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COUNTERMINE SYSTEMS STUDY: PART IA: BASELINE SYSTEM DESCRIPTION

Robert R. Wallace, et al

Army Mobility Equipment Research and Development Center

September 1972

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Report 2036

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PART IA
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by

R. R. Wallace
R. K. Young
R. Felts

September 1972

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U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

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13. ABSTRACT

This study determines the range of time, labor, materiel dollars, weight, volume, energy, casualties, and vehicles associated with breaching a 1-4-8 minefield using selected doctrine and materiel as of 1 September 1971.

It is intended that this system description serve as a baseline for the comparison of alternative conceptual countermine systems.

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Armored Vehicles						
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Neutralization						
AN/PRS-7						
M14						
M15						
M16						
M60						
M113						
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RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

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September 1972

Distributed by

The Commanding Officer
U. S. Army Mobility Equipment Research and Development Center

Prepared by

R. R. Wallace
R. K. Young
R. Felts
Systems Engineering Division
Systems Engineering and Computation Support Office

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SUMMARY

This study determines the range of time, labor, materiel dollars, weight, volume, energy, casualties, and vehicles associated with breaching a 1-4-8 minefield using selected doctrine and materiel as of 1 September 1971.

It is intended that this system description serve as a baseline for the comparison of alternative conceptual countermine systems.

FOREWORD

The Systems Engineering Division of the Systems Engineering and Computation Support Office was requested by the Mine Neutralization Division of Countermine/ Counter Intrusion Department to undertake a countermine systems study. This report covers effort directed toward the initial baseline systems description, which was done during the period from 2 January 1972 to 17 April 1972.

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COUNTERMINE SYSTEMS STUDY
PART IA
BASELINE SYSTEM DESCRIPTION

I. INTRODUCTION

1. **Objective.** The objective of this study is to identify and evaluate alternative approaches for the improvement of armored vehicle mobility where and when enemy mines are present.

2. **Approach to the Problem.** In order to reach the stated objective, the total study has been planned along the following lines:

a. **Part IA: Medium- and High-Density Mining.**

(1) Tactical Mission Functions.

(2) Countermine Mission Functions.

(3) Barrier Minefield Model and Countermine System Breaching Data.

(a) Dismounted Breaching Operations: Time, Labor, Materiel, and other Associated Costs.

(b) Armored Vehicle Breaching Operations: Time, Labor, Materiel, and other Associated Costs.

(c) Combined Dismounted/Armored Breaching Operations: Time, Labor, Materiel, and Other Associated Costs.

(d) Red Barrier Minefield Costs: Time, Labor, Materiel, and other Costs.

b. **Part IB: Low-Density Mining.**

c. **Part II: Alternative Conceptual Systems for the Near-Term Army.**

d. **Part III: Alternative Conceptual Systems for the Far-Term Threat.**

This interim report covers Part IA of the above study outline and is limited to the analysis of costs associated with deliberate breaching operations against a barrier minefield. The report is intended to serve as a system description or yardstick for the evaluation of alternative conceptual countermine systems.

II. INVESTIGATION

3. **Medium- and High-Density Mining.** The potential existence of a high-density, deliberate, barrier minefield in a tactical operations area poses a serious threat to the system elements and mission of a military force. The purpose of this report is to provide a base for evaluating the type-classified countermine system elements in the current Army inventory in response to this threat and to provide a basis for comparison of possible future alternative approaches to defeating this threat. The first step taken to establish this baseline was to place the countermine mission in the context of a tactical mission to give this study the proper perspective. The second step necessary to establish a meaningful baseline was to determine all functions which are performed by the existing countermine systems in response to the minefield threat and to determine what system elements exist in the Army inventory to perform these functions. The third step in establishing the basis for future comparison was to determine the effectiveness of existing countermine systems in terms of quantifiable penalties to the system elements incurred through an interaction of the system with a barrier minefield. This interaction was simulated by means of a model barrier minefield using U. S. Army minefield doctrine and then breaching this minefield using models of existing countermine systems. The final step was to estimate the resources used to set up the barrier minefield and then to compare red and blue costs.

4. **Tactical Mission Functions.** The relationship of a countermine mission to a tactical mission is best understood if the answers to the following two questions are considered:

(1) What types of military operations involve countermine activity?

(2) How extensive is countermine activity relative to the total tactical mission?

The first question may be answered by considering Fig. 1 which presents the types of military operations and situations as the elements of a complex matrix.[1] The spectrum of countermine activity is shown to be extensive to the point where it may be involved to some degree in all military operations. Since countermine activity is potentially widespread, the answer to the second question is essential to the establishment

[1] "Family of Scatterable Mines," Phase II Report., Vol. 1, 70826, ACN 17852, CDC Engineering Agency, 1 Feb. 72.

TYPES OF MILITARY OPERATIONS	SITUATIONS
AREA DEFENSE	SECURITY
MOBILE DEFENSE	FLANK
MOVEMENT TO CONTACT	REAR
RECON IN FORCE	BRIDGEHEAD
COORDINATED ATTACK	FORWARD
EXPLOITATION	LZ
PURSUIT	DOWNED AIRCRAFT
WITHDRAWAL	ROAD BLOCKS
DELAYING ACTION	AIR HEAD
	FRIENDLY COUNTER ATTACK ROUTES
	BEACH HEAD
	OBJECTIVE
	SENSOR PROTECTION
	ANTI FORDING
	REINFORCE PERIMETER
	AREA DENIAL
	POTENTIAL ARTILLERY POSITIONS
	RESERVE POSITIONS
	KEY TERRAIN
	ASSEMBLY AREAS
	POTENTIAL ATTACK POSITIONS
	DENIAL OF ENEMY LZ IN REAR AREAS
	CONSTRICTED AREAS
	BLOCK AVENUES OF APPROACH
	DECEPTION
	PREVENT WITHDRAWAL
	COUNTER ATTACK ROUTES
	CANALIZE
	LETHALITY
	FIX FORCES
	HINDER REPAIRS
	AIRFIELDS
	ROAD CRATERS
	BRIDGES
	REINFORCE OBSTACLES
	CLOSE LANES AND GAPS
	SCHEDULED FIRES
	INTERDICT REINFORCEMENT & SUPPLIES
	DEEP MISSIONS
	ENEMY AA POSITIONS
	FERRY SITES

Fig. 1. Spectrum of Countermine Activity (taken from Figure 7 of *Family of Scatterable Mines*, Phase II Report, Vol. 1, 70825, ACN 17852, CDC Engineering Agency, 1 Feb. 72).

of a proper perspective with respect to tactical missions. To obtain this perspective, it was necessary to define the functions performed in the conception, planning, and execution of a tactical mission. The most general functions are shown in Fig. 2. From this outline, the next lower level of detail is shown in Fig. 3. But even this amount of detail is not sufficient to show the role of countermine activity in a tactical mission. Consequently, many lower levels of detail were developed and studied. To conserve effort, only those functions directly related to countermine activity were broken down to evolve and to track countermine functions from tactical functions. Figure 4 shows a mixed level of detail that accomplishes this track. It is implied from the many functions that were not expanded in Fig. 4 that the details of countermine activity may be a very small part indeed of the details of a tactical mission. Thus, the relative importance of successful countermine functions is completely dependent upon tactical factors beyond the scope of this study. Then, the real world of countermine activity is highly complex to the point where countermine activity must be regarded as a subsystem or even a subsubsubsystem. The following analysis should be interpreted in that light.[2-14]

---

[2] "Armor Operations," FM 17-1, October 1966.

[3] "Tank Units Platoon, Company and Battalion," FM 17-15, March 1966.

[4] "Divisional Armored and Air Cavalry Units," FM 17-36, November 1968.

[5] "Engineer Battalion Armor Infantry and Infantry (Mechanized) Divisions," FM 5-135, November 1965.

[6] "The Infantry Battalions," FM 7-20, December 1969.

