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This thesis examines cost effectiveness of smoke screens employed by indirect fire means. Large area smoke employment means are included for comparison with the indirect fire means, and for demonstration of a potential source of smoke screens unfamiliar to many tacticians. Optimal tactics for smoke screen employment are not addressed. Two computer models are developed, one for indirect fire means (60mm, 81mm, and 4.2in mortars, as well as 105mm and 155mm howitzers) and one for large area means (smoke generators and smoke pots). Performance characteristics of indirect fire smoke ammunition are incorporated into the model based on recent experimentation by the U.S. Army Systems Analysis Activity. Smoke screens are described by input parameters, which are varied by a heuristic search procedure. These parameters (and their limits) include: weather (lapse, neutral, and inverse conditions with accompanying wind), screen duration (1 through 60 minutes), and sheaf width (100 through 1050 meters). Cost effective preferences are recommended for various smoke screen employment means. Possible areas for future research are suggested.

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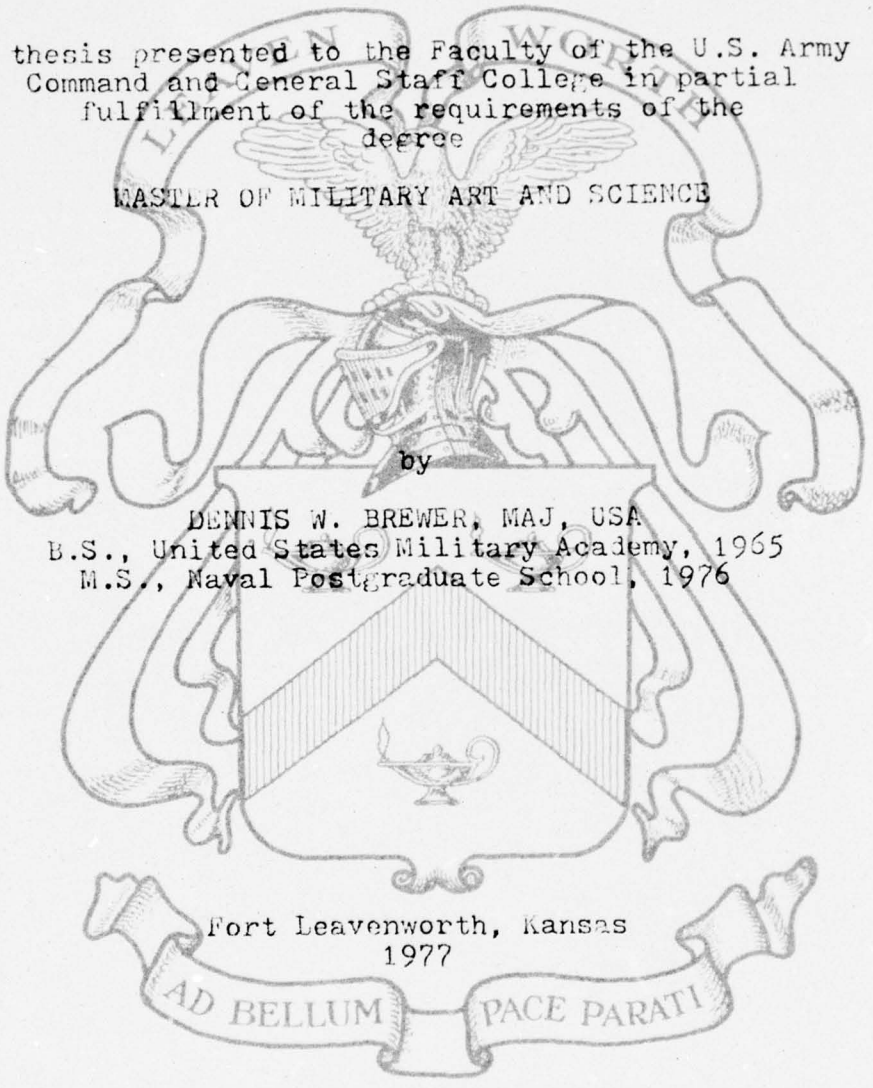
COST EFFECTIVENESS OF SMOKE SCREENS EMPLOYED BY INDIRECT FIRE MEANS

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

by

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1977

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The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

This thesis examines cost effectiveness of smoke screens employed by indirect fire means. Large area smoke employment means are included for comparison with the indirect fire means, and for demonstration of a potential source of smoke screens unfamiliar to many tacticians. Optimal tactics for smoke screen employment are not addressed. Two computer models are developed, one for indirect fire means (60mm, 81mm, and 4.2in mortars, as well as 105mm and 155mm howitzers) and one for large area means (smoke generators and smoke pots). Performance characteristics of indirect fire smoke ammunition are incorporated into the model based on recent experimentation by the U.S. Army Systems Analysis Activity. Smoke screens are described by input parameters, which are varied by a heuristic search procedure. These parameters (and their limits) include: weather (lapse, neutral, and inverse conditions with accompanying wind), screen duration (1 through 60 minutes), and sheaf width (100 through 1050 meters). Cost effective preferences are recommended for various smoke screen employment means. Possible areas for future research are suggested.

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Chapter I

Introduction

A. Background

A study of military history suggests that modern warfare may be viewed as a contest of measure and countermeasure. As an example, for a tank one countermeasure is an anti-tank guided missile (ATGM), for field artillery one countermeasure is counter battery fire. For many enemy actions smoke can be an effective countermeasure. In general, smoke can obscure and suppress the enemy, and degrade the effectiveness of his weapons systems. (Ref 1, page 2.) Smoke can obscure the enemy so that he cannot acquire or track targets, or gain combat intelligence on friendly activities. A military target may be defined to be suppressed if its performance of a function needed for mission accomplishment is degraded below a minimum level for a specified time. (Ref 2, page 1.) Accordingly, smoke can suppress the enemy soldier by producing confusion, disorientation, fear of the unexpected, and vulnerability. Smoke can degrade the effectiveness of enemy weapons systems by obfuscating the visual and infra-red (IR) regions of the electromagnetic spectrum needed for observation, target acquisition, and fire control. (Ref 1, page 2.) In particular, smoke can degrade the performance of laser range finders, as well as optically guided missiles, such as the Sagger. (Ref 3, page 2.)

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in the Arab-Israeli War of October 1973, or the Yom Kippur War, the Egyptians used smoke effectively to facilitate their expeditious crossing of the Suez Canal. This example illustrates the tenet that if the enemy cannot see you, your survivability is improved. This tenet might also be expressed as "what can be seen might be hit" and "what can be hit might be killed." (Ref 1, pages 3 and 9.) Smoke is a flexible weapon of significant potential, as the Suez Canal example points out.

Essentially, United States (Ref 1 and 3 through 5.) and Warsaw Pact (Ref 6 through 10.) doctrine on the tactical use of smoke is similar. It is a national security objective that the U.S. Army must maintain its preparedness for all intensity levels of warfare. A powerful and potential adversary such as the Warsaw Pact can and probably will use smoke in a conventional war. Therefore, the salient aspects of tactical smoke employment bear analysis. This paper considers one such aspect. Other aspects are currently under consideration. (Ref 15, pages 1 through 14.)

B. Objective

The objective of this paper is to determine the most cost effective type of indirect fire smoke ammunition to provide a preplanned smoke sheaf for visual obscuration. The types of ammunition considered are the 60mm WP, 81mm WP, 4.2in WP, 105mm

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WP and HC, and the 155mm WP and HC. Large area smoke employment weapons are included for comparison with the indirect fire means, and for demonstration of a potential source of smoke screens unfamiliar to many tacticians.

B. Assumptions

Of critical significance to a model, as to any military analysis or staff study, are the underlying assumptions. The assumptions made in this paper include:

1. Smoke will be used on future battlefields by the U.S. military forces.

2. Indirect fire will be a primary means of employing smoke screens.

3. Smoke screens will be employed so as to produce obscuration with a probability of 95%. In other words, the probability is 95% that the screen will obscure a line of sight through it. If a screen cannot be employed to produce this probability of obscuration, it will not be employed at all.

4. A smoke screen fire mission will be assigned to only one firing unit (mortar section or platoon, howitzer battery) at a time.

5. All screens are located within range of all weapons systems.

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Parameters Varied

The parameters varied in this study include the time of
een duration, screen width, and weather. In addition, special
culations were made concerning the number of tubes per firing
t. These special calculations were made to examine the effect
Table of Organization and Equipment (TOE) structure on the
imum screen cost. For example, if, by adding a mortar tube
the firing unit the 4.2in mortar platoon can, on the average,
duce a screen more cheaply than the 155mm howitzer battery,
if this cost savings is greater than the price of the
itional mortar tube, the U.S. Army would save money by changing
4.2in mortar TOE structure to accomodate the additional tube.
is thesis considers materiel costs only.)

Scope

The scope of this paper is limited to the objective as
ted. It does not include optimal employment criteria for
tical success, nor does it include tactical guidance for
bat unit commanders. Mission accomplishment may require a
s effective screen (in terms of obscuration level) than
sidered here, or a less cost effective means of employment,
both.

For comparison with indirect fire means this paper considers he M3 Mechanical Smoke Generator, and the military series of moke pots, i. e. M1, ABC M-5, M4A2, AN-M7 SGF2, and AN-M7A1 SGF2. mployment criteria (Ref 13, page 21.) for smoke generators and moke pots enable construction of a computer model of employme t ost effectiveness. A copy of this model appears as Appendix C.

At present, 16 United States Army Reserve (USAR) companies omprise the total U.S. Army employment capability for smoke enerators and smoke pots. (Ref 14, page 1.) The tactical ituation will dictate which means of smoke screen employment re feasible without unduly jeopardizing the safety of the mploying personnel.

f. Terminology

In this paper the term screen is used in the sense of a smoke screen. It is recognized that artillery doctrine separates the functions of screening and obscuring. (Ref 3, page 4.) However, in this paper, the word screen will be used to describe both activities. Sheaf is another term for a screen. Screen width or sheaf width is the dimension of the screen perpendicular to the line(s) of sight being obscurred by the smoke.

As used in the stated objective the term cost includes that of the ammunition (total objective) only. Thus, the term does not

include costs from sources such as equipment maintenance, crew operations, personnel, ammunition transportation and stockage, or opportunity costs. The latter occur when a smoke mission is fired in lieu of any other mission. For example, a smoke mission fired in lieu of a high explosive, anti-personnel mission would produce opportunity costs. These costs would be the expected number of enemy casualties foregone in order to free the firing unit for the smoke mission.

G. Decision Basis

To aid in placing smoke employment cost effectiveness in proper context, let us consider the thought process of a tactical commander employing a smoke screen. His thought process may be depicted by a decision tree, which appears as Figure 1. (Ref 17, pages 10 through 11.)

The particular questions which he or his staff must answer are as follows:

1. What guidance has been issued from higher level headquarters concerning the use and/or priority of employment means of smoke screens?

2. What are the weather and terrain conditions?

3. What weapons are available to employ the smoke screen?

4. How much smoke ammunition is available for each

weapon?

These and other pertinent questions may be represented by the following decision tree.

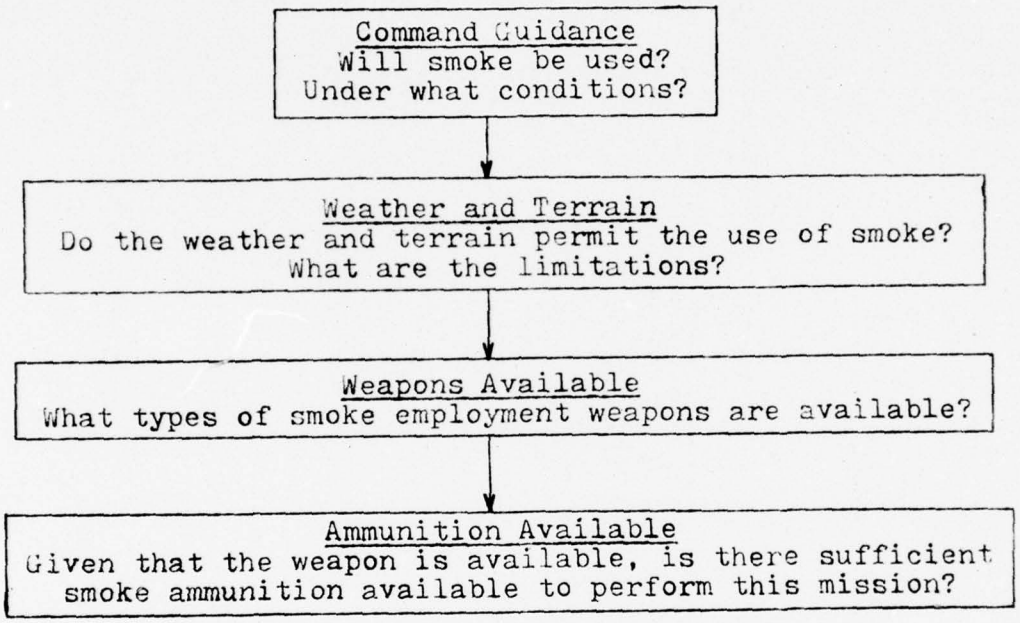


Figure 1

Typical Decision Tree

It is this writer's opinion that only when all tactical decision factors have been satisfied does cost effectiveness become a valid criteria. Thus, the tactical commander using Figure 1 as a guide should apply cost effective criteria on the employment means produced at the bottom of Figure 1.

