuccessful. Plot various MOE on graph paper to determine if some MOE behave differently under the two conditions. During Quickfire Experiment I, for instance, burst size was found to be an important factor. Multivariate analysis is an expeditious means of isolating these differences. The same result can be obtained by employing several sequential sorting steps on the data base. For instance, after sorting on weapon and mode to get all automatic engagements for one



RIFLE PERFORMANCE PROFILE

Figure 16

weapon, sort on hits to subdivide the set into successful and unsuccessful categories within these subtests, calculate means for burst size, time to first rounds, etc., to find differences in behavior as a function of degree of success. Once a problem is identified, recommendation to correct the problem and improve performance can be made. Such recommendations might include a change in stock design, sighting system, ammunition carrying pouches, sling arrangement, magazine size, or burst size. In many cases, problems will be identified but cause and effect will not be established. If the problem is important enough, subsequent, controlled tests may be required to determine the exact cause of the problem. The many MOE available can provide a very complete picture of weapon system performance and should be used to the extent possible to produce this picture.

3.4.2.4 Quartile Analysis - Another technique is called a quartile analysis. The effectiveness analysis section above was concerned with engagements. The quartile analysis, although similar, focuses on the effective soldiers. In this analysis the most effective soldiers (upper 25%) and least effective soldiers (lower 25%) are pulled from the data base. The effectiveness criteria are the number of hits achieved on a specific facility. Once the two groups have been isolated the MOE pertinent to that facility will be calculated for each set of individuals. A series of t-tests are run on each MOE to compare the two quartiles. In addition to a t-test comparison across groups, a correlation analysis among MOE both within groups and between groups is suggested. The correlation analysis can include physical characteristics in addition to performance data to determine the possible effect of left-handedness, height, visual acuity or other human factors. Figure 17 shows the quickfire MOE and the letter in the right hand column references paragraphs below which attempt to define the meaning of significant differences.

Quickfire Facility MOE	Lower Quartile (X)	Upper Quartile (X)	Significance* (t-test)
Time to first round			A
Time to first hit			B
Hit probability			C
Time between trigger pulls			D
Time to shift fire			E
Rounds fired			F
Miss distance			G

Quartile Analysis for Quickfire Facility MOE

Figure 17

*Significance:

A - Time to First Round - A significant difference in favor of the lower quartile would imply that the lower quartile were rushing their shots and that possibly more training could improve their performance. A significant difference in favor of the upper quartile would imply one of two things - the lower group was having either target acquisition difficulties or interface problems. It would be advisable to do a human factors correlations analysis to determine if some physical attribute could be causing the problem (size, poor vision, etc.).

B - Time to First Hit - The same implications described above should apply to this MOE.

C - Hit Probability - The upper and lower extremes provided in this analysis is a measure of human variation. If the variation is smaller for the inferior weapon than for the selected weapon, this indicates a possible human interface problem with the sights, recoil, or target obscuration. Possibly more training is indicated.

D - Time Between Trigger Pulls - A significant difference would imply interface problems in coping with recoil and realigning the sights. The problem could be influenced by some physical attribute that one quartile has in common. A human factors analysis is indicated. Possibly improvements could be found in training methods or weapon design.

E - Time to Shift Fire - The comments under D above generally apply to this MOE; emphasis should be placed on vision since target acquisition is an added variable.

F - Rounds Fired - A correlation with hit probability that was not significant would indicate that the lower quartile was simply not firing a sufficient number of rounds at the target. The problem may be due to acquisition which again emphasizes the importance of human factors. A significant positive correlation would indicate that the lower quartile consists of a set of soldiers who are simply less adept at handling fire arms.

G - Miss Distance - This measure of spread is related to human factors and interface problems. A high "negative" correlation with hit probability, that is, a low mean spread and a high hit probability, should be expected. No correlation or a negative correlation would indicate potential improvement either through solving the interace problem or improving training.

Figure 18 shows the MOE for the attack facility and the letters refer to subparagraphs below which suggest possible interpretations of specific meaningful differences.

Attack Facility MOE	Lower Quartile (X)	Upper Quartile (X)	Significance (t-test)
Hit Probability			A
Miss Distance			B
Time Between Trigger Pulls			C
Rounds Between Hits			D
Movement Times			E
Time to Change Magazine			F

Quartile Analysis for Attack Facility MOE

Figure 18

A - Hit Probability - Reference quickfire facility, paragraph C above.