[7] "Field Fortifications," FM 5-15, August 1968.

[8] "Terrain Intelligence," FM 30-10, October 1967.

[9] "Combat Intelligence," FM 30-5, June 1967.

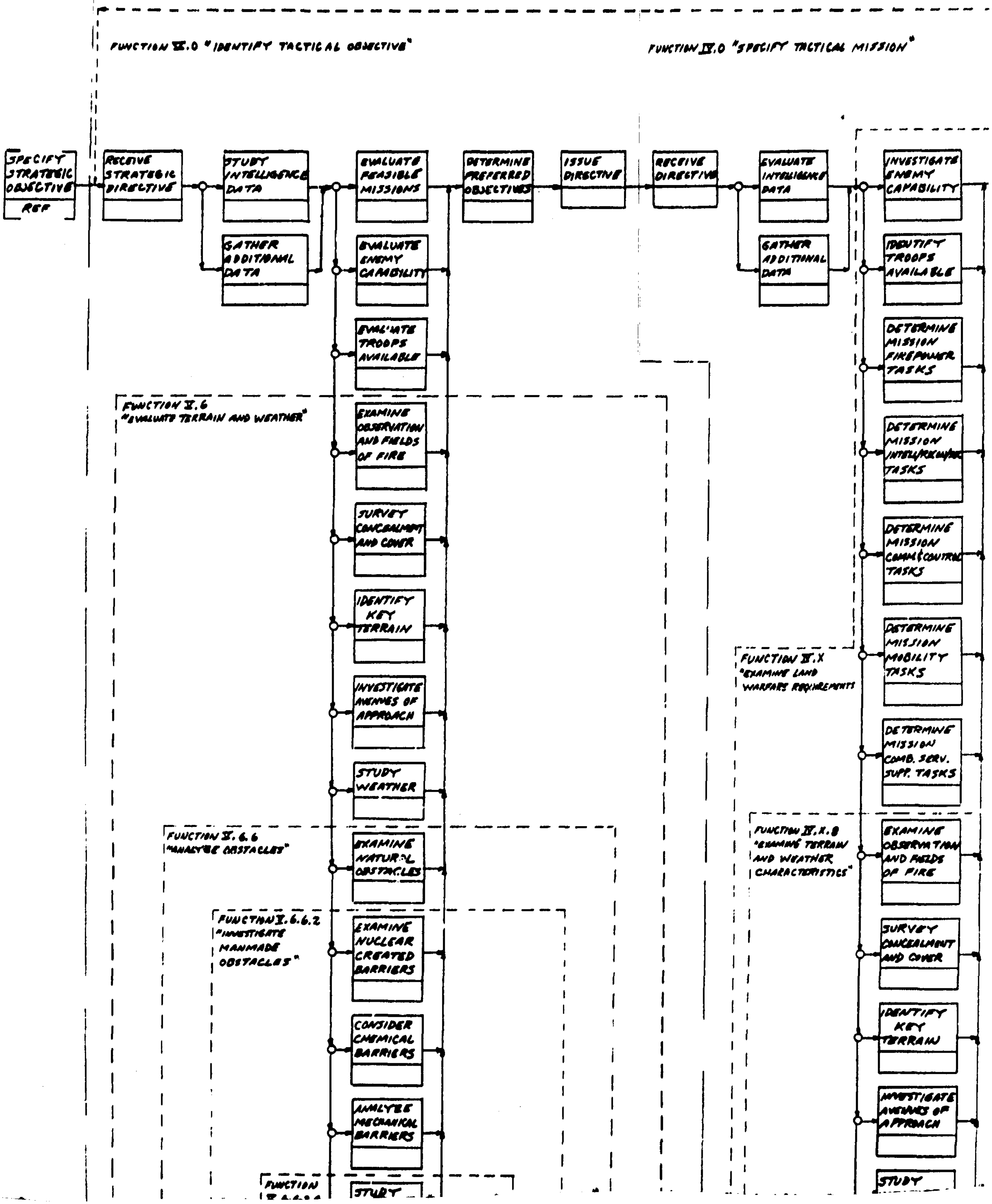
[10] "Landmine Warfare," FM 20-32, August 1966.

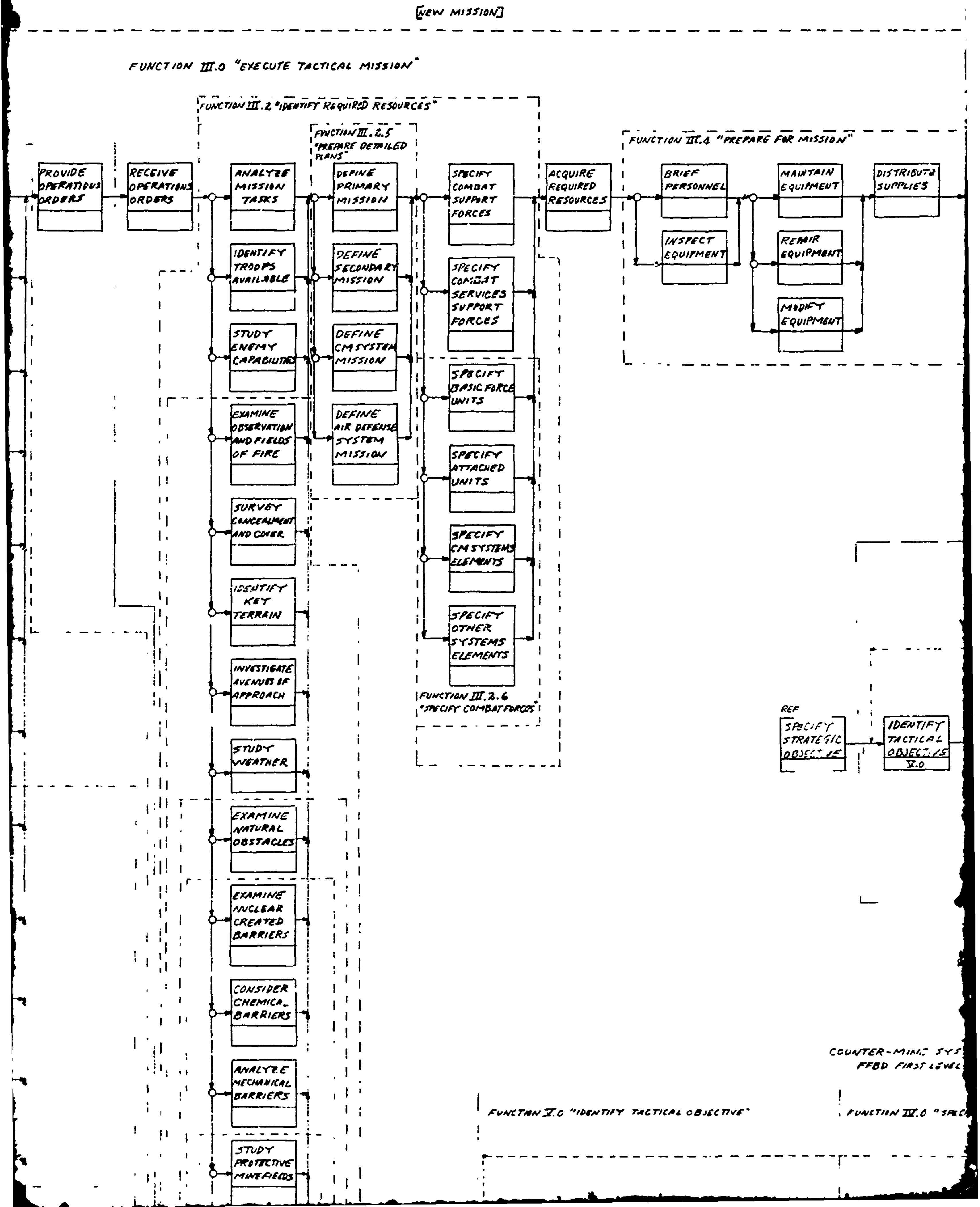
[11] "Explosives and Demolitions," FM 5-25, May 1967.