H. Hypothetical Application

As a hypothetical example, let us consider 155mm howitzer and 4.2in mortar as potential smoke employment means. For tactical reasons not germane to this discussion, the combat commander decides to consider only those two means for potential smoke screen employment. Because of tactical considerations, his anticipated employment may be depicted by Figure 2.

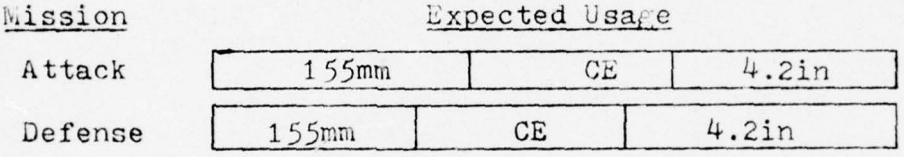


Figure 2

Hypothetical Anticipated Employment Chart

The bars represent 100% of the approved smoke screen fire missions for 155mm howitzers and 4.2in mortars. Portions of the bars inscribed with a specific weapons caliber denote relative percentages of employment by the inscribed weapons system. The portions inscribed with CE denote relative percentages of employment where cost effective criteria apply. In general, the bars portray the tactical commander's expected usage of smoke screen employment means. In the attack he anticipates using 155mm howitzers more often than 4.2in mortars to produce smoke screens. According to his tactical concept the majority of smoke

screens are out of 4.2in mortar range. In the defense he anticipates using 4.2in mortars more often than 155mm howitzers to produce smoke screens. According to his tactical concept the majority of smoke screens are within range of the 4.2in mortars. he wants to be cost effective, and he wants to save his 155mm howitzers for high explosive missions. Overall, he anticipates applying cost effective criteria more often in the defense than in the offense. Because of more time available for detailed planning and coordinating, the defense allows him more flexibility in applying cost effective criteria to indirect fire missions.

As another hypothetical example, let us consider a specific tactical scenario, either attack or defense. For tactical reasons, the combat commander again decides to consider only 155mm howitzers and 4.2in mortars as potential smoke employment means. Figure 3 is a graph which depicts when the 155mm or both weapon systems can be used, as a function of sheaf width and screen duration. It should be noted that we assume the intended screen location is within 4.2in mortar range, otherwise the commander could not consider that system for screen employment. (155mm howitzer range is greater than 4.2in mortar range.)

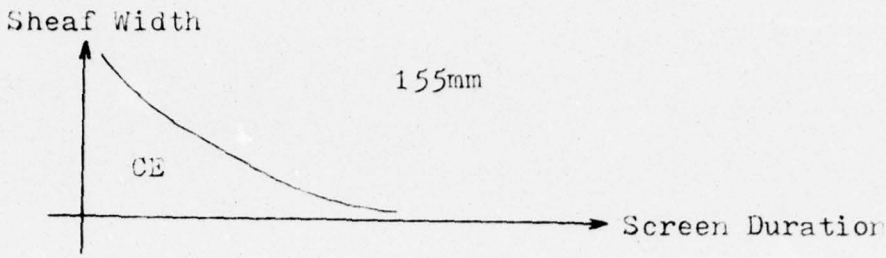


Figure 3

Hypothetical Anticipated Employment Graph

The portion of the graph inscribed with 155mm denotes the area where only the 155mm howitzer battery can produce the desired screen (the 4.2in mortar platoon cannot), either because of the sheaf width or screen duration desired. These two parameters largely determine the number of rounds required for the smoke mission; if the requirement is too high, the unit's maximum firing rate will be exceeded. Excessive firing rates are usually avoided, to preclude tube burn-out due to undue temperature and pressure from too many rounds being fired in too rapid a succession. The portion of the graph inscribed with CE denotes the area where either the 155mm or 4.2in weapon system can produce the desired screen. Hence, in the CE area, cost effective criteria apply. For each screen duration value, the graphed function indicates a corresponding sheaf width value. First let us consider a constant sheaf width. Below the corresponding screen duration value, cost effective criteria will be applied; above the value, the 155mm howitzers will produce the screen.

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Next let us consider a constant screen duration. Below the corresponding sheaf width value, cost effective criteria will be applied; above the value, the 155mm howitzers will produce the screen. In general, given a uniform distribution of intended screens in terms of sheaf width and screen duration, the tactical commander anticipates using 155mm howitzers more often than applying cost effective criteria.

I. Sample Calculations

An example will aid in explaining the calculation procedure used in the Indirect Fire Smoke Model (Appendix A). For a nominal situation, let us consider a sheaf width of 200 meters, a screen duration of 5 minutes, and weather conditions of lapse (smoke rises slowly) with a 5 knot cross wind. In this example only the 4.2in WP and 155mm HC projectiles will be calculated with detailed comments. In the model (Appendix A) all indirect fire weapons systems are considered for each set of employment parameters.

For the 4.2in WP the following calculations apply. The maximum firing rate is 9 rounds/tube/minute for the first 5 minutes and 3 rounds/tube/minute for each succeeding minute. (Ref 11, page 4-2.) To parallel the U.S. Army Materiel Systems Analysis Activity (AMSAA) experimentation which produced the JTCG Model (Appendix B), 2 minutes of firing are needed to

establish the screen. Thus, for a 4 tube platoon, a maximum of (9x4x5) + (3x4x2) = 204 rounds may be fired in the 7 minutes needed for the mission. From the JTCG Model, the number of rounds needed to establish the screen is (.03375 x 200 meters) - .75 = 6; the number of rounds needed to maintain the screen is (the same value) 6 + (a constant) 3 = 9 per minute, or 9x5 = 45 rounds total to maintain the screen for 5 minutes. Thus, the total number of rounds for the fire mission is 6 + 45 = 51. Since 51 is less than 204, the platoon can fire the mission. The cost of each 4.2in WP projectile is $49.54. (Ref 12, page 2-51.) The cost of the mission, then would be 51 x $49.54 = $2526.54.

For the 155mm HC the following calculations apply. The maximum firing rate is 4 rounds/tube/minute for the first 3 minutes and 1 round/tube/minute for each succeeding minute. (Ref 11, page 4-3.) To parallel the AMSAA experimentation which produced the JTCG Model, 2 minutes of firing are needed to establish the screen. Thus, for a 6 howitzer battery, a maximum of (4x6x3) + (1x6x4) = 96 rounds may be fired in the 7 minutes needed for the mission. From the JTCG Model, the number of rounds needed to establish the screen is (.01 x 200 meters) + 1 = 3; the number of rounds needed to maintain the screen is (the same value) 3 + (a constant) 3 = 6 per minute, or 6x5 = 30 rounds to maintain the screen for five minutes. Thus, the total number of rounds for the mission is 3 + 30 = 33. Since 33 is less than 96, the battery can fire the mission. The cost of each 155mm HC

projectile is $60.40. (Ref 12, page 2-163.) The cost of the mission, then would be 33 x $60.40 = $1993.20.

Similar calculations were made with the following results. The 60mm WP could not produce the screen since the 3 tube platoon's maximum firing rate was exceeded. The remaining costs, by projectile type, would be: 81mm WP = $2262.70, 105mm WP = $4874.76, 105mm HC = $1343.04, and 155mm WP = $3131.10.

Considering all of the previous projectiles, the decision maker using cost effective criteria would select the 105mm HC, saving a minimum of $650.16 and a maximum of $3531.72, compared to the other costs. It should be noted that the minimum savings of $650.16 is approximately 48% of the cost of the mission. Thus, by using cost effective criteria the decision maker saves, as a minimum, almost half as much as he spends!

J. Comment on Basic Loads

U.S. Army planning guidance suggests basic loads for WP and HC rounds for specific weapon systems. In the armored or mechanized Division, the 4.2in mortar platoon should carry 84 rounds of WP, while the 155mm self-propelled (SP) howitzer battery should carry 72 rounds of WP and 102 rounds of HC. (Ref 16, pages 3-47 and 3-58, respectively.) The example screen of the preceeding paragraph would require 15 rounds of 4.2in WP (approximately 4.9%

of the doctrinally suggested basic load). Accordingly, the 4.2in mortar platoon could fire approximately 5, and the 155mm howitzer battery could fire approximately 20 nominal smoke screen missions like the one discussed in the preceeding paragraph. This calculation illustrates that the number of rounds in the basic load, as well as the relative effectiveness of the weapon system, greatly affects fire mission capability. If a combat scenario can be anticipated with acceptable accuracy, fire mission requirements can be estimated. This estimate may allow judicious application of cost effective criteria. For example, if a tactical commander planning an active defense can anticipate the enemy's axis of advance, he (the defending commander) can plan where he desires smoke screens to disrupt the enemy's advance. He could then make calculations similar to those of paragraph I above. Accordingly he could provide for the screen, apply cost effective criteria, minimize cost, and preposition the required ammunition. The savings thus gained should facilitate increased procurement of needed materiel with minimal risk to mission accomplishment. In today's milieu of combat readiness and budgetary constraints, minimal risk is often necessary for mission accomplishment.

Chapter II

Model Development

A. Model Construction

In the model, a smoke screen is employed by establishing the sheaf, then maintaining it with additional smoke rounds fired at properly timed intervals. The timed intervals are a characteristic of the weapon system, to include the projectile. The number of rounds to establish the screen (TNE) and the number of rounds to maintain the screen per minute (TNM) are two separate functions, and are determined by the weapon system, sheaf width, and weather. The total cost (TC) of a smoke screen may be expressed as:

$$TC = (TNE + (TNM \times time)) \times (price\ per\ round).$$

The types of weapons systems considered in this study are the 60mm, 81mm, and 4.2in mortars, and the 105mm and 155mm howitzers. The maximum rate of fire of each weapon system was used to determine whether or not the weapon system could support the fire missions. If the maximum rate of fire was exceeded, the weapon system could not fire the smoke mission. The fire missions were defined as a particular width of screen established and maintained over a particular time interval during particular weather conditions. Sheaf width varied from 100 meters to 1050 meters in 50 meter increments. Time interval varied from 1 minute

to 60 minutes in 1 minute increments. The weather conditions included: lapse (smoke rises slowly) and 5 knot wind, neutral (smoke neither rises nor falls) and 5 knot wind, neutral and 10 knot wind, neutral and 15 knot wind, and inversion (smoke fall slowly) and 5 knot wind. These weather conditions were selected as representative of the spectrum of climatic conditions where smoke screen employment is feasible. In addition, these weather conditions were the ones used in the AMSAA JTCG Model, upon which the models of Appendix A and Appendix C were based. It is anticipated that weather, like the other parameters varied in this study, will have a significant effect on smoke screen production means selected by cost effective criteria.

In a parametric analysis encompassing multiple independent parameters, each having many discreet values, a heuristic search procedure is often employed. The purpose of the procedure is to produce a finite number of data points which is large enough to be representative yet small enough to be tractable. In this study the search procedure consisted of varying parameters in the following order. First, duration of screen was varied from 1 through 60 minutes in 1 minute increments. Second, sheaf width was varied from 100 through 1050 meters in 50 meter increments. Third, the number of tubes per firing unit was increased by one for each weapon separately and then all weapon systems together. After variation, each parameter was reset to its value in the base case, or Run 1. (Chapter III contains the specific parameter

settings of the base case.) The reason for resetting the values after each variation was to retain the base case as a valid basis for comparison of results. This comparison will be discussed in Chapter IV.

The fire missions considered in this study were functions of weapon system, sheaf width, screen duration, and weather conditions. Due to the large number of situations, a computer model was constructed. A copy of the model appears as Appendix A.

The computational procedure is as follows. For a particular sheaf width, a particular weather condition and a particular screen duration, the number of rounds needed for the fire mission is calculated by weapon system. This number is compared to the maximum number of rounds which can be fired by the same weapon system in the time interval of screen duration plus two minutes. The additional two minutes are used so as to parallel the experimentation which produced the AMSAA JTCG Model; the experimenters found that it took approximately two minutes of firing to establish a screen producing 95% obscuration. If the weapon system can produce the screen, the cost is calculated by the equation

$$TC = (TNE + (TNM \times time)) \times (\text{price per round}).$$

If the weapon system cannot produce the screen (unit's maximum rate of fire was exceeded), an abnormally high cost of $9999999.99 is assigned. This procedure is repeated for each weapon system.

sequently, the lowest cost is selected and printed. This
pletes the computations for one set of parameter values. A
set is specified, and the same computations made, until all
s have been considered.

The procedure for parameter variation is as follows. The
el accepts as input parameter values of five sheaf widths,
e weather conditions, and ten screen durations. The model nests
parameters for variation as screen duration within weather
dition within sheaf width. In other words, the first value
sheaf width and the first value of weather condition are fixed
le the screen duration values are varied from first to tenth.
next weather condition is then fixed and the screen duration
in varied, until all five weather conditions have been applied
all screen durations. The next sheaf width value is fixed
the same weather conditions and screen duration combinations
applied, until all sheaf widths have been applied to all
ther conditions and screen durations. The results are
splayed in a matrix of 250 rows and 8 columns. Each row
rresponds to a set of parameter conditions. Columns 1 through
contain the cost of the screen under the appropriate parameter
ditions by weapon system type in the order 60mm WP, 81mm WP,
2in WP, 105mm WP, 105mm HC, 155mm WP, and 155mm HC. The 8th
umn contains the minimum cost of the seven weapon system
ues in the row.