B - Miss Distance - Reference quickfire facility, paragraph G above.

C - Time Between Trigger Pulls - The interpretation of significant differences on the attack facility is slightly different than on the quickfire facility. On the attack facility a fast reaction, quick response is not necessarily required, and firing is more deliberate with emphasis on accuracy at the longer ranges and ammunition conservation. The test soldier must judge the time to complete the attack with reference to his basic load. Rate of expenditure of basic load is a measure of the adequacy of the basic load. Rate of expenditure is also an indicator of the potential combat time of the weapon system. If the mean for the upper quartile is extremely high in terms of ammunition available, a potential sustainability problem is indicated. A broad spread between groups would be indicative of a potential training problem since all test soldiers should be expected to behave similarly in an identical situation. During the assault phase of the attack, this MOE takes on more of the responsiveness characteristics described in quickfire paragraph D above.

D - Number of rounds Between Hits - The spread between means of the two quartiles would be an indicator of the importance the test soldiers place on getting rounds down range and the accuracy of the weapon system. A high correlation with hit probability within groups would indicate the latter; a low correlation indicates the former. Again, an extreme spread would indicate training problems.

E - Movement Times - This measure should indicate potential problems in physical characteristics among test soldiers. A correlation with various physical attributes should be performed.

F - Magazine Change Time - A large spread between quartiles would indicate training problems. Compared across rifles, a large spread would indicate a potential problem with the magazine component of the weapon system, e.g., pouch, pouch closure, seating and removing the magazine.

Figure 19 shows MOE for the defense facility and the letters refer to subparagraphs below:

Defense Facility MOE	Lower Quartile (X)	Upper Quartile (X)	Significance (t-test)
Hit Probability			A
Miss Distance			B
Time to First Hit			C
Time to Shift Fire			D
Time Between Trigger Pulls			E
Time to Change Magazine			F
Time to Clear Malfunction			G
Number of Rounds Between Malfunction			H

Quartile Analysis for Defense Facility MOE

Figure 19

A - Hit Probability - See quickfire facility, Paragraph C.

B - Miss Distance - See quickfire facility, Paragraph G.

C - Time to First Hit - See quickfire facility, Paragraph B. The measure has slightly less impact on the defense facility due to the more deliberate firing method.

D - Time to Shift Fire - See quickfire facility, Paragraph E. This measure has slightly less impact on the defense facility due to the more deliberate firing method.

E - Time Between Trigger Pulls - See attack facility, Paragraph C.

F - Time to Change Magazines - See attack facility, Paragraph F.

G - Time to Clear Malfunctions - A significant difference between quartiles may be indicative of a training problem in that some test soldiers are not adept in the actions of reducing a malfunction, especially if poor performance with this measure does not correlate with poor over-all performance.

H - Number of Rounds between Malfunctions - Again, a significant difference may indicate a training problem such as failing to seat the magazine properly or failing to keep the magazine clean. Further, it may indicate nonuniformity between weapons; that is, certain weapons are more prone to malfunction than other weapons of the same type due to quality control of specific parts.

3.4.2.5 Multivariate Analysis - The final technique for optimizing weapon performance is multivariate discriminant analysis. This technique was useful for sifting through the large amounts of information generated by an operational service test to search for meaningful measures. The independent or test variables are weapon, mode of fire, range, and facility. The dependent variables are the various measures of effectiveness. The recommended method is to begin the analysis with all applicable MOE for each set of test variables and to reduce the number of MOE in subsequent analysis by eliminating MOE that fail to correlate with the discriminant function. The procedure terminates when the best four or five MOE are found for each set of test variables. The results are then interpreted in a manner similar to that described in the preceding paragraphs.

3.4.2.6 A Precautionary Note - The MOE are indicators of weapon system performance and will pinpoint strengths and weaknesses of a system. The MOE will not necessarily provide the causes of those strengths and weaknesses. Cause and effect relationships at this stage are somewhat subjective. If the cause is not readily identifiable, subsequent testing may be required to identify the cause objectively. Factors that weigh in the decision to continue testing are costs, time, and the commitment of other resources versus the potential gain from isolating the cause and implementing corrective action.