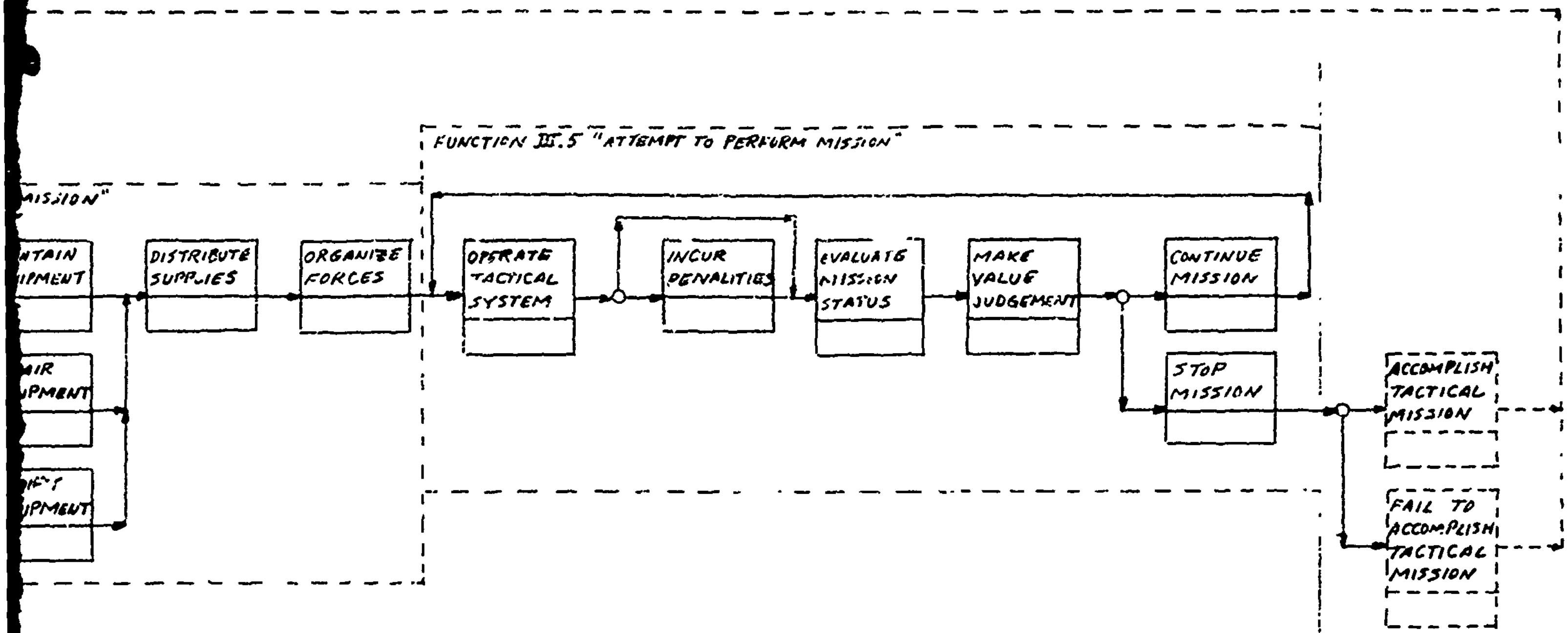
[12] "Engineer Field Data," FM 5-34, December 1969.

[13] "Staff Officers' Field Manual Organization, Technical, and Logistical Data Unclassified Data," FM 101-10-1, January 1966.

[14] "Encyclopedia of Mine/Countermine Warfare," Engineer Agency for Resources Inventories, October 1971.


FUNCTION III.0 "IDENTIFY TACTICAL OBJECTIVE"
FUNCTION IV.0 "SPECIFY TACTICAL MISSION"
SPECIFY STRATEGIC OBJECTIVE
REF
RECEIVE STRATEGIC DIRECTIVE
STUDY INTELLIGENCE DATA
GATHER ADDITIONAL DATA
EVALUATE FEASIBLE MISSIONS
EVALUATE ENEMY CAPABILITY
EVALUATE TROOPS AVAILABLE
DETERMINE PREFERRED OBJECTIVES
ISSUE DIRECTIVE
RECEIVE DIRECTIVE
EVALUATE INTELLIGENCE DATA
GATHER ADDITIONAL DATA
INVESTIGATE ENEMY CAPABILITY
IDENTIFY TROOPS AVAILABLE
DETERMINE MISSION FIREPOWER TASKS
DETERMINE MISSION INTELLIGENCE TASKS
DETERMINE MISSION COMM & CONTROL TASKS
DETERMINE MISSION MOBILITY TASKS
DETERMINE MISSION COMB. SERV. SUPP. TASKS
FUNCTION III.6 "EVALUATE TERRAIN AND WEATHER"
EXAMINE OBSERVATION AND FIELDS OF FIRE
SURVEY CONCEALMENT AND COVER
IDENTIFY KEY TERRAIN
INVESTIGATE AVENUES OF APPROACH
STUDY WEATHER
FUNCTION III.6.6 "ANALYZE OBSTACLES"
EXAMINE NATURAL OBSTACLES
FUNCTION III.6.6.2 "INVESTIGATE MANMADE OBSTACLES"
EXAMINE NUCLEAR CREATED BARRIERS
CONSIDER CHEMICAL BARRIERS
ANALYZE MECHANICAL BARRIERS
FUNCTION
STUDY
FUNCTION IV.X "EXAMINE LAND WARFARE REQUIREMENTS"
FUNCTION IV.X.8 "EXAMINE TERRAIN AND WEATHER CHARACTERISTICS"
EXAMINE OBSERVATION AND FIELDS OF FIRE
SURVEY CONCEALMENT AND COVER
IDENTIFY KEY TERRAIN
INVESTIGATE AVENUES OF APPROACH
STUDY


[NEW MISSION]
FUNCTION III.0 "EXECUTE TACTICAL MISSION"
FUNCTION III.2 "IDENTIFY REQUIRED RESOURCES"
FUNCTION III.2.5 "PREPARE DETAILED PLANS"
FUNCTION III.4 "PREPARE FOR MISSION"
PROVIDE OPERATIONS ORDERS
RECEIVE OPERATIONS ORDERS
ANALYZE MISSION TASKS
IDENTIFY TROOPS AVAILABLE
STUDY ENEMY CAPABILITIES
EXAMINE OBSERVATION AND FIELDS OF FIRE
SURVEY CONCEALMENT AND COVER
IDENTIFY KEY TERRAIN
INVESTIGATE AVENUES OF APPROACH
STUDY WEATHER
EXAMINE NATURAL OBSTACLES
EXAMINE NUCLEAR CREATED BARRIERS
CONSIDER CHEMICAL BARRIERS
ANALYZE MECHANICAL BARRIERS
STUDY PROTECTIVE MINEFIELDS
DEFINE PRIMARY MISSION
DEFINE SECONDARY MISSION
DEFINE CM SYSTEM MISSION
DEFINE AIR DEFENSE SYSTEM MISSION
SPECIFY COMBAT SUPPORT FORCES
SPECIFY COMBAT SERVICES SUPPORT FORCES
SPECIFY BASIC FORCE UNITS
SPECIFY ATTACHED UNITS
SPECIFY CM SYSTEMS ELEMENTS
SPECIFY OTHER SYSTEMS ELEMENTS
FUNCTION III.2.6 "SPECIFY COMBAT FORCES"
ACQUIRE REQUIRED RESOURCES
BRIEF PERSONNEL
INSPECT EQUIPMENT
MAINTAIN EQUIPMENT
REPAIR EQUIPMENT
MODIFY EQUIPMENT
DISTRIBUTE SUPPLIES
REF
SPECIFY STRATEGIC OBJECTIVE
IDENTIFY TACTICAL OBJECTIVES
V.0
COUNTER-MINE SYS
FFBD FIRST LEVEL
FUNCTION V.0 "IDENTIFY TACTICAL OBJECTIVE"
FUNCTION IV.0 "SPEC