For general interest, it should be observed that the average osts for all conditions are computed by weapon system. The verage computation does not include those cases where the weapon ystem cannot produce the smoke screen.

. Sources of Data

The numbers of rounds to establish and maintain a smoke creen under given conditions were calculated from the smoke model roduced by the U.S. Army Materiel Systems Analysis Activity AMSAA). A copy of this model appears as Appendix B. It should e noted that, as of this writing, only the 155mm HC portion of he AMSAA JTCG Model has been validated. However, it is the only such model known to exist.

The maximum firing rates of selected weapon systems (Ref 11, ages 4-2 and 4-3.) are given in Table 1. Undimensioned numbers re in rounds per minute. The second row of entries for 81mm and .2in mortars indicate successive firing rates (after the first inute of firing). This writer is aware of several such tables; he figures in Table 1 are representative of the range of values bserved.

Weapon	Max Rate, For	Sustained Rate
60mm	30, 1 min	8
81mm	30, 1 min	5
	18, 2 min	5
4.2in	18, 1 min	3
	9, 5 min	3
105mm	10, 3 min	3
155mm	4, 3 min	1

Table 1

Maximum Firing Rates

The prices per selected rounds (Ref 12) and the tubes per firing unit are given in Table 2. The rounds, for correlation, are the same as those selected for the JTCG Model.

Weapon	Type	Model	Cost/Round	Tubes/Firing Unit
60mm	WP	M302	$19.31	3
81mm	WP	M57	$18.70	3
4.2in	WP	M328A1	$49.54	4
105mm	WP	M60	$36.93	6
105mm	HC	M84BE	$55.96	6
155mm	WP	M110	$69.58	6
155mm	HC	M116BE	$60.40	6

Table 2

Cost and Tube Data

C. Measure of Effectiveness

The measure of effectiveness to be used on the output of the computer model is that of cost, which will be minimized while holding effectiveness constant. An attempt will be made to

recognize trends for minimum cost screens so as to produce a cost effective priority of fire for a given situation of screen width, screen duration, and weather condition.

D. Large Area Smoke Model

Large area smoke employment costs were used for general comparison with indirect fire smoke employment costs. Accordingly the detailed development of the Large Area Smoke Model will not be included herein. It should suffice to observe that the computational procedure was the same for large area smoke employment means. To facilitate comparison of results, the computer model output format and parametric terminology were also the same. Large area smoke employment means include smoke pots such as M1, ABC M-5, M4A2, AN-M7 SGF2, and AN-M7A1 SGF2, as well as the M3 Mechanical Smoke Generator. The interested reader is invited to refer to Appendix C for details on the large area smoke employment model. Bibliography entries numbered 5, 9, and 10 apply.

Chapter III

Exercising the Models

Runs 1 through 16 pertain to the model of Appendix A, Indirect Fire Smoke Model. After Run 1, only parametric variations are specified. In all runs the average total cost and number of rounds required were computed, weighting equally each of the 250 situations considered. (The result of 5 screen lengths, 5 weather conditions, and 10 screen durations is a total of 5x5x10 = 250 situations.)

Run 1. Run 1 was the base run, and formed the basis for parametric variation in later runs. In Run 1 the time of screen duration (DT) was from 1 minute to 10 minutes, in 1 minute increments. Sheaf width (SH) was from 200 meters to 1000 meters in 200 meter increments. Weather conditions (W) included all five specifications.

Run 2. In Run 2 DT varied from 11 minutes to 20 minutes in 1 minute increments.

Run 3. In Run 3 DT varied from 21 minutes to 30 minutes in 1 minute increments.

Run 4. In Run 4 DT varied from 31 minutes to 40 minutes in 1 minute increments.

Run 5. In Run 5 DT varied from 41 minutes to 50 minutes in 1 minute increments.

Run 6. In Run 6 DT varied from 51 minutes to 60 minutes in 1 minute increments.

After Run 6, DT was reset to its values in Run 1.

Run 7. In Run 7 SH varied from 100 meters to 300 meters in 50 meter increments.

Run 8. In Run 8 SH varied from 350 meters to 550 meters in 50 meter increments.

Run 9. In Run 9 SH varied from 600 meters to 800 meters in 50 meter increments.

Run 10. In Run 10 SH varied from 850 meters to 1050 meters in 50 meter increments.

After Run 10, SH was reset to its values in Run 1.

Run 11. In Run 11 the number of 60mm mortar tubes in the firing unit was changed from 3 to 4.

After Run 11 the number of 60mm mortar tubes was reset to 3.

Run 12. In Run 12 the number of 81mm mortar tubes in the firing unit was changed from 3 to 4.

After Run 12 the number of 81mm mortar tubes was reset to 3.

Run 13. In Run 13 the number of 4.2in mortar tubes in the firing unit was changed from 4 to 5.

After Run 13 the number of 4.2in mortar tubes was reset to 4.

Run 14. In Run 14 the number of 105mm howitzers in the firing unit was changed from 6 to 7.

After Run 14 the number of 105mm howitzers was reset to 6.

Run 15. In Run 15 the number of 155mm howitzers in the firing unit was changed from 6 to 7.

Run 16. In Run 16 the number of 60mm mortar tubes was changed from 3 to 4, the number of 81mm mortar tubes was changed from 3 to 4, the number of 4.2in mortar tubes was changed from 4 to 5, the number of 105mm howitzers was changed from 6 to 7, and the number of 155mm howitzers was left unchanged (at 7). In other words, the number of tubes in each firing unit was increased by one from its value in Run 1.

Run 17 pertains to the model of Appendix C, Large Area Smoke Model.

Run 17. In Run 17 the base case situations of Run 1, above, were applied to the employment means of smoke generators and smoke pots. It was felt that one such run should be sufficient for the comparison desired between smoke screen employment costs of indirect fire means and smoke screen employment costs of large area means.

Chapter IV

Analysis of Model Output

A. General

The following weather coding will be used, for brevity, in this chapter.

W1 - lapse conditions, 5 knot wind

W2 - neutral conditions, 5 knot wind

W3 - neutral conditions, 10 knot wind

W4 - neutral conditions, 15 knot wind

W5 - inversion conditions, 5 knot wind

Also for brevity, the terms 1st, 2nd, and 3d will be used to denote the least cost (cost effective), next expensive, and third next expensive of the weapon systems, respectively, that can support the smoke mission(s) of interest.

B. Indirect Fire Results

The analysis of Runs 1 through 11 will be presented in two parts. In Part 1, general comments on trends will be presented. In Part 2, a set of composite matrices (compiled from Runs 1 through 11) will be presented, showing cost effective preferences (1st, 2nd, 3d) of weapon systems for all combinations of parameters varied in this paper. (See Chapter III for a discussion

of parametric variation in each run of the Indirect Fire Model.)

Part 1. A general pattern became evident from the statistics produced in Runs 1 through 11. The pattern was that for W1, W3, and W5 the 155mm HC was cost effective (least expensive); for W2 and W4 the 105mm HC was cost effective. Where the 155mm HC was cost effective, or 1st, the 105mm HC was 2nd, and vice versa. Where it could support the smoke mission, the 81mm WP was usually 3d; where the 81mm WP could not support the smoke mission, the 4.2in WP was 3d. Although the 60mm WP was not a serious challenger for 1st, 2nd, or 3d choice under cost effective criteria, there were some situations where the 60mm WP could produce the desired smoke screen. These situations were generally in W5, for a sheaf width of 200 meters, and for a screen duration of 20 minutes or less.

As a basis for comparison with subsequent outcomes, the results of the base run, or Run 1, are presented in Table 3. The deceptively low values for the 60mm WP, 81mm WP, and 4.2in WP systems are the result of those systems' inability to support the smoke missions of wider sheaf widths and/or longer screen durations. Hence, these more expensive missions were not included in the averaging calculations for those systems. This omission reduced those systems' average costs and average numbers of rounds required. Of the mortar systems, the ability to support the smoke missions was, in descending order of ability, the 4.2in WP, 81mm WP, and 60mm WP. In Table 3, costs are in dollars.

System	Cost (Average)	Rounds (Average)
60mm WP	174.79	9.05
81mm WP	1364.50	72.97
4.2in WP	4126.86	83.30
105mm WP	3061.13	82.89
105mm HC	1240.85	33.60
155mm WP	2047.51	29.43
155mm HC	990.47	14.24

Table 3

Run 1 Averages

Equally weighting the outcomes of Runs 2 through 10 produced the average values displayed in Table 4. Run 1 was excluded in the averaging since its situations are repeated in the other runs. The same comment on deceptively low values for mortar systems made for Table 3 applies to Table 4. In Table 4, costs are in dollars.

System	Cost (Average)	Rounds (Average)
60mm WP	232.95	12.06
81mm WP	2494.65	133.40
4.2in WP	7888.99	159.24
105mm WP	6337.86	171.62
105mm HC	4040.53	109.41
155mm WP	5596.87	80.44
155mm HC	3027.55	43.51

Table 4

System Averages

By adding another 60mm mortar tube to the firing unit (in Run 11), the 60mm WP system could support only 12.4% of the smoke

missions. These supported missions were primarily in W5, with a few in the other weather conditions, and virtually all at 200 meter sheaf width. The 60mm WP did not qualify for any cost effective ranking (1st, 2nd, or 3d).

By adding another 81mm mortar tube to the firing unit (in Run 12), the 81mm WP system could support 24 additional missions. In those situations, it qualified for 3d cost effective system, over the 4.2in WP. The distribution of those 24 additional situations is displayed in Table 5. The heading "ACS" denotes Average Cost Savings. Prior to adding the additional 81mm mortar tube, the 4.2in WP system was 3d cost effective. By adding the tube, the 81mm WP system became 3d cost effective at a reduced cost. The reduction was averaged over the screen duration times (same sheaf width and weather conditions) and is displayed as ACS. The 2119.33 ACS value bears comment. There was no savings generated here, since there was previously no 3d cost effective system. Hence, the additional tube enabled the 81mm WP system to provide a heretofore unavailable 3d cost effective choice for those three situations. The ACS value is, therefore, the cost of the system averaged over the screen duration times, in this case. In Table 5, sheaf widths are in meters, screen durations are in minutes, and ACS's are in dollars.

Frequency	Sheaf Width	Weather	Screen Duration	ACS
4	400	W1	5 - 8	205.49
4	600	W1	1 - 4	274.45
5	800	W3	6 -10	4330.51
1	800	W4	6	3980.39
4	800	W4	7 -10	2119.33
3	1000	W3	4 - 6	3761.72
3	1000	W4	5 - 7	5600.1[illegible]

Table 5

Run 12 Exceptions

By adding another 4.2in mortar tube to the firing unit (in Run 13), the 4.2in WP system could support 13 additional smoke missions. This result provided a heretofore unavailable 3d cost effective choice for those 13 situations. The distribution of those 13 additional situations is displayed in Table 6. The term ACS does not apply here. In Table 6, sheaf widths are in meters, screen durations are in minutes, and average costs are in dollars.

Frequency	Sheaf Width	Weather	Screen Duration	Avg Cost
2	800	W1	9 -10	15066.36
3	800	W4	8 -10	12236.38
3	1000	W1	7 - 9	15902.34
2	1000	W3	9 -10	15849.50
3	1000	W4	8 -10	16001.42

Table 6

Run 13 Exceptions

The addition of another 105mm howitzer (in Run 14) or another 155mm howitzer (in Run 15) to their respective firing units

produced no change in outcome from the base run (Run 1).

The addition of an appropriate tube or howitzer to the respective firing unit (in Run 16) produced 33 changes in outcome from the base run. The distribution of these changes is displayed in Table 7. The same definition of ACS (from Table 5) applies. The numbered comments explain specific line entries. In Table 7, sheaf widths are in meters, screen durations are in minutes, and ACS's are in dollars. The term "CMT" denotes comment.

Frequency	Sheaf Width	Weather	Screen Duration	ACS	CMT
4	400	W1	5 - 8	205.49	1
4	600	W1	1 - 4	274.46	1
2	800	W1	9 -10	15066.36	2
5	800	W3	6 -10	4330.51	1
1	800	W4	7	3980.39	3
3	800	W4	8 -10	6395.40	4
3	1000	W1	7 - 9	15902.34	2
3	1000	W3	4 - 6	3761.72	1
2	1000	W3	9 -10	15849.50	2
3	1000	W4	5 - 7	5600.14	1
3	1000	W4	8 -10	16001.42	2

Table 7

Run 16 Exceptions

Comment 1. In these situations the 81mm WP system qualified for 3d cost effective choice over the previous (in Run 1) 3d choice, the 4.2in WP system.

Comment 2. In these situations the 4.2in WP system qualified for 3d cost effective choice where previously (in Run 1) there was no 3d choice. As a result, the respective ACS value is actually

average cost of the new 3d choice. The averaging calculation performed, like the ACS calculation as defined, over the lusive screen durations.

Comment 3. In this situation the 81mm WP system qualified 3d cost effective choice over the previous (in Run 1) 3d oice, the 105mm WP system.

Comment 4. In this situation the 81mm WP system qualified r 3d cost effective choice where previously (in Run 1) there was 3d choice. As a result, the respective ACS value is actually e average cost of the new 3d choice. The averaging calculation s, like the ACS calculation as defined, over the inclusive reen durations.