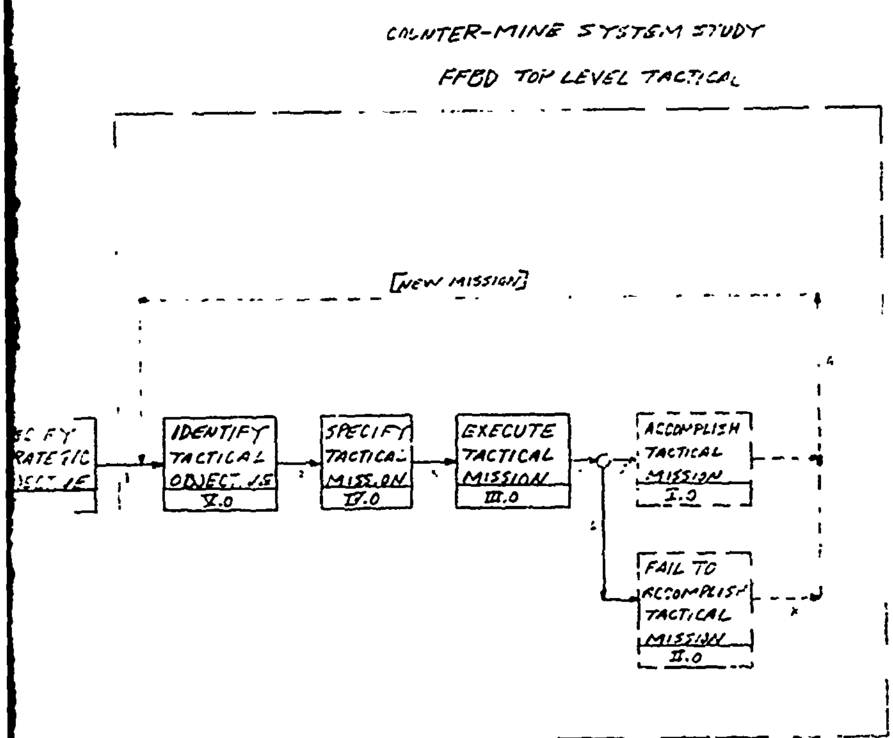
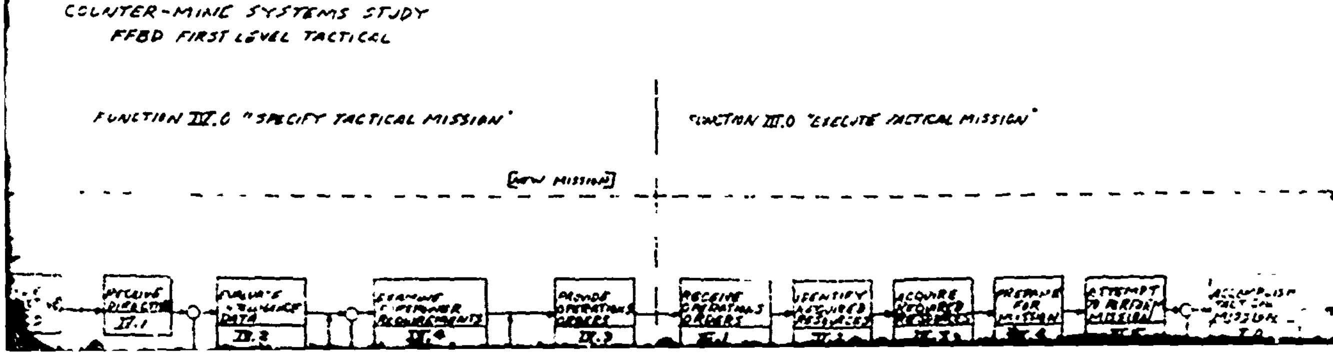
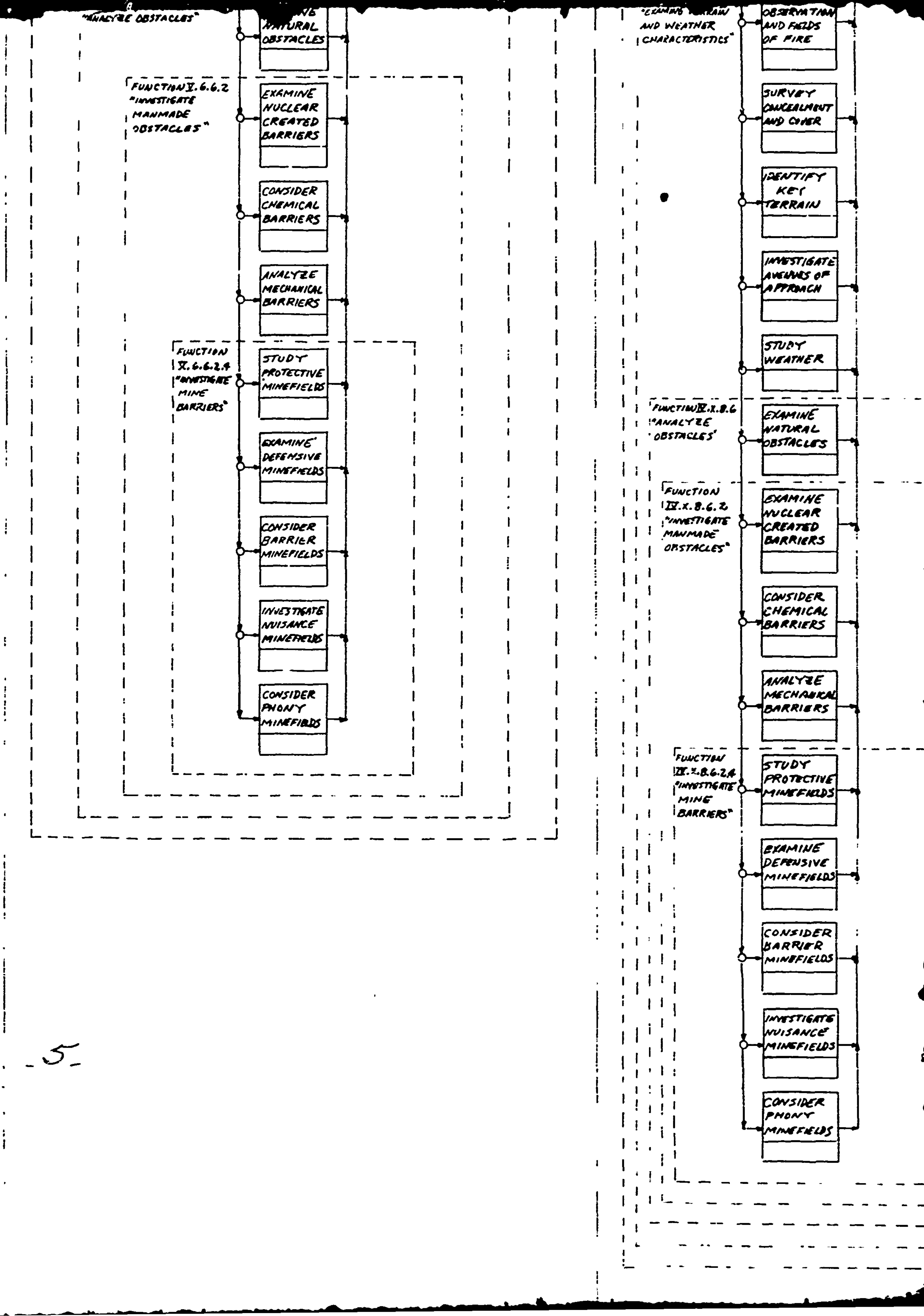
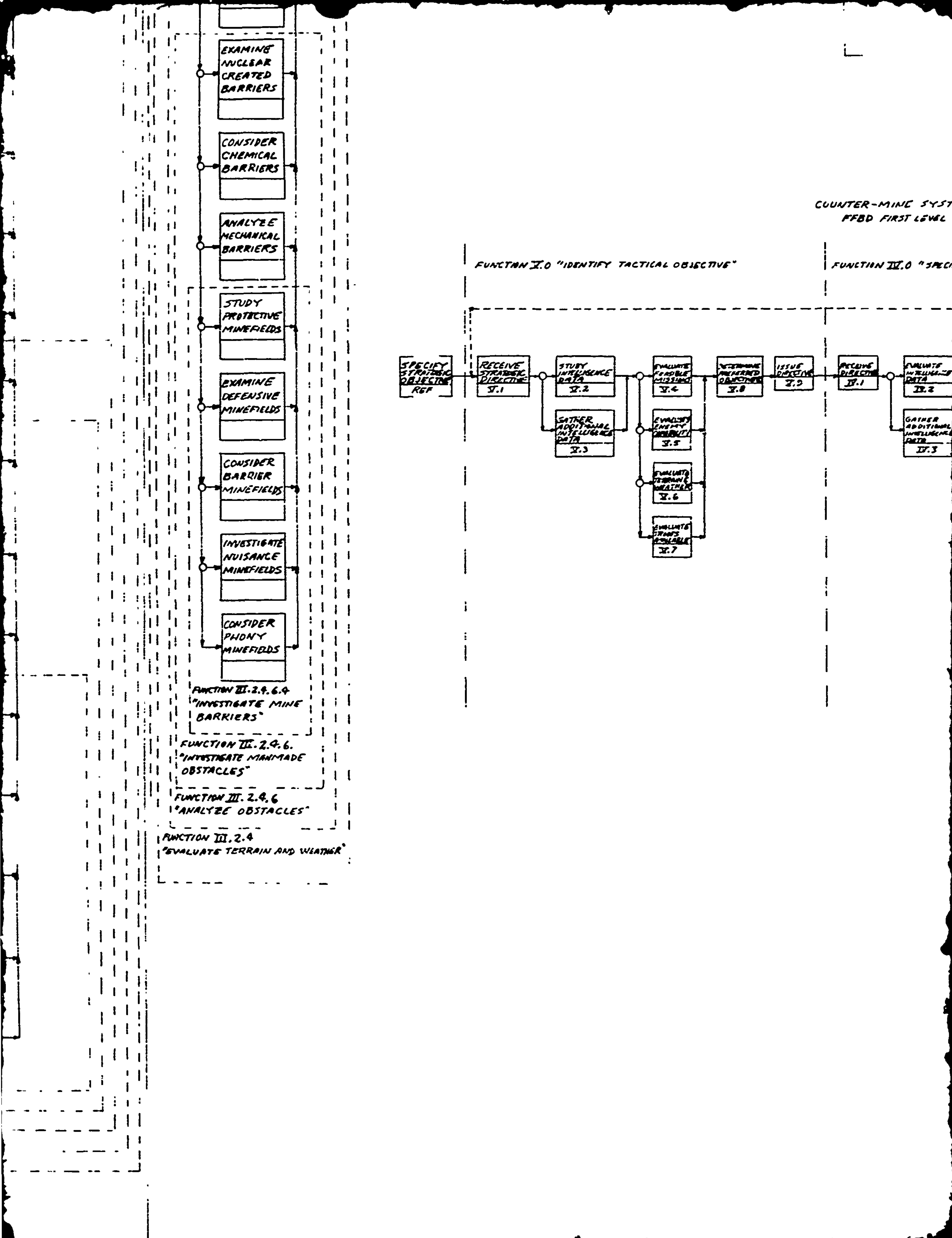


Fig. 2. Tactical mission function flow block diagram, top level.




"ANALYZE OBSTACLES"
NATURAL OBSTACLES
FUNCTION V.6.6.2 "INVESTIGATE MANMADE OBSTACLES"
EXAMINE NUCLEAR CREATED BARRIERS
CONSIDER CHEMICAL BARRIERS
ANALYZE MECHANICAL BARRIERS
FUNCTION V.6.6.2.4 "INVESTIGATE MINE BARRIERS"
STUDY PROTECTIVE MINEFIELDS
EXAMINE DEFENSIVE MINEFIELDS
CONSIDER BARRIER MINEFIELDS
INVESTIGATE NUISANCE MINEFIELDS
CONSIDER PHONY MINEFIELDS
AND WEATHER CHARACTERISTICS"
OBSERVATION AND FIELDS OF FIRE
SURVEY CONCEALMENT AND COVER
IDENTIFY KEY TERRAIN
INVESTIGATE AVENUES OF APPROACH
STUDY WEATHER
FUNCTION IV.X.8.6 "ANALYZE OBSTACLES"
EXAMINE NATURAL OBSTACLES
FUNCTION IV.X.8.6.2 "INVESTIGATE MANMADE OBSTACLES"
EXAMINE NUCLEAR CREATED BARRIERS
CONSIDER CHEMICAL BARRIERS
ANALYZE MECHANICAL BARRIERS
FUNCTION IV.X.8.6.2.4 "INVESTIGATE MINE BARRIERS"
STUDY PROTECTIVE MINEFIELDS
EXAMINE DEFENSIVE MINEFIELDS
CONSIDER BARRIER MINEFIELDS
INVESTIGATE NUISANCE MINEFIELDS
CONSIDER PHONY MINEFIELDS



EXAMINE NUCLEAR CREATED BARRIERS
CONSIDER CHEMICAL BARRIERS
ANALYZE MECHANICAL BARRIERS
STUDY PROTECTIVE MINEFIELDS
EXAMINE DEFENSIVE MINEFIELDS
CONSIDER BARRIER MINEFIELDS
INVESTIGATE NUISANCE MINEFIELDS
CONSIDER PHONY MINEFIELDS
FUNCTION III.2.4.6.4 "INVESTIGATE MINE BARRIERS"
FUNCTION III.2.4.6. "INVESTIGATE MANMADE OBSTACLES"
FUNCTION III.2.4.6 "ANALYZE OBSTACLES"
FUNCTION III.2.4 "EVALUATE TERRAIN AND WEATHER"
COUNTER-MINE SYST
FFBD FIRST LEVEL
FUNCTION V.0 "IDENTIFY TACTICAL OBJECTIVE"
FUNCTION IV.0 "SPECI
SPECIFY STRATEGIC OBJECTIVE REF
RECEIVE STRATEGIC DIRECTIVE V.1
STUDY INTELLIGENCE DATA V.2
GATHER ADDITIONAL INTELLIGENCE DATA V.3
V.4
V.5
EVALUATE TERRAIN & WEATHER V.6
V.7
V.8
ISSUE OBJECTIVE V.9
RECEIVE DIRECTIVE IV.1
IV.2
GATHER ADDITIONAL INTELLIGENCE DATA IV.3