Part 2. The general trends discussed earlier were signifi-ntly influenced by the parameters varied. For clarity of display e cost effective choices will be presented in a series of 5 bles, one table corresponding to each weather condition as ded in paragraph A of this chapter. Only sheaf width and reen duration combinations that were run in the model will be own in the tables. Thus, blanks indicate that the combination s not run. The entries in the tables were the result of the uristic search procedure used. The purpose was to produce a nite number of data points which is large enough to be presentative, yet small enough to be tractable.

The following coding applies to Tables 8 through 12. The codes specify the appropriate sequence of cost effective choices: 1st, 2nd, and 3d, in that order, as applicable.

A - 155mm HC, 105mm HC, 81mm WP
B - 105mm HC, 155mm HC, 81mm WP
C - 155mm HC, 105mm HC, 4.2in WP
D - 105mm HC, 81mm WP, 155mm HC
E - 155mm HC, 105mm HC
F - 105mm HC, 155mm HC
G - 155mm HC, 105mm HC, 105mm WP
H - 105mm HC, 155mm HC, 155mm WP
I - 155mm HC, 105mm HC, 155mm WP
J - 105mm HC, 155mm HC, 4.2in WP
K - 81mm WP, 105mm HC, 155mm HC
L - 155mm HC, 81mm WP, 105mm HC
M - 81mm WP, 155mm HC, 105mm HC
N - 105mm HC, 81mm WP, 4.2in WP

For Tables 8 through 12, sheaf widths are in meters and screen durations are in minutes.

To use Tables 8 through 12, first select the proper table to correspond to prevailing weather conditions. Next, select the proper row and column of the matrix to agree with the desired screen width and duration, respectively. The appropriate cost effective choice sequence code lies at the intersection. For example, let us assume prevailing conditions of W1; hence Table 8 applies. For a sheaf width of 200 meters and a screen duration of 10 minutes, coding sequence A is indicated. This sequence means that, applying cost effective criteria, the tactical commander should use 155mm HC, 105mm HC, or 81mm WP, in that order, to produce the desired smoke screen. The costs for this

example are 155mm HC: $1252.44, 105mm HC: $1642.92, and 81mm MT: $4319.70. Accordingly, if 155mm howitzers are not employed, and 105mm howitzers support the mission, the screen cost is increased by $372.48, which is approximately 30% of the 155mm HC cost. If both types of howitzers are not employed and 81mm mortars support the mission, the screen cost is increased by $3067.26, which is approximately 245% of the 155mm HC cost. For a sheaf width of 500 meters and a screen duration of 12 minutes, there is no entry in Table 8, since that combination was not run in the model. Yet, by a reasonable consideration of the neighboring coding sequences, a local pattern may be subjectively constructed. In this case of 500 meters and 12 minutes in W1, the local pattern suggests coding sequence C. Thus, in cases where objective results were not derived from the model, subjective pattern construction may be used to obtain coding sequences with the "best" accuracy and reliability available.

Sheaf Width \ Screen Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	B	B	B	B	B	B	B	B	B	B										
150	B	B	A	A	A	A	A	A	A	A										
200	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250	A	A	A	A	A	A	A	A	A	A										
300	A	A	A	A	A	A	A	A	C	C										
350	A	A	A	A	A	A	C	C	C	C										
400	A	A	A	A	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
450	A	A	A	C	C	C	C	C	C	C										
500	A	A	A	C	C	C	C	C	C	C										
550	A	A	C	C	C	C	C	C	C	C										
600	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	E	E	E	E	E
650	C	C	C	C	C	C	C	C	C	C										
700	C	C	C	C	C	C	C	C	C	C										
750	C	C	C	C	C	C	C	C	C	E										
800	C	C	C	C	C	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E
850	C	C	C	C	C	C	C	C	E	E										
900	C	C	C	C	C	C	C	E	E	E										
950	C	C	C	C	C	C	E	E	E	E										
1000	C	C	C	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050	I	E	E	E	E	E	E	E	E	E										

Table 8

W1 Results

Screen Duration / Sheaf Width	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100																				
150																				
200	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
250																				
300																				
350																				
400	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
450																				
500																				
550																				
600	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 8a

W1 Results (contd)

Sheaf Width \ Screen Duration	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
100																				
150																				
200	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
250																				
300																				
350																				
400	C	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
450																				
500																				
550																				
600	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 8b

W1 Results (contd)

Screen Duration

Sheaf Width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	K	K	K	K	K	K	K	K	D	D										
150	D	D	B	B	B	B	B	B	B	B										
200	D	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
250	D	B	B	B	B	B	B	B	B	B										
300	N	B	B	B	B	B	B	B	B	B										
350	B	B	B	B	B	B	B	B	B	B										
400	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A
450	B	B	B	B	B	B	B	B	B	B										
500	B	B	B	B	B	B	B	B	B	B										
550	B	B	B	B	B	B	B	B	B	B										
600	B	B	B	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A
650	B	B	B	B	B	B	B	B	B	B										
700	B	B	B	B	B	B	B	B	B	B										
750	B	B	B	B	B	B	B	B	B	B										
800	B	B	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A	A
850	B	B	B	B	B	B	B	B	B	B										
900	B	B	B	B	B	B	B	B	B	B										
950	B	B	B	B	B	B	B	B	B	B										
1000	B	B	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A	A
1050	B	B	B	B	B	B	B	B	B	B										

Table 9

W2 Results

Sheaf Width \ Screen Duration	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100																				
150																				
200	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450																				
500																				
550																				
600	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
650																				
700																				
750																				
800	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
850																				
900																				
950																				
1000	A	A	I	I	I	I	I	I	I	I	H	H	H	H	H	H	H	H	H	H
1050																				

Table 9a

W2 Results (contd)

Sheaf Width \ Screen Duration	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
100																				
150																				
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450																				
500																				
550																				
600	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
650																				
700																				
750																				
800	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
850																				
900																				
950																				
1000	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
1050																				

Table 9b

W2 Results (contd)

Sheaf Width \ Screen Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	L	L	A	A	A	A	A	A	A	A										
150	A	A	A	A	A	A	A	A	A	A										
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250	A	A	A	A	A	A	A	A	A	A										
300	A	A	A	A	A	A	A	A	A	A										
350	A	A	A	A	A	A	A	A	A	A										
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450	A	A	A	A	A	A	A	A	A	A										
500	A	A	A	A	A	A	A	A	A	A										
550	A	A	A	A	A	A	A	A	A	A										
600	A	A	A	A	A	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C
650	A	A	A	A	A	A	A	A	C	C										
700	A	A	A	A	A	A	A	C	C	C										
750	A	A	A	A	A	A	C	C	C	C										
800	A	A	A	A	A	C	C	C	C	C	C	C	C	E	E	E	E	E	E	E
850	A	A	A	A	A	C	C	C	C	C										
900	A	A	A	A	C	C	C	C	C	C										
950	A	A	A	A	C	C	C	C	C	E										
1000	A	A	A	C	C	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E
1050	A	A	A	C	C	C	C	E	E	E										

Table 10

W3 Results

Sheaf Width \ Screen Duration	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100																				
150																				
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450																				
500																				
550																				
600	C	C	C	C	C	C	C	C	C	C	C	C	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 10a

M3 Results (contd)

Screen Duration / Sheaf Width	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
100																				
150																				
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	C	C	C	I	I	I	I	I	I	I	I	I	I
450																				
500																				
550																				
600	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 10b

W3 Results (contd)

Sheaf Width \ Screen Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	B	B	B	B	B	B	B	B	B	B										
150	B	B	B	B	B	B	B	B	B	B										
200	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
250	B	B	B	B	B	B	B	B	B	B										
300	B	B	B	B	B	B	B	B	B	B										
350	B	B	B	B	B	B	B	B	B	B										
400	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
450	B	B	B	B	B	B	B	B	B	B										
500	B	B	B	B	B	B	B	B	B	B										
550	B	B	B	B	B	B	B	B	B	B										
600	A	A	A	A	A	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C
650	A	A	A	A	A	A	A	A	A	C										
700	A	A	A	A	A	A	A	A	C	C										
750	A	A	A	A	A	A	A	I	C	C										
800	A	A	A	A	A	A	G	E	E	E	E	E	E	E	E	E	E	E	E	E
850	A	A	A	A	A	A	C	C	C	C										
900	A	A	A	A	A	C	C	C	C	E										
950	A	A	A	A	A	C	I	C	E	E										
1000	A	A	A	A	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E	E
1050	A	A	A	A	C	C	E	E	E	E										

Table 11

W4 Results

Sheaf Width \ Screen Duration	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100																				
150																				
200	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
250																				
300																				
350																				
400	B	B	B	B	B	B	B	B	H	H	H	H	H	H	H	H	H	H	H	H
450																				
500																				
550																				
600	C	C	C	C	C	C	C	C	E	E	E	E	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 11a

W4 Results (contd)

Screen Duration																				
Sheaf Width	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
100																				
150																				
200	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
250																				
300																				
350																				
400	J	J	J	J	J	J	J	J	J	J	H	H	H	H	H	H	H	H	H	H
450																				
500																				
550																				
600	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
650																				
700																				
750																				
800	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
850																				
900																				
950																				
1000	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1050																				

Table 11b

W4 Results (contd)

Sheaf Width \ Screen Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	M	M	K	K	K	K	K	K	K	K										
150	M	M	M	M	M	K	D	D	D	D										
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250	A	A	A	A	A	A	A	A	A	A										
300	A	A	A	A	A	A	A	A	A	A										
350	B	A	A	A	A	A	A	A	A	A										
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450	A	A	A	A	A	A	A	A	A	A										
500	B	A	A	A	A	A	A	A	A	A										
550	B	A	A	A	A	A	A	A	A	A										
600	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
650	B	A	A	A	A	A	A	A	A	A										
700	B	A	A	A	A	A	A	A	A	A										
750	B	A	A	A	A	A	A	A	A	A										
800	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
850	B	A	A	A	A	A	A	A	A	A										
900	B	B	A	A	A	A	A	A	A	A										
950	B	B	A	A	A	A	A	A	A	A										
1000	B	B	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1050	B	B	B	A	A	A	A	A	A	A										

Table 12

W5 Results

Sheaf Width \ Screen Duration	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100																				
150																				
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450																				
500																				
550																				
600	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
650																				
700																				
750																				
800	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
850																				
900																				
950																				
1000	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1050																				

Table 12a

W5 Results (contd)

Sheaf Width \ Screen Duration	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
100																				
150																				
200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
250																				
300																				
350																				
400	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
450																				
500																				
550																				
600	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
650																				
700																				
750																				
800	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
850																				
900																				
950																				
1000	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1050																				

Table 12b

W5 Results (contd)

C. Large Area Smoke Results

For comparison, large area smoke employment means, such as smoke pots and smoke generators, were applied (in Run 17) to the 250 situations comprising the base run (Run 1). Both employment means could support all smoke missions; to increase the size of a smoke screen employed by smoke generators or smoke pots, the operator merely adds another device. Unlike the indirect fire means, then, there is no constraint as restrictive as a maximum rate of fire. The applicable constraint to large area smoke employment means is the number of devices available. For purposes of the model, the number of devices that were available by TOE was sufficiently large to support all Run 1 smoke missions easily. The results of Run 17 were averaged over all 250 situations and are displayed in Table 13. In every situation the employment cost by smoke generators was less than that by smoke pots. In general, it can be seen from Table 13 that the average cost and average number of devices required by smoke generators were significantly less than the same factors required by smoke pots. The reader is reminded that, in the context of this paper, the term "cost" includes materiel that is consumed, only. The smoke pots are totally consumed in use, the smoke generators consume only fuel. In Table 13, costs are in dollars.

System	Cost (Average)	Devices (Average)
Smoke Generators	2.07	9.64
Smoke Pots	401.01	28.40

Table 13

Run 17 Averages

Chapter V

Conclusions

As a result of the discussion in the previous chapters, with particular emphasis on the assumptions (Chapter I), as well as the measure of effectiveness and nature of the models (Chapter II), the conclusions from this study effort are as follows.

The following weather coding will be used, for brevity.

W1 - lapse conditions, 5 knot wind

W2 - neutral conditions, 5 knot wind

W3 - neutral conditions, 10 knot wind

W4 - neutral conditions, 15 knot wind

W5 - inversion conditions, 5 knot wind

1. Significant cost savings may be attained by employing cost effective criteria to smoke screen employment means. Table 4 suggests that these savings not only are in costs, but also may be in the number of rounds required by and resupplied to the firing unit.

2. The savings obtained by cost effective criteria are a function of weather conditions, sheaf width and screen duration.

3. Basic loads and ammunition supply rates are heavily influenced by anticipated expenditure of ammunition. Thus, the

results of this study effort may, with judicious tactical anticipation, be used to plan basic loads of smoke ammunition and decrease required smoke ammunition expenditure and resupply during battle.

4. Cost effective savings may be obtained with minimal effort by the tactical commander in his planning and execution of the battle. Cost effective application can be easily included in planning for the active defense.

5. In general, artillery HC systems are cost effective over mortar WP systems.

6. The cost effective pattern between the artillery HC systems varies as a function of weather conditions, sheaf width, and screen duration. For W1, W3, and W5 the 155mm HC was cost effective; for W2 and W4 the 105mm HC was cost effective. When the 155mm HC was the 1st cost effective choice, the 105mm HC was 2nd, and vice versa.

7. Due to the complex nature of the cost effective function, an expedient method of applying the cost effective criteria is by reference to Tables 8 through 12, as appropriate for the prevailing weather conditions.