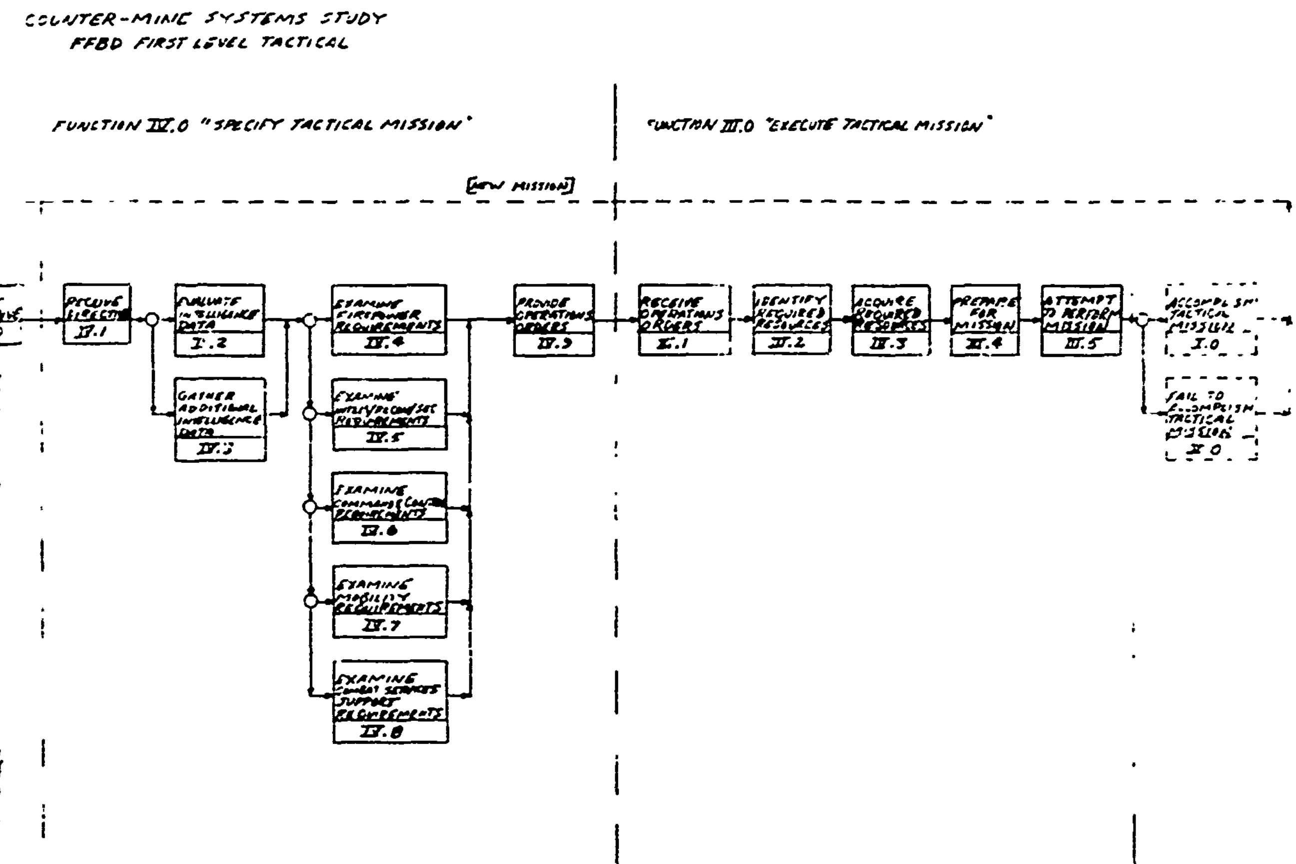


Fig. 3. Tactical mission function flow block diagram, first level.

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SYSTEMS ENGINEERING AND COMPUTATIONAL SUPPORT OFFICE
COUNTER MINE MOBILITY SYSTEMS STUDY
FFBD TACTICAL MIXED LEVEL

Fig. 4. Tactical mission function flow block diagram, mixed level.

pages 5 → 6
(5 pages)

5. **Countermine Mission Functions.** For the preparation of a system description, it was first necessary to identify and then to relate the functions to be performed by the countermine "system." The top-level functions for countermine operations are shown in Fig. 5. These were defined to provide a visible track of rationale from function requirements to hardware and other system elements.

Particular emphasis was placed upon the identification and analysis of Function 4.0, "Incur Penalty," because this function has been designed to provide a rationale framework for the eventual establishment of measures of effectiveness, cost ratios, incremental cost effectiveness relationships, and other qualitative and quantitative yardsticks for the comparison of alternative conceptual countermine systems. From the standpoint of system analysis, the chief significance of the "Incur Penalty" function concept is that it permits the examination of concepts and features without the complexity of relating countermine outcomes to tactical outcomes. To expand briefly upon this subject, Fig. 6 shows that Function 4.0, "Incur Penalty," is composed of four separate and distinct penalty elements:

4.02 Incur lost time

4.03 Incur loss of stealth

4.04 Incur damage to system elements:

- 4.04.01 Hardware
- 4.04.02 Facilities
- 4.04.03 Personnel
- 4.04.04 Procedural Data
- 4.04.05 Computer Programs
- 4.04.05 Animals

4.05 Incur loss of maneuver.

Each of these elements is measurable to some extent. Thus, a quantitative evaluation of penalties, both Red and Blue, for a given countermine situation can be made without the need to relate these penalties to a tactical outcome. Hence, alternative system concepts may be compared in terms of penalty without consideration of what yardstick is to be used for defining acceptable or unacceptable.

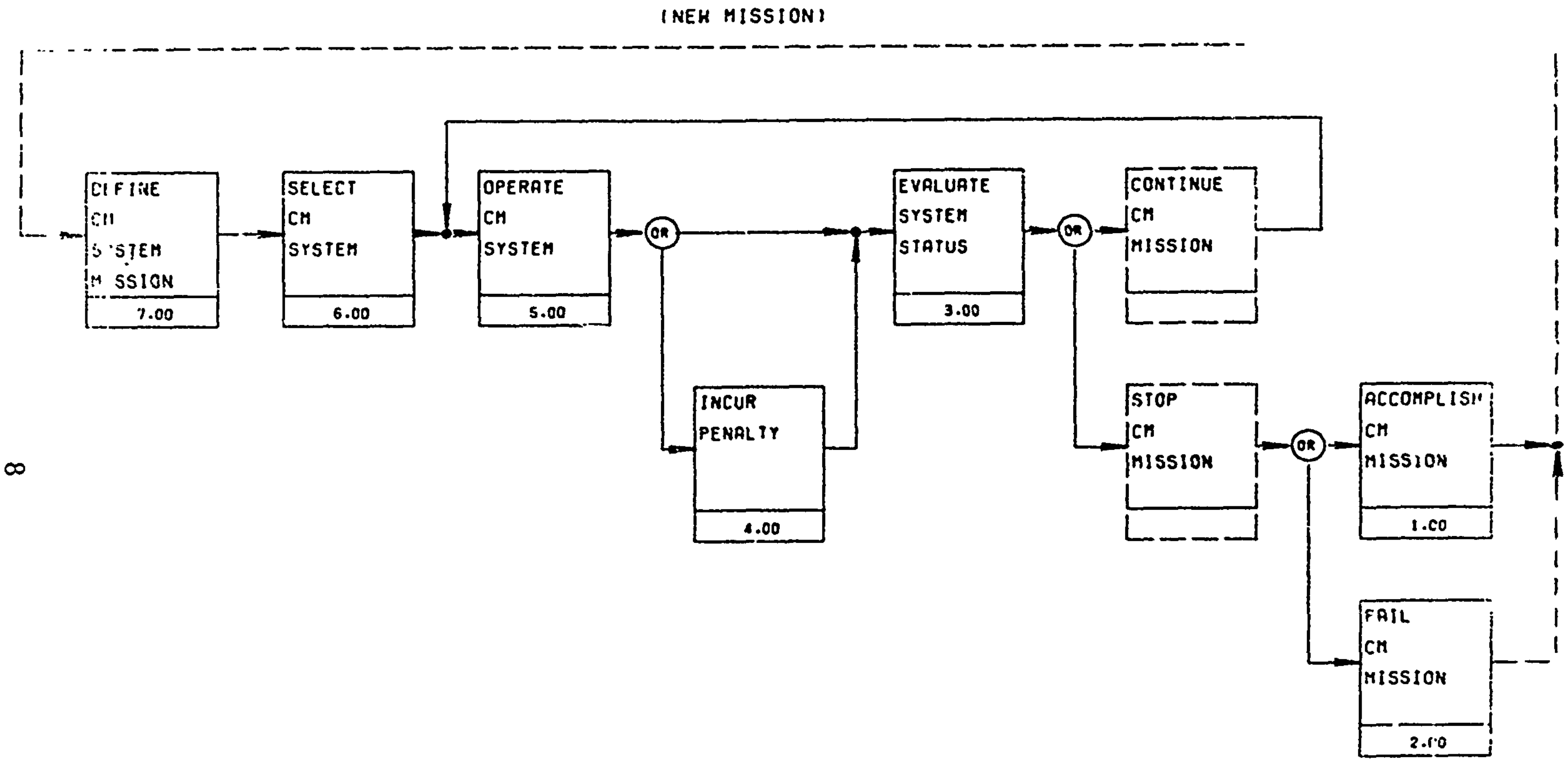


Fig. 5. Countermine mobility systems study function flow block diagram (top level).

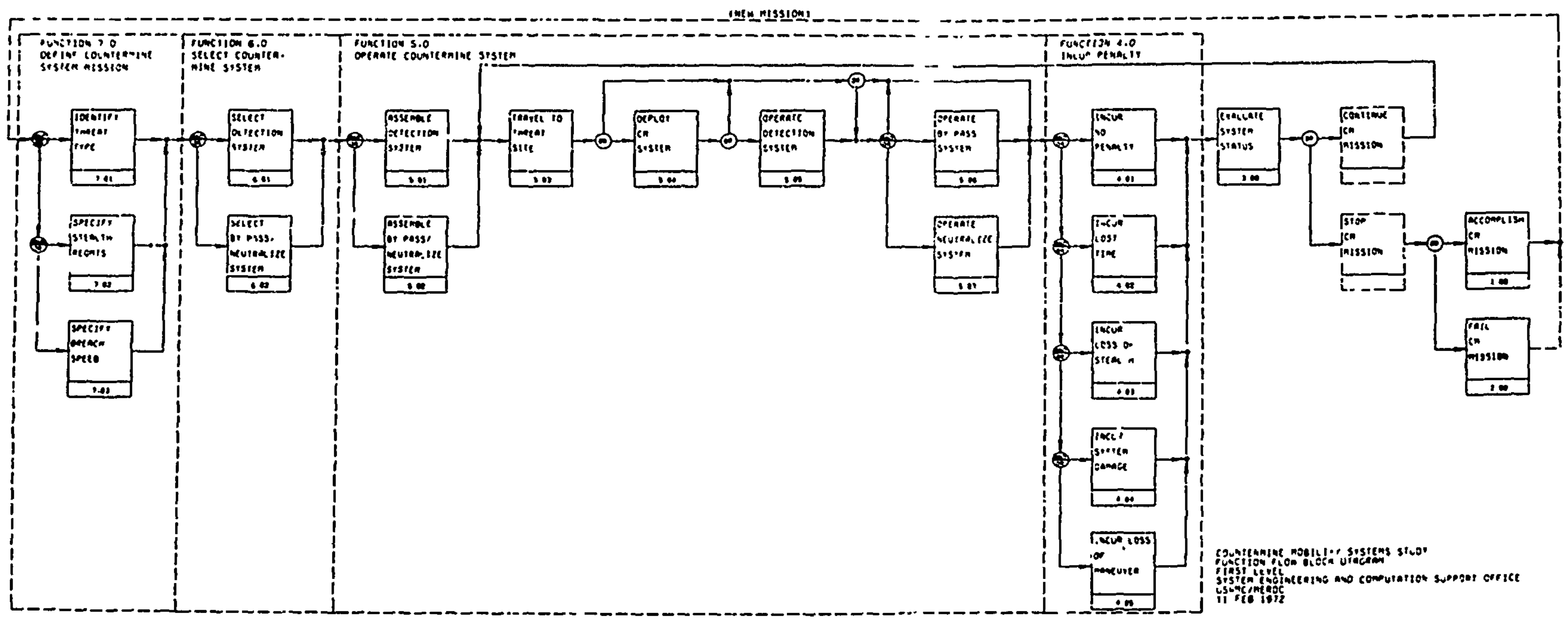
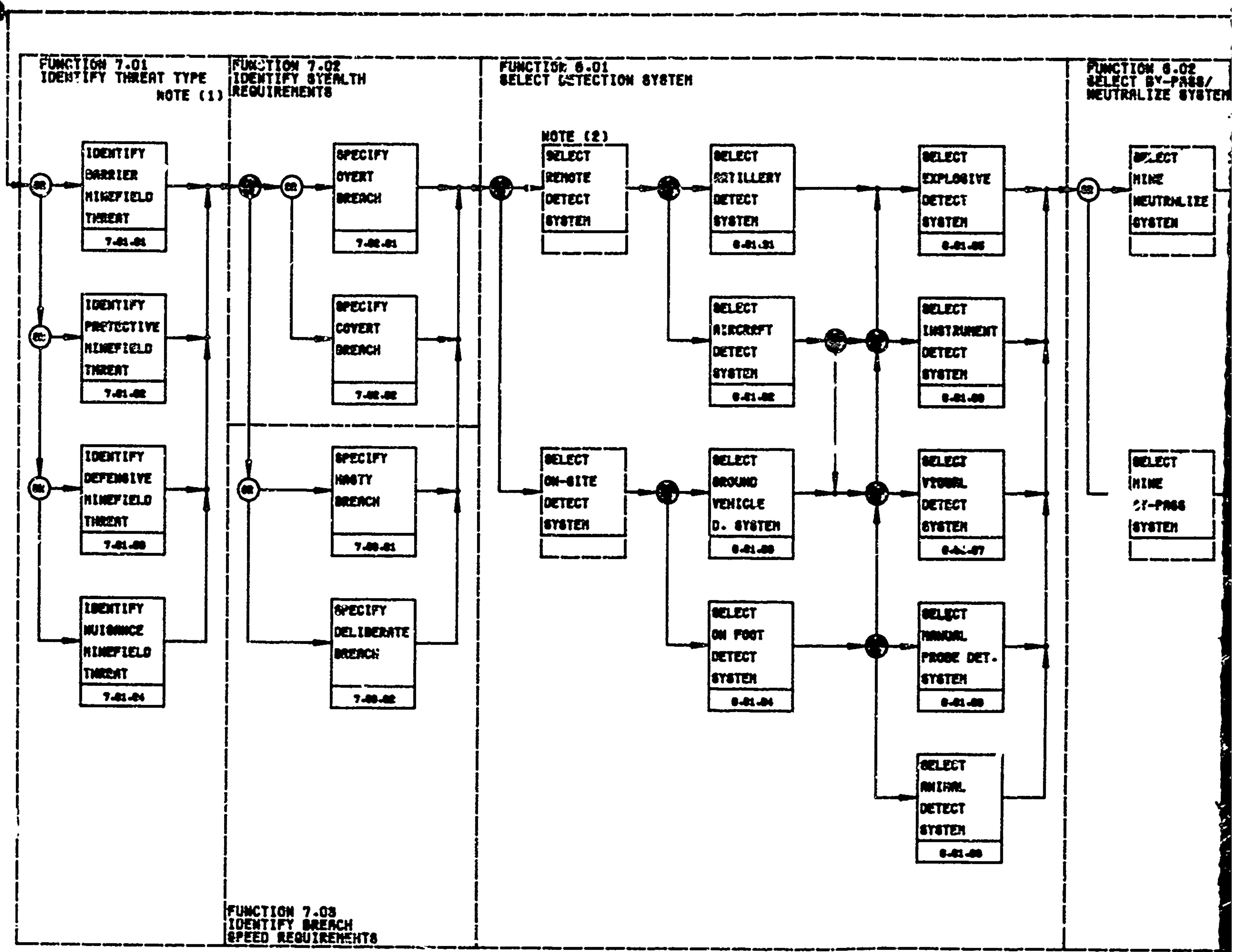
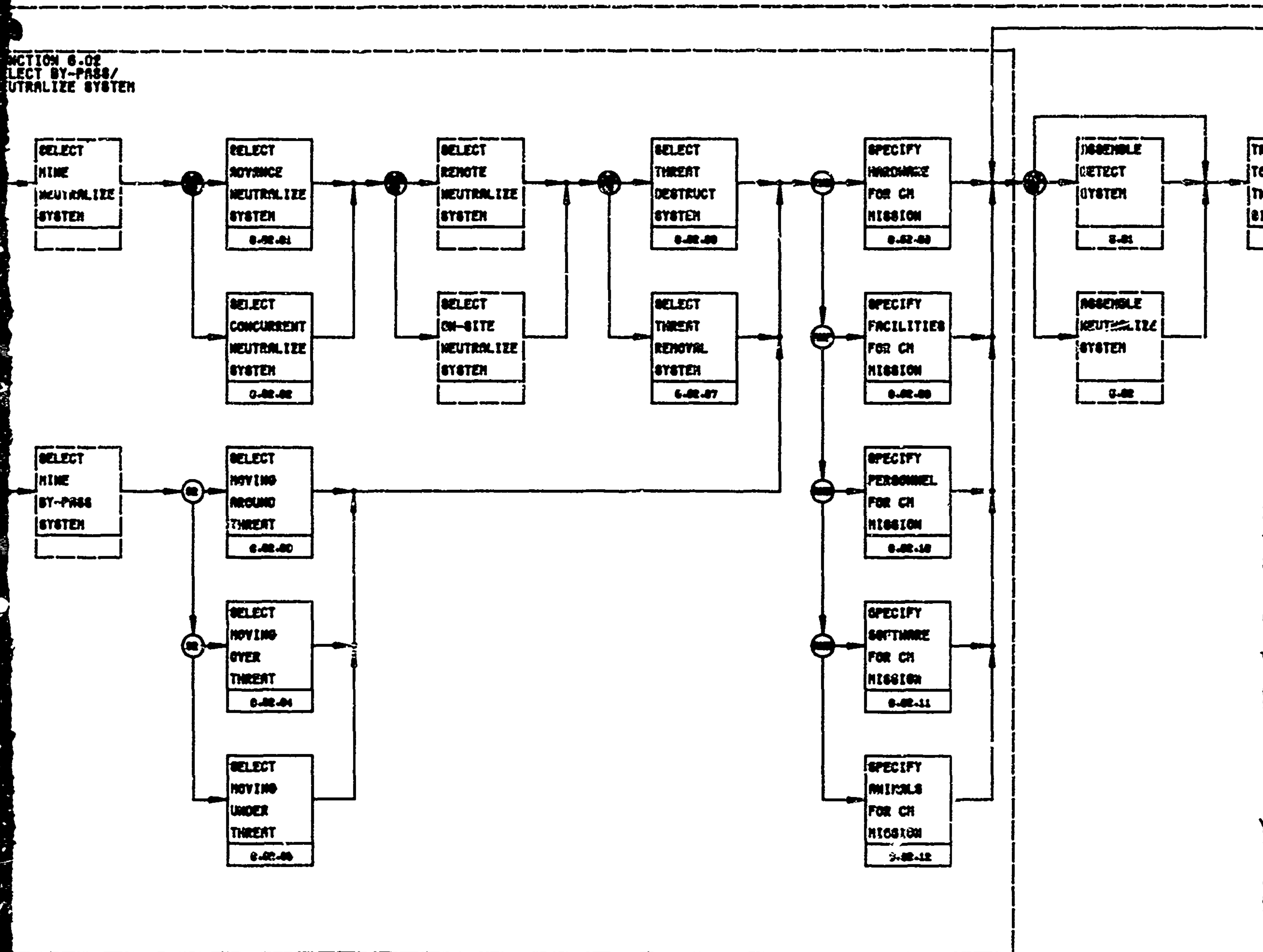