8. WP systems are not competitive with HC systems under cost effective criteria. However, it is possible that the results of this study could be significantly altered by an improved WP system or a new HC system. Particularly among the 81mm and 4.2in mortars a new HC system may prove particularly fruitful in reaping cost savings.

9. The 60mm WP system is not a cost effective employment means for smoke screens. However, it can produce a few smoke screens in W5, with a sheaf width of 200 meters or less and for a screen duration of 20 minutes or less.

10. An additional tube in the 60mm mortar firing unit would enable the unit to support only a few more smoke missions.

11. An additional tube in the 81mm mortar firing unit would produce a new 3d cost effective choice (over the previous 4.2in WP) at considerable savings. If the 4.2in mortar is phased out of U.S. Army units, an additional 81mm mortar tube could be significant. The addition would result in a 3d cost effective choice. If the available howitzer firing units were saturated by anti-personnel missions and counter-battery fire, the additional 81mm mortar tube would enable the firing unit to support the smoke mission.

12. An additional tube in the 4.2in mortar firing unit would produce a 3d cost effective choice in only a few situations. If the available howitzer firing units were saturated by anti-personnel missions and counter-battery fire, the addition of a 4.2in mortar tube would enable the firing unit to support the smoke mission.

13. The addition of another 105mm howitzer or another 155mm howitzer to their respective firing units would produce no change in cost effective outcome. With respect to cost effective criteria, current 105mm and 155mm howitzer batteries Tables of Organization and Equipment are optimal.

14. Smoke generators are cost effective over smoke pots to a considerable degree.

15. Smoke generators and smoke pots are cost effective over indirect fire employment means to a considerable degree.

Some of the above conclusions are considered intuitively obvious by many personnel experienced in smoke screen employment. However, this study has provided some quantitative basis for such qualitative opinion; in this writer's opinion, this result alone was worth the study effort.

Chapter VI

Recommendations

In view of the preceeding five chapters, the commensurate modeling effort, and subsequent analysis, the following recommendations are made, relative to the hypothetical applications as described.

1. That cost effective criteria be applied to smoke screen employment means whenever permitted by the tactical situation.

2. That cost effective criteria be applied in the planning of basic loads of smoke ammunition.

3. That Tables 8 through 12 be included in FM 101-10-1, "Staff Officer's Field Manual; Organizational, Technical and Logistic Data (Unclassified Data)," for expeditious application of cost effective criteria.

4. That howitzer and mortar Tables of Organization and Equipment retain their current configurations.

5. That vigorous experimentation be conducted to produce 81mm and 4.2in mortar HC smoke projectiles, or the equivalent.

6. That, if the 4.2in mortar is deleted from U.S. Army combat divisions, consideration be given to an 81mm mortar firing unit of 4 tubes.

7. That large area smoke employment means, such as smoke pots and smoke generators, be incorporated into U.S. Army unit field training for cost effectiveness and for familiarization by military personnel.

8. That the areas for further study, such as (a) optimal employment criteria for tactical success and (b) calculations described in Conclusion 4, be undertaken as follow-on to this study effort.

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Appendix A

Computer Program Listing: Indirect Fire Smoke Model

```
      PROGRAM NAB4(INPUT,OUTPUT,DWB1,TAPE5=DWB1)
      DIMENSION A(7,5),C(7),SH(5),DT(10),TC1(5,5,10),TC2(5,5,10),
     1  TC3(5,5,10),TC4(5,5,10),TC5(5,5,10),TC6(5,5,10),
     1  TC7(5,5,10),TC8(5,5,10),AC(7),AN(7)
     1 ,TR1(5,5,10),TR2(5,5,10),TR3(5,5,10),TR4(5,5,10),
     1  TR5(5,5,10),TR6(5,5,10),TR7(5,5,10),TR8(5,5,10)
C
C  A=FIRING RATE MATRIX
C  C=COST PER ROUND MATRIX
C  SH=SHEAF WIDTH MATRIX, IN METERS
C  DT=TIME DURATION MATRIX, IN MINUTES
C  TC1,TC2,TC3,TC4,TC5,TC6,TC7=COST MATRICES PER WEAPON SYSTEM
C           C1=LAPSE, 5 KNOT WIND
C           C2=NEUTRAL, 5 KNOT WIND
C           C3=NEUTRAL, 10 KNOT WIND
C           C4=NEUTRAL, 15 KNOT WIND
C           C5=INVERSION, 5 KNOT WIND
C  TI=DT(I), THE TIME INTERVAL WITHIN A LOOP
C  X=SH(I), THE SHEAF WIDTH WITHIN A LOOP
C  RC=COST OF ROUND, WITHIN A LOOP
C  RM=(MAX NUMBER OF ROUNDS THAT CAN BE FIRED PER WEAPON)*(NO. OF
C           WEAPONS FIRED)
C  TNE=TOTAL NUMBER OF ROUNDS NEEDED TO ESTABLISH SCREEN
C  TNM=TOTAL NUMBER OF ROUNDS NEEDED TO MAINTAIN SCREEN PER BARRAGE
C  FR=FIRING RATE, I'T ROUNDS PER ( ) MINUTES BETWEEN BARRAGES
C  CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
C           =SUBROUTINE TO CHECK FR AND CALCULATE TNR AND TCO
C           N=INDEX FOR WEAPON SYSTEM
C           M=INDEX FOR WEATHER CONDITION
C           TNR=TOTAL NUMBER OF ROUNDS REQUIRED FOR SCREEN
C           TCO=TOTAL COST FOR MISSION
C
      REWIND 5
C  READ IN DATA
      DO 10 I=1,7
      READ(5,30) (A(I,J),J=1,5)
      PRINT 30,A(I,1),A(I,2),A(I,3),A(I,4),A(I,5)
   30 FORMAT(5F10.5)
   10 CONTINUE
      READ(5,31) (C(I),I=1,7)
      PRINT 31,C(1),C(2),C(3),C(4),C(5),C(6),C(7)
   31 FORMAT(7F10.2)
      READ(5,32) (SH(I),I=1,5)
      PRINT 32,SH(1),SH(2),SH(3),SH(4),SH(5)
```

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```
   32 FORMAT(1X,8F10.0)
      READ(5,33) (OT(I),I=1,10)
      PRINT 33,(OT(I),I=1,10)
   33 FORMAT(1X, 10F5.0)
C  COMPUTE COSTS
C  C1 = LAPSE, 5 KNOT WIND
C  C2 = NEUTRAL, 5 KNOT WIND
C  C3 = NEUTRAL, 10 KNOT WIND
C  C4 = NEUTRAL, 15 KNOT WIND
C  C5 = INVERSION, 5 KNOT WIND
      DO 41 L=1,10
      DO 40 K=1,5
      TI=OT(L)
      X=SH(K)
C
C  60 MM MORTAR
C
      RC=C(1)
      N=1
C  COMPUTE MAX FIRE RATE
      IF(TI.LE. 1.) RM=30.
      IF(TI.GT. 1.) RM=30. + 8.*(TI-1.)
      RM=RM*3.
C  C1
      M=1
      TNE=.1*X + 2.
      TNM=.22*X
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC1(K,M,L)=TCO
      TR1(K,M,L)=TNR
C  C2
      M=2
      TNE=.055*X
      TNM=.1*X + 2.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC1(K,M,L)=TCO
      TR1(K,M,L)=TNR
C  C3
      M=3
      TNE=.025*X + 11.
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC1(K,M,L)=TCO
      TR1(K,M,L)=TNR
C  C4
      M=4
      TNE=.055*X
```

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```
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC1)
      TC1(K,M,L)=TC1
      TR1(K,M,L)=TNR
C  C5
      M=5
      TNE=.1275*X + 1.5
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC1)
      TC1(K,M,L)=TC1
      TR1(K,M,L)=TNR
C
C  81 MM MORTAR
C
      RC=C(2)
      N=2
C  COMPUTE MAX FIRE RATE
      IF(TI.LE. 3.) RM=60.
      IF(TI.LE. 2.) RM=40.
      IF(TI.LE. 1.) RM=20.
      IF(TI.GT. 3.) RM=50. + 5.*(TI-3.)
      RM=RM*3.
C  C1
      M=1
      TNE=.05*X + 1.
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC1)
      TC2(K,M,L)=TC1
      TR2(K,M,L)=TNR
C  C2
      M=2
      IF(X.LE.400.) TNE=.025*X - 1.
      IF(X.LE.400.) TNM=TNE
      IF(X.GT. 400.) TNE=.02*X + 1.
      IF(X.GT. 400.) TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC1)
      TC2(K,M,L)=TC1
      TR2(K,M,L)=TNR
C  C3
      M=3
      TNE=.02625*X - 1.25
      TNM=.025*X - 1.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC1)
      TC2(K,M,L)=TC1
      TR2(K,M,L)=TNR
```

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```
C   C4
        M=4
        TNE=.02*X + 2.
        TNM=TNE*2.
        FR=A(N,M)
        CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
        TC2(K,M,L)=TCO
        TR2(K,M,L)=TNR
C   C5
        M=5
        IF(X.LE.400.) TNE=.025*X - 1.
        IF(X.LE.400.) TNM=TNE
        IF(X.GT.400.) TNE=.02*X + 1.
        IF(X.GT.400.) TNM=TNE
        FR=A(N,M)
        CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
        TC2(K,M,L)=TCO
        TR2(K,M,L)=TNR
C
C   4.2 INCH MORTAR
C
        RC=C(3)
        N=3
C   COMPUTE MAX FIRE RATE
        IF(TI.LE.6.) RM=53.
        IF(TI.LE.5.) RM=54.
        IF(TI.LE.4.) RM=45.
        IF(TI.LE.3.) RM=35.
        IF(TI.LE.2.) RM=27.
        IF(TI.LE.1.) RM=18.
        IF(TI.GT. 6.) RM=63. + 3.*(TI-6.)
        RM=RM*4.
C   C1
        M=1
        TNE=.03375*X - .75
        TNM=TNE + 3.
        FR=A(N,M)
        CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
        TC3(K,M,L)=TCO
        TR3(K,M,L)=TNR
C   C2
        M=2
        TNE=.02*X + 1.
        TNM=TNE - 1.
        FR=A(N,M)
        CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
        TC3(K,M,L)=TCO
        TR3(K,M,L)=TNR
```

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```
C  C3
      M=3
      IF(X.LE.400.)  TNE=.01*X + 1.
      IF(X.LE.400.)  TNM=TNE*2.
      IF(X.GT.400.)  TNE=.01933*X - 2.33333
      IF(X.GT.400.)  TNM=.03866*X - 4.66667
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC3(K,M,L)=TCO
      TR3(K,M,L)=TNR
C  C4
      M=4
      IF(X.LE.400.)  TNE=.005*X + 3.
      IF(X.LE.400.)  TNM=TNE*2.
      IF(X.GT.400.)  TNE=.02*X - 3.
      IF(X.GT.400.)  TNM=TNE*2.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC3(K,M,L)=TCO
      TR3(K,M,L)=TNR
C  C5
      M=5
      TNE=.015*X
      TNM=.00625*X + 4.75
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC3(K,M,L)=TCO
      TR3(K,M,L)=TNR
C
C  105 MM WP
C
      RC=C(4)
      N=4
C  COMPUTE MAX FIRE RATE
      IF(TI.LE.3.)  RM=30.
      IF(TI.GT.3.)  RM=30. + 3.*(TI-3.)
      RM=RM*6.
C  C1
      M=1
      TNE=.045*X + 3.
      TNM=.05*X + 14.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC4(K,M,L)=TCO
      TR4(K,M,L)=TNR
C  C2
      M=2
      TNE=.03*X - 1.
      TNM=.03375*X + 1.25
      FR=A(N,M)
```

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```
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC4(K,M,L)=TCO
      TR4(K,M,L)=TNR
C  C3
      M=3
      TNE=.225*X
      TNM=TNE*2.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC4(K,M,L)=TCO
      TR4(K,M,L)=TNR
C  C4
      M=4
      TNE=.32*X + 1.
      TNM=.3375*X + 2.5
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC4(K,M,L)=TCO
      TR4(K,M,L)=TNR
C  C5
      M=5
      TNE=.3175*X - .5
      TNM=.31625*X + 2.75
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC4(K,M,L)=TCO
      TR4(K,M,L)=TNR
C
C  1.5 MM HC
C
C  RC AND RM ALREADY COMPUTED
      CR=C(5)
      N=5
C  C1
      M=1
      TNE=.22*X
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC5(K,M,L)=TCO
      TR5(K,M,L)=TNR
C  C2
      M=2
      TNE=.30625*X + .75
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC5(K,M,L)=TCO
      TR5(K,M,L)=TNR
```

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```
C  C3
      M=3
      TNE=.1*X + 1.
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC5(K,M,L)=TCO
      TR5(K,M,L)=TNR
C  C4
      M=4
      TNE=.1375*X + .25
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC5(K,M,L)=TCO
      TR5(K,M,L)=TNR
C  C5
      M=5
      TNE=.225*X + 1.
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC5(K,M,L)=TCO
      TR5(K,M,L)=TNR
C
C  155 MM HP
C
      RC=C(6)
      N=6
C  COMPUTE MAX FIRE RATE
      IF(TI.LE.3.) RM=12.
      IF(TI.GT.3.) RM=9. + TI
      RM=RM*6.
C  C1
      M=1
      IF(X.LE.800.) TNE=.025*X
      IF(X.LE.800.) TNM=TNE + 3.
      IF(X.GT.800.) TNE=.02*X + 4.
      IF(X.GT.800.) TNM=TNE + 3.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC6(K,M,L)=TCO
      TR6(K,M,L)=TNR
C  C2
      M=2
      TNE=.01625*X - .25
      TNM=6.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TCO)
      TC6(K,M,L)=TCO
      TR6(K,M,L)=TNR
```

```
C  C3
      M=3
      IF(X.LE.400.) TNE=.015*X
      IF(X.LE.400.) TNM=.015*X + 3.
      IF(X.GT.400.) TNE=.01*X + 2.
      IF(X.GT.400.) TNM=1.43333*X + 1.66667
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC0)
      TC3(K,M,L)=TC0
      TR3(K,M,L)=TNR
C  C4
      M=4
      IF(X.LE.400.) TNE=3.
      IF(X.LE.400.) TNM=5.
      IF(X.GT.400..AND.X.LE.600.) TNE=.02*X-5.
      IF(X.GT.400..AND.X.LE.600.) TNM=TNE*2.
      IF(X.GT.600.) TNE=.015*X-2.
      IF(X.GT.600.) TNM=TNE*2.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC0)
      TC4(K,M,L)=TC0
      TR4(K,M,L)=TNR
C  C5
      M=5
      TNE=.01625*X - .25
      TNM=6.
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC0)
      TC5(K,M,L)=TC0
      TR5(K,M,L)=TNR
C
C  155 MM HC
C
C  RC AND RM ALREADY COMPUTED
      C2=C(7)
      N=7
C  C1
      M=1
      TNE=.01*X + 1.
      TNM=TNE
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC0)
      TC7(K,M,L)=TC0
      TR7(K,M,L)=TNR
C  C2
      M=2
      TNE=.0075*X + .5
      TNM=.0025*X + .5
      FR=A(N,M)
      CALL CALC(TNE,TNM,RM,TI,RC,FR,X,N,M,TNR,TC0)
```

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```
      TC7(K,M,L)=TC
      TR7(K,M,L)=TR
C  C3
      M=3
      TNF=.05*X
      TNM=TNF
      FR=A(N,M)
      CALL CALC(TNF,TNM,FM,TI,RC,FR,X,N,M,TNR,TCO)
      TC7(K,M,L)=TCO
      TR7(K,M,L)=TNR
C  C4
      M=4
      TNF=.0625*X + .75
      TNM=TNF
      FR=A(N,M)
      CALL CALC(TNF,TNM,FM,TI,RC,FR,X,N,M,TNR,TCO)
      TC7(K,M,L)=TCO
      TR7(K,M,L)=TNR
C  C5
      M=5
      TNF=.05*X
      IF(X.LE.80.) TNM=1.
      IF(X.GT.80.) TNM=.005*X - 3.
      FR=A(N,M)
      CALL CALC(TNF,TNM,FM,TI,RC,FR,X,N,M,TNR,TCO)
      TC7(K,M,L)=TCO
      TR7(K,M,L)=TNR
   40 CONTINUE
   41 CONTINUE
C  DETERMINE MINIMUM COST VS SITUATION
      DO 20 I=1,5
      DO 20 J=1,5
      DO 20 K=1,10
      C1=TR1(I,J,K)
      C2=TR2(I,J,K)
      C3=TR3(I,J,K)
      C4=TR4(I,J,K)
      C5=TR5(I,J,K)
      C6=TR6(I,J,K)
      C7=TR7(I,J,K)
      TR8(I,J,K)=AMIN1(C1,C2,C3,C4,C5,C6,C7)
      C1=TC1(I,J,K)
      C2=TC2(I,J,K)
      C3=TC3(I,J,K)
      C4=TC4(I,J,K)
      C5=TC5(I,J,K)
      C6=TC6(I,J,K)
      C7=TC7(I,J,K)
   20 TC8(I,J,K)=AMIN1(C1,C2,C3,C4,C5,C6,C7)
      DO 59 I=1,7
```

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```
      AC(I)=0.
   59 AN(I)=0.
      DO 60 I=1,5
      DO 60 J=1,5
      DO 60 K=1,10
      IF(TC1(I,J,K).EQ.9999999.99) GO TO 61
      AC(1)=AC(1) + TC1(I,J,K)
      AN(1)=AN(1) + TR1(I,J,K)
   61 IF(TC2(I,J,K).EQ.9999999.99) GO TO 62
      AC(2)=AC(2) + TC2(I,J,K)
      AN(2)=AN(2) + TR2(I,J,K)
   62 IF(TC3(I,J,K).EQ.9999999.99) GO TO 63
      AC(3)=AC(3) + TC3(I,J,K)
      AN(3)=AN(3) + TR3(I,J,K)
   63 IF(TC4(I,J,K).EQ.9999999.99) GO TO 64
      AC(4)=AC(4) + TC4(I,J,K)
      AN(4)=AN(4) + TR4(I,J,K)
   64 IF(TC5(I,J,K).EQ.9999999.99) GO TO 65
      AC(5)=AC(5) + TC5(I,J,K)
      AN(5)=AN(5) + TR5(I,J,K)
   65 IF(TC6(I,J,K).EQ.9999999.99) GO TO 66
      AC(6)=AC(6) + TC6(I,J,K)
      AN(6)=AN(6) + TR6(I,J,K)
   66 IF(TC7(I,J,K).EQ.9999999.99) GO TO 60
      AC(7)=AC(7) + TC7(I,J,K)
      AN(7)=AN(7) + TR7(I,J,K)
   60 CONTINUE
      DO 70 I=1,7
      AC(I)=AC(I)/250.
   70 AN(I)=AN(I)/250.
C  PRINT OUT RESULTS
      PRINT 34
   34 FORMAT(" ")
      DO 35 I=1,5
      DO 35 J=1,5
      DO 35 K=1,10
      PRINT 36, TR1(I,J,K),TR2(I,J,K),TR3(I,J,K),TR4(I,J,K),
     1  TR5(I,J,K),TR6(I,J,K),TR7(I,J,K),TR8(I,J,K)
   35 PRINT 36, TC1(I,J,K),TC2(I,J,K),TC3(I,J,K),TC4(I,J,K),
     1  TC5(I,J,K),TC6(I,J,K),TC7(I,J,K),TC8(I,J,K)
   36 FORMAT(1X,8F15.2)
      PRINT 37
   37 FORMAT(1X,"AVERAGES - MPN,COST,ROUNDS")
      DO 71 I=1,7
   71 PRINT 38, I,AC(I),AN(I)
   38 FORMAT(1X,I5,2F15.2)
      STOP
      END
      SUBROUTINE CALC(TNB,TNR,PM,TI,AC,ER,X,N,M,TNR,TCO)
      DIMENSION A(7,5),C(7),SH(5),DT(10),TC1(5,5,10),TC2(5,5,10),
```

```
     1   TC3(5,5,10),TC4(5,5,10),TC5(5,5,10),TC6(5,5,10),
     2   TC7(5,5,10),TC8(5,5,10),CC(7),AN(7)
     1  ,TR1(5,5,10),TR2(5,5,10),TR3(5,5,10),TR4(5,5,10),
     1   TR5(5,5,10),TR6(5,5,10),TR7(5,5,10),TR8(5,5,10)
      RINF=9999999.99
      IF(X.GE.88...AND.X.EQ.2) GO TO 50
      GO TO 51
   50 IF(N.EQ.3) FR=1.5
   51 IF(X.GE.88...AND.X.EQ.3) GO TO 52
      GO TO 53
   52 IF(N.EQ.6) FR=1.5
   53 CONTINUE
      TNR=TNF + TNM*TI/FR
      TC)=TNR*RC
      IF(TNR.GT.RM) TC)=RINF
      RETURN
      END
```

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Appendix B

AMSAA JTCG Smoke Model

In order to use a chart, construct a perpendicular from t desired screen length (X axis) to intercept the appropriate weather condition and wind speed line (lapse 5; neutral 5,10, or 15; inversion 5). From that point, move on a horizontal to the left scale (Y axis) which gives the number of rounds required to establish the screen. From the same intercept point on the appropriate weather condition line, move on a horizontal to the right to the column for the desired weather condition, read the number of rounds required to maintain the screen. Entries at the column heading provide the time between firings and placement of rounds to maintain the screen.

As an example, to establish an 800 meter smoke screen using the 155mm HC round with a crosswind and an inversion condition, locate on the appropriate chart (155mm, HC, M116BE) the 800 meter screen length (X axis). Follow the perpendicular up to the inversion line and move horizontally to the Y axis. Four rounds are required to establish the screen, as determined by the Y intercept. Moving horizontally to the right to the inversion column, one round is necessary to maintain the screen. Within this column it is shown that it is necessary to repeat with one round every two minutes to maintain the screen, and it is also necessary to place the round 30 meters upwind of the area to be

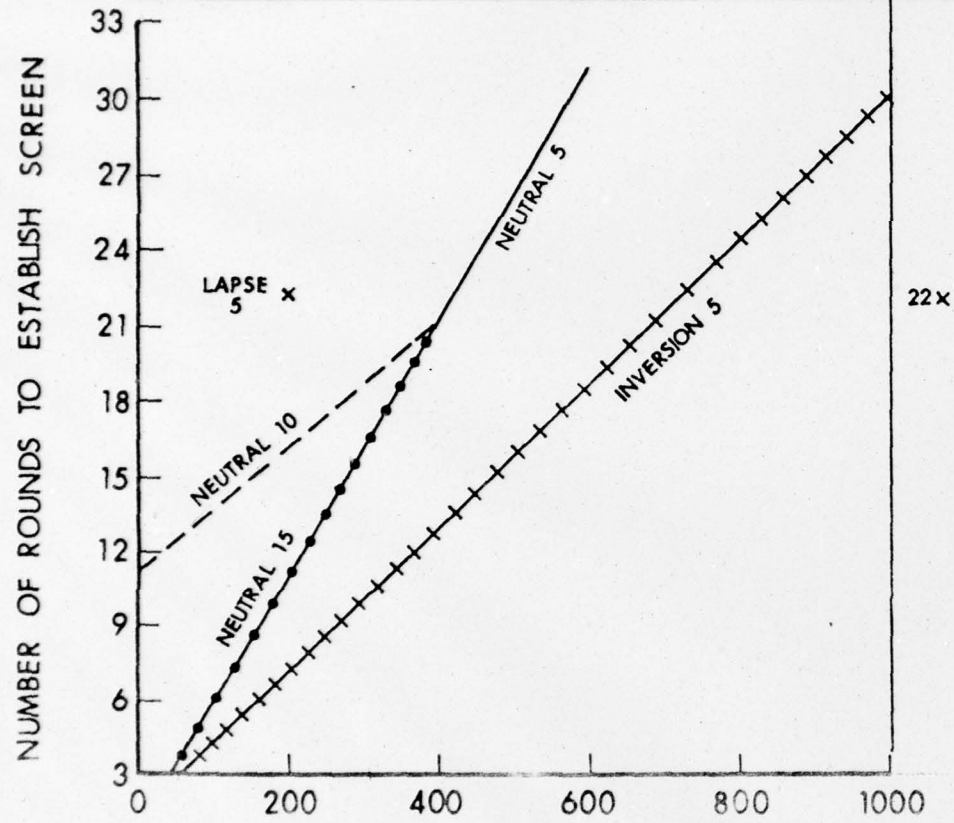
screened in order to cover this area adequately.