Fig. 6. Countermine mobility systems study fur.ction flow block diagram (first level).

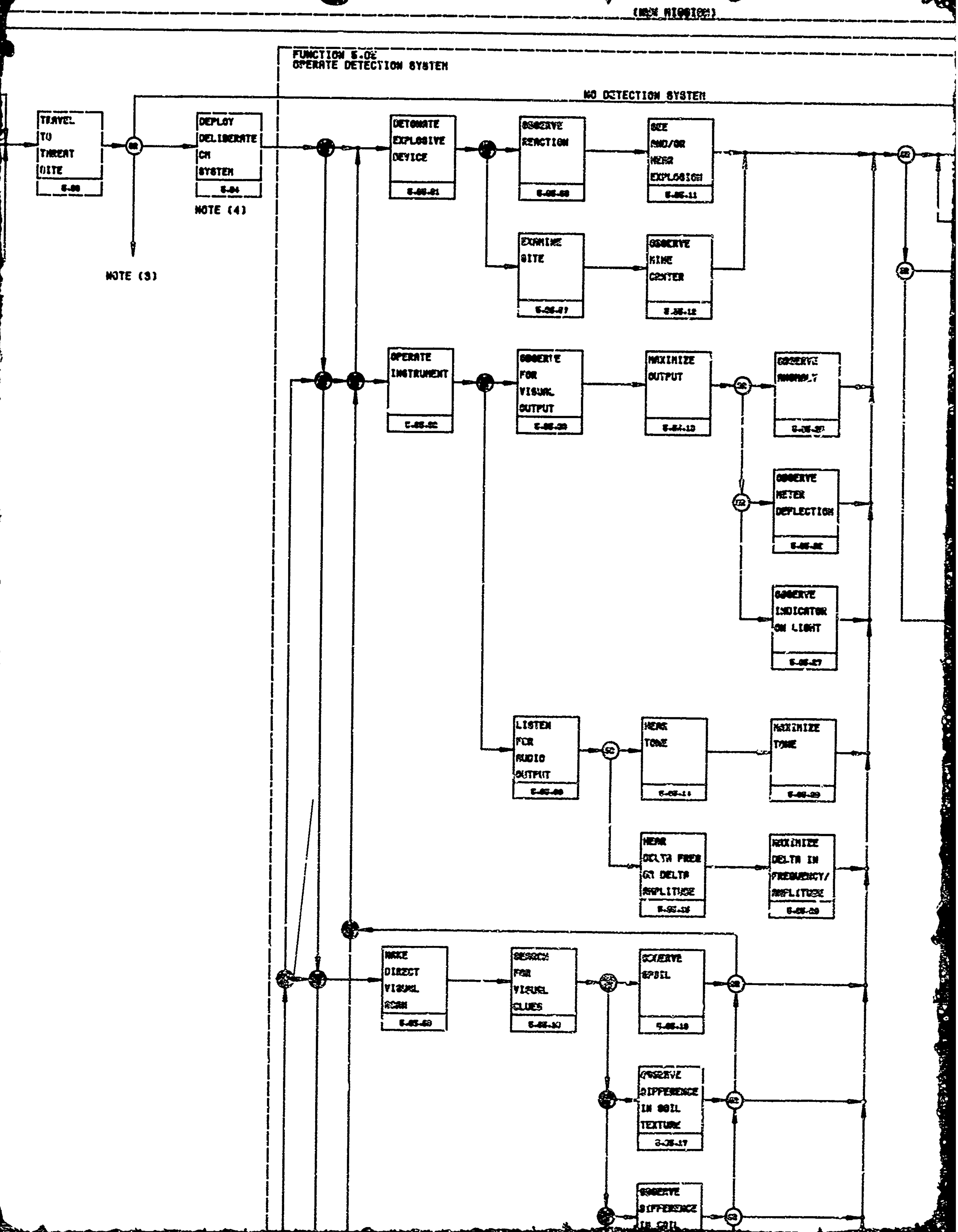


NOTES