Ammunition Expenditure to Establish and Maintain Smoke Screen

60 mm
WP M302
CROSS WIND

NUMBER OF ROUNDS TO MAINTAIN SCREEN

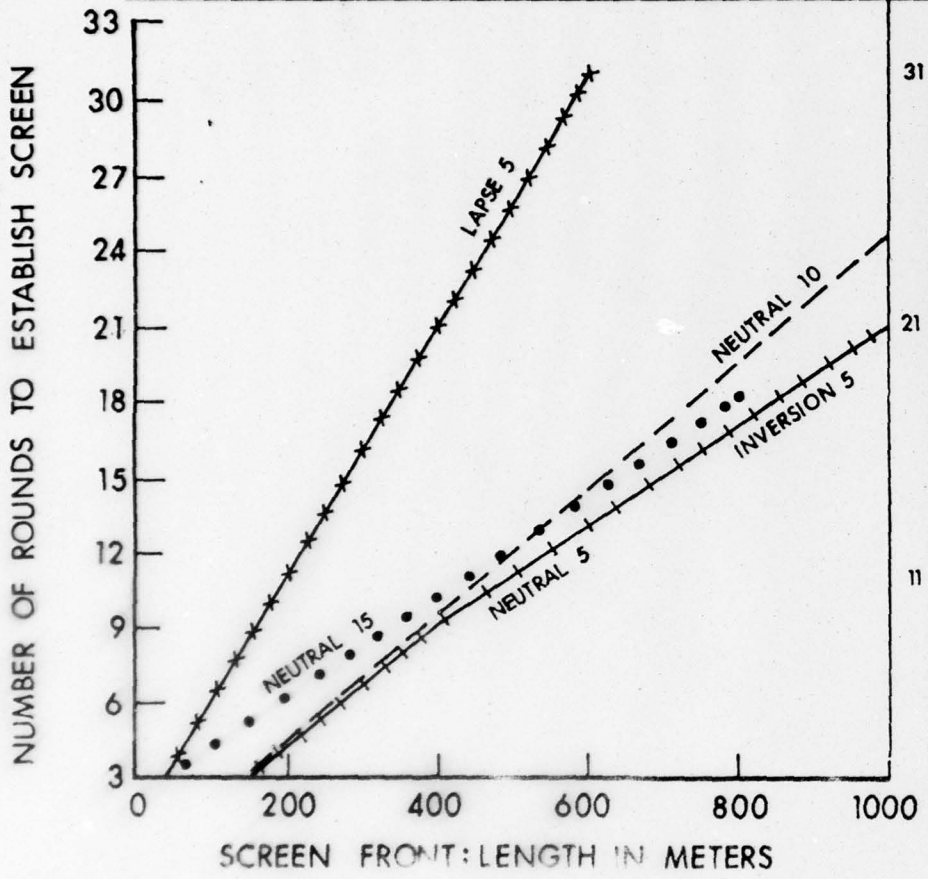
WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	.5	.5	.25	.25	.25
UPWIND IN METERS	50	50	75	100	100
	22 x	62 42 22	21 16	21 11	30 24 18 13 7



Ammunition Expenditure to Establish and Maintain Smoke Screen

81 mm
WP M57
CROSS WIND

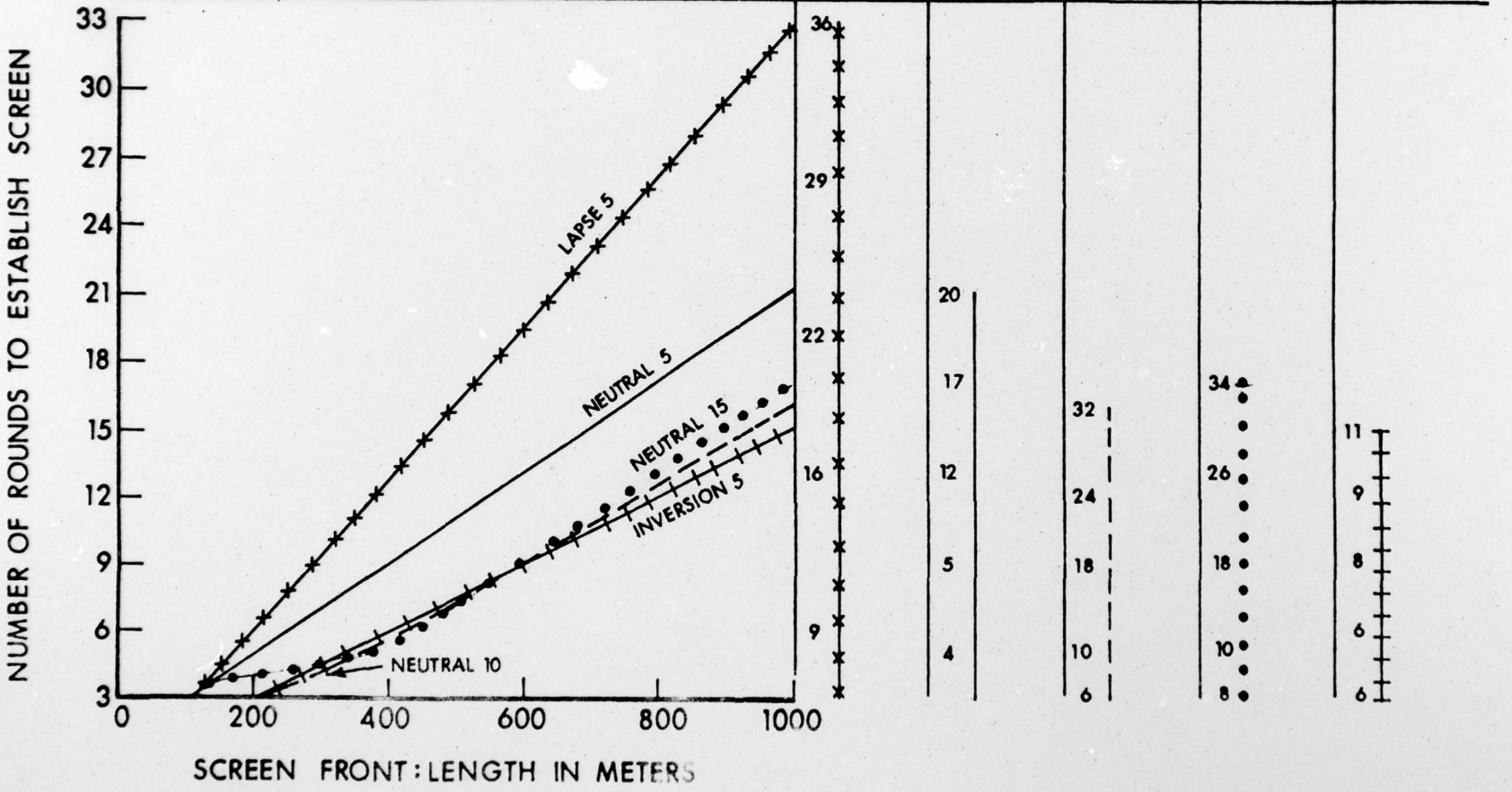
WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	5	1	5	1	1.5
UPWIND IN METERS	25	50	50	50	50
NUMBER OF ROUNDS TO MAINTAIN SCREEN	31 / 21 / 11	21 / 17 / 13 / 9 / 4	24 / 19 / 14 / 9 / 4	36 / 28 / 20 / 12	21 / 17 / 13 / 9 / 4



Ammunition Expenditure to Establish and Maintain Smoke Screen

4.2-inch
WP M328A1
CROSS WIND

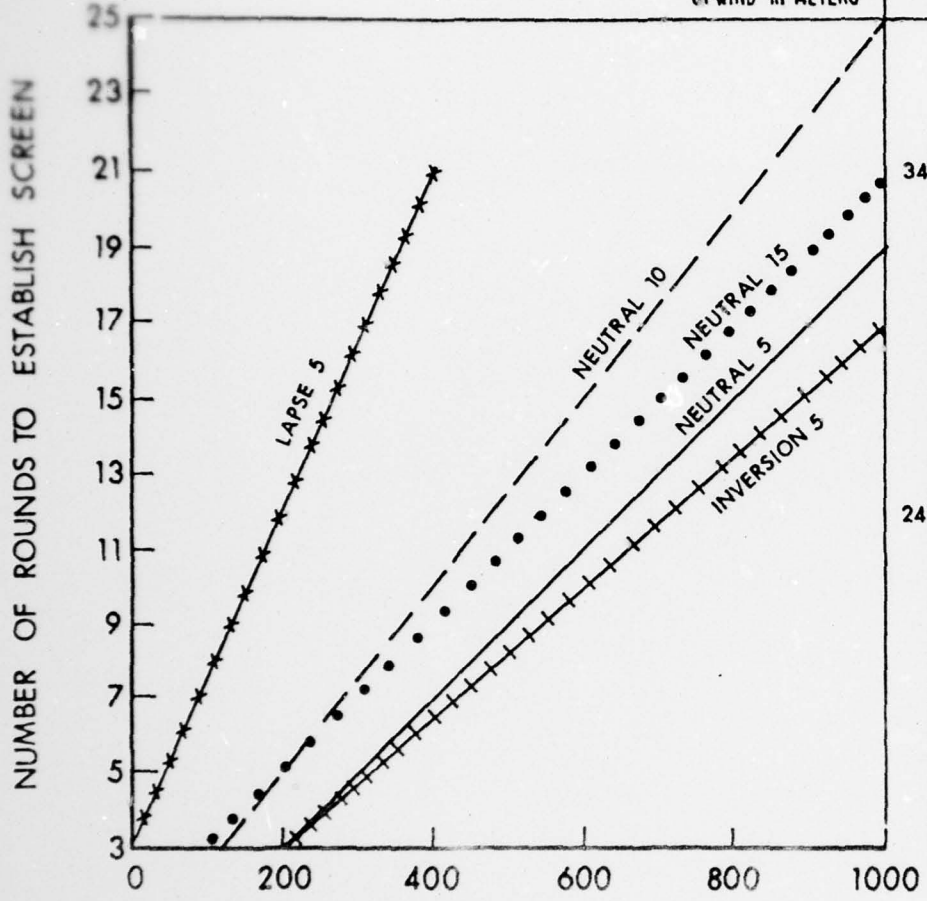
WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	1	1	1	1	1
UPWIND IN METERS	60	250	125	200	60



Ammunition Expenditure to Establish and Maintain Smoke Screen

105 mm
WP M60
CROSS WIND

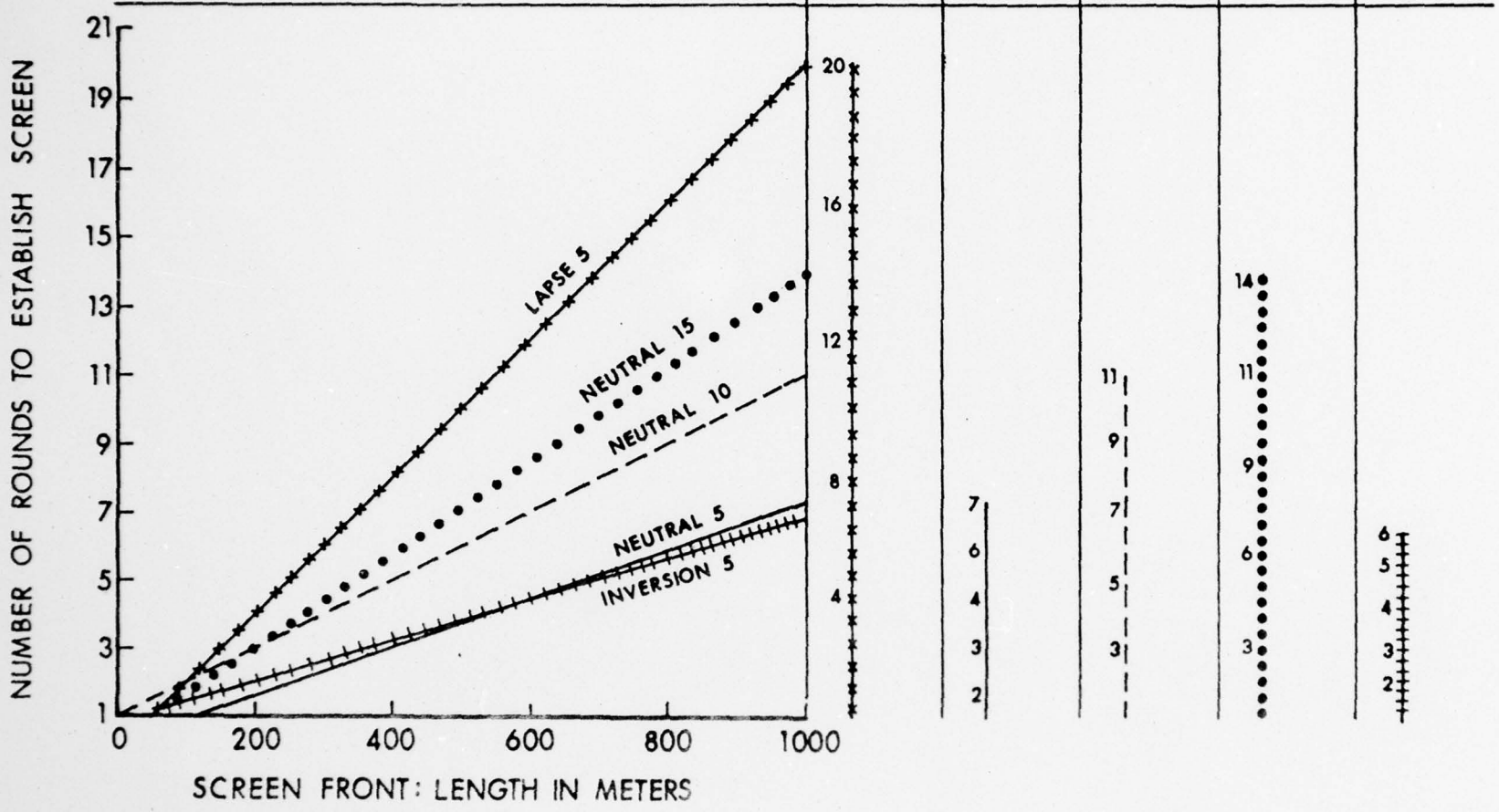
WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	1	1 200-600 1.5 800-1000	1	1	1
UPWIND IN METERS	60	60	125	200	75
NUMBER OF ROUNDS TO MAINTAIN SCREEN	34 24	25 21 14 10 6	50 40 30 20 10	40 32 24 16 10	19 15 11 9 6



Ammunition Expenditure to Establish and Maintain Smoke Screen

105 mm
HC M84 BE
CROSS WIND

WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	1	2	2	2	2
UPWIND IN METERS	50	50	50	25	50

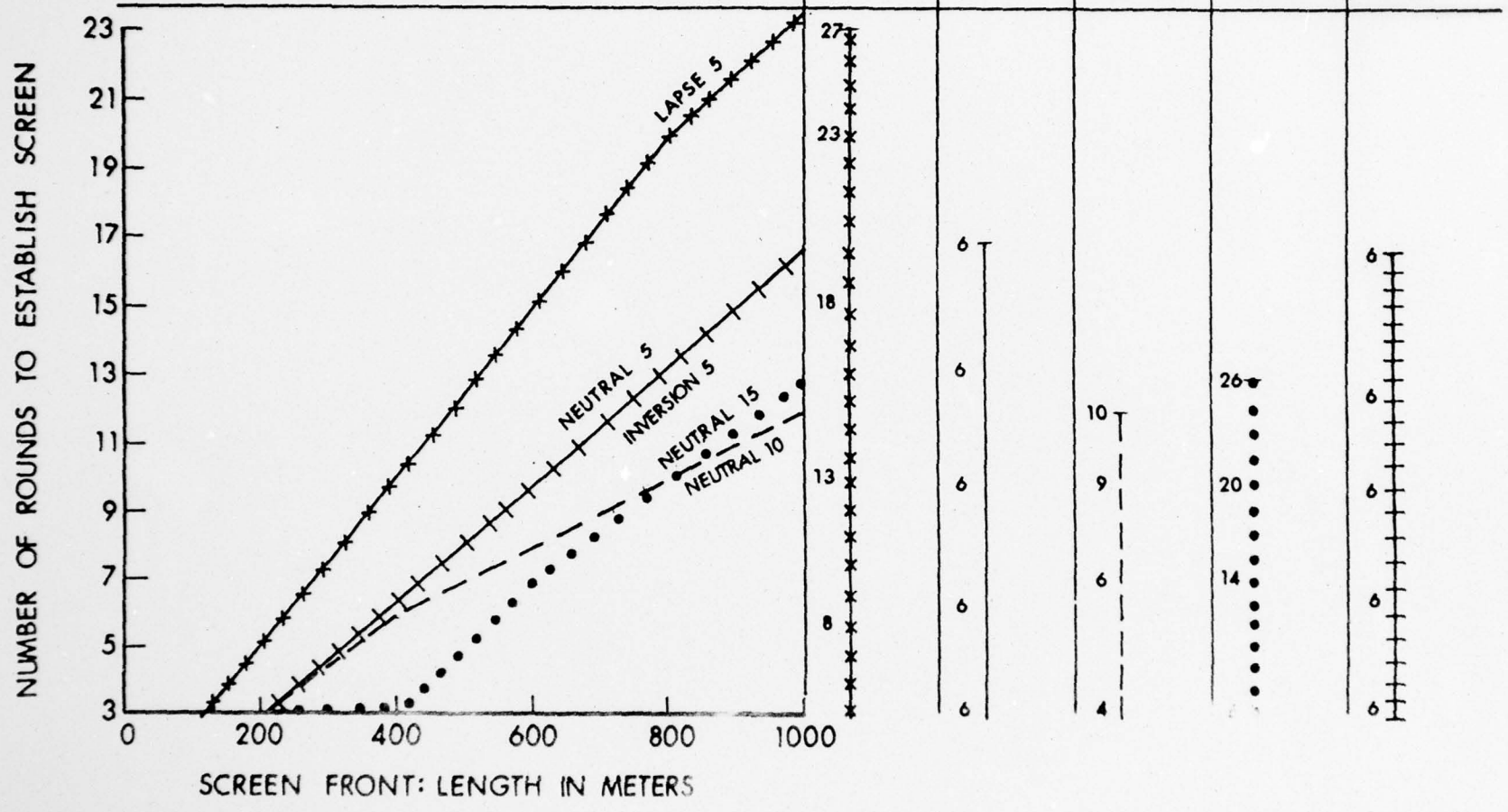


Ammunition Expenditure to Establish and Maintain Smoke Screen

155 mm
WP M110
CROSS WIND

NUMBER OF ROUNDS TO MAINTAIN SCREEN

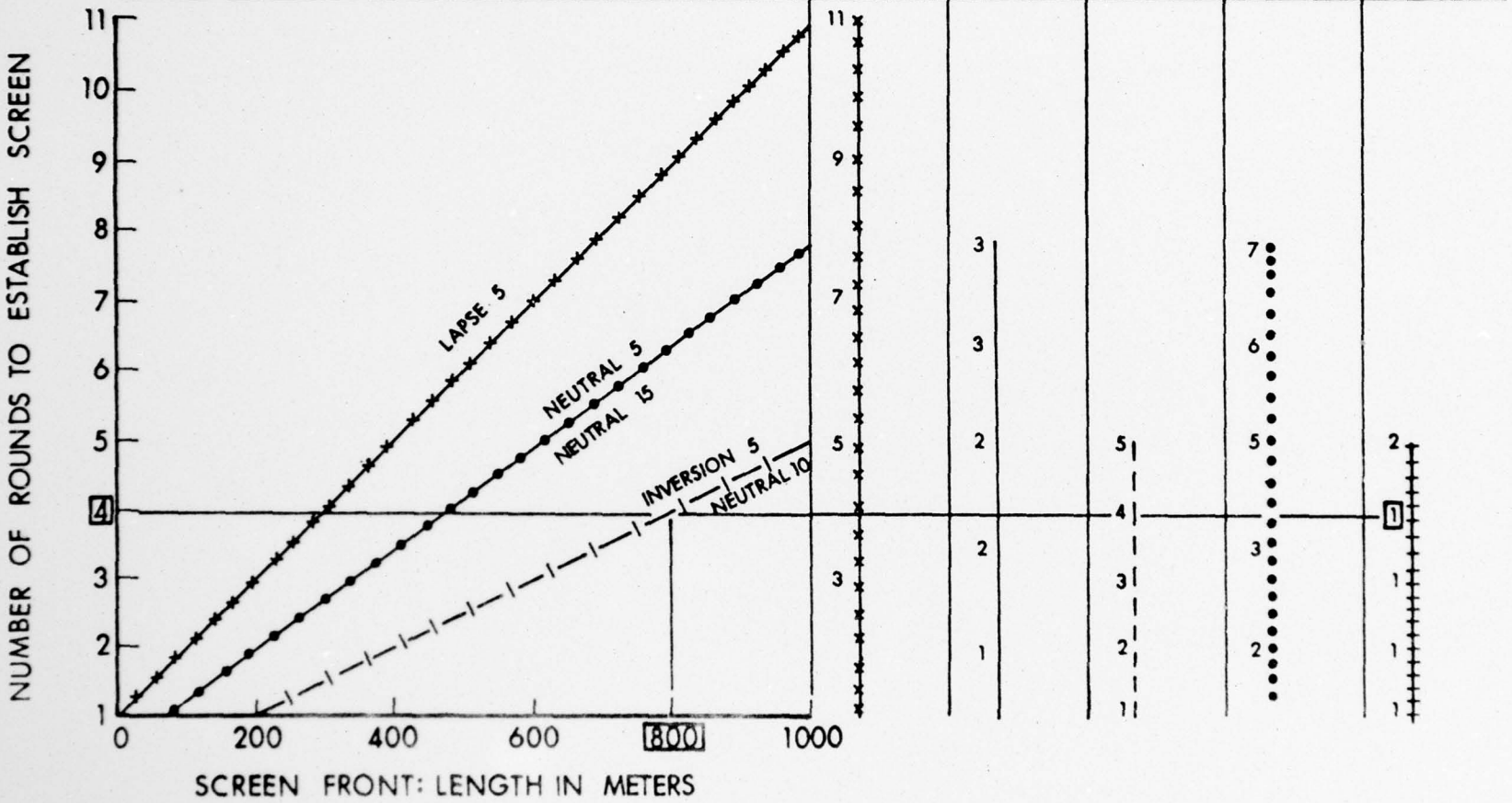
WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	1	1	1 200-400 1.5 600-1000	1	.1
UPWIND IN METERS	75	75	150 - 500	175	75



Ammunition Expenditure to Establish and Maintain Smoke Screen

155mm
HC M116 BE
CROSS WIND

WEATHER CONDITION CLOUD BEHAVIOR	LAPSE RAPID VERTICAL RISE	NEUTRAL	NEUTRAL MODERATE VERTICAL RISE	NEUTRAL	INVERSION SLOW VERTICAL RISE
WIND SPEED	5	5	10	15	5
MINUTES BETWEEN FIRING TO MAINTAIN	2	2	2	2	2
UPWIND IN METERS	50	50	50	50	30



Appendix C

Computer Program Listing: Large Area Smoke Model

```
      PROGRAM NAB3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
C  PROGRAM TO CALCULATE COST OF SMOKE SHEAF
C
      DIMENSION GL(3,3),GIN(3,3),PL(3,3),PIN(3,3),TCG(5,5,10),
     1  TCP(5,5,10),TCM(5,5,10),TNG(5,5,10),TNP(5,5,10),SH(5),DT(10)
C  READ IN DATA
      DO 10 I=1,3
      READ(5,100)  (GL(I,J),J=1,3)
      WRITE(6,100) (GL(I,J),J=1,3)
      READ(5,100)  (GIN(I,J),J=1,3)
      WRITE(6,100) (GIN(I,J),J=1,3)
      READ(5,100)  (PL(I,J),J=1,3)
      WRITE(6,100) (PL(I,J),J=1,3)
      READ(5,100)  (PIN(I,J),J=1,3)
   10 WRITE(6,100) (PIN(I,J),J=1,3)
  100 FORMAT(1X,3F10.5)
      READ(5,200)  (SH(I),I=1,5)
      WRITE(6,200) (SH(I),I=1,5)
  200 FORMAT(1X,5F10.5)
      READ(5,300)  (DT(I),I=1,10)
      WRITE(6,300) (DT(I),I=1,10)
  300 FORMAT(1X,10F7.0)
C  PRICE OF GAS(G),SGF 2(S), AND FUEL COST/MINUTE (F) FOR SMOKE GEN
      G=.38
      S=.40
      F=(G+S)*3./60.
C  PRICE OF SMOKE POT
      P=14.12
C
C  CALCULATE COSTS
C
      DO 41 L=1,10
      DO 40 K=1,5
      TI=DT(L)
      X=SH(K)
C
C  SMOKE GENERATOR
C
C  C1
      M=1
      RN=GL(2,1)
      TN=X/RN
      TC=TN*TI*F
      TCG(K,M,L)=TC
      TNG(K,M,L)=TN
```

```
C   C2
          M=2
          RN=GIN(2,1)
          TN=X/RN
          TC=TN*TI*F
          TCG(K,M,L)=TC
          TNG(K,M,L)=TN
C   C3
          M=3
          RN=GIN(2,2)
          TN=X/RN
          TC=TN*TI*F


          TCG(K,M,L)=TC
          TNG(K,M,L)=TN
C   C4
          M=4
          RN=GIN(2,3)
          TN=X/RN
          TC=TN*TI*F
          TCG(K,M,L)=TC
          TNG(K,M,L)=TN
C   C5
          M=5
          RN=GIN(2,1)
          TN=X/RN
          TC=TN*TI*F
          TCG(K,M,L)=TC
          TNG(K,M,L)=TN
C
C   SMOKE POT
C
C   C1
          M=1
          RN=PL(2,1)
          TN=X/RN
          TC=TN*P
          TCP(K,M,L)=TC
          TNP(K,M,L)=TN
C   C2
          M=2
          RN=PIN(2,1)
          TN=X/RN
          TC=TN*P
          TCP(K,M,L)=TC
          TNP(K,M,L)=TN
```

```
C  C3
       M=3
       RN=PIN(2,2)
       TN=X/RN
       TC=TN*P
       TCP(K,M,L)=TC
       TNP(K,M,L)=TN
C  C4
       M=4
       RN=PIN(2,3)
       TN=X/RN
       TC=TN*P
       TCP(K,M,L)=TC
       TNP(K,M,L)=TN
C  C5
       M=5
       RN=PIN(2,1)
       TN=X/RN
       TC=TN*P
       TCP(K,M,L)=TC
       TNP(K,M,L)=TN
   40 CONTINUE
   41 CONTINUE
C  DETERMINE MIN COST VS SITUATION


       DO 20 I=1,5
       DO 20 J=1,5
       DO 20 K=1,10
       C1=TCG(I,J,K)
       C2=TCP(I,J,K)
   20 TCM(I,J,K)=AMIN1(C1,C2)
C  COMPUTE AVERAGES
       ACG=0.
       ANG=0.
       ACP=0.
       ANP=0.
       DO 60 I=1,5
       DO 60 J=1,5
       DO 60 K=1,10
       ACG=ACG + TCG(I,J,K)
       ANG=ANG + TNG(I,J,K)
       ACP=ACP + TCP(I,J,K)
   60 ANP=ANP + TNP(I,J,K)
       ACG=ACG/250.
       ANG=ANG/250.
       ACP=ACP/250.
       ANP=ANP/250.
```

```
C  PRINT OUT RESULTS
       WRITE(6,400)
  400  FORMAT(1X,"RESULTANT COSTS - GENERATORS,POTS,MIN")
       DO 700 I=1,5
       DO 700 J=1,5
       DO 700 K=1,10
       WRITE(6,701) TNG(I,J,K),TNP(I,J,K)
  700  WRITE(6,702) TCG(I,J,K),TCP(I,J,K),TCM(I,J,K)
  701  FORMAT(1X,2F15.2)
  702  FORMAT(1X,3F15.2)
       WRITE(6,800)
  800  FORMAT(" ")
       WRITE(6,801)
  801  FORMAT(1X,"AVERAGES - TYPE,COST,AMT")
       WRITE(6,802) ACG,ANG
  802  FORMAT(1X,"GENS",5X,2F15.2)
       WRITE(6,803) ACP,ANP
  803  FORMAT(1X,"POTS",5X,2F15.2)
       STOP
       END
```

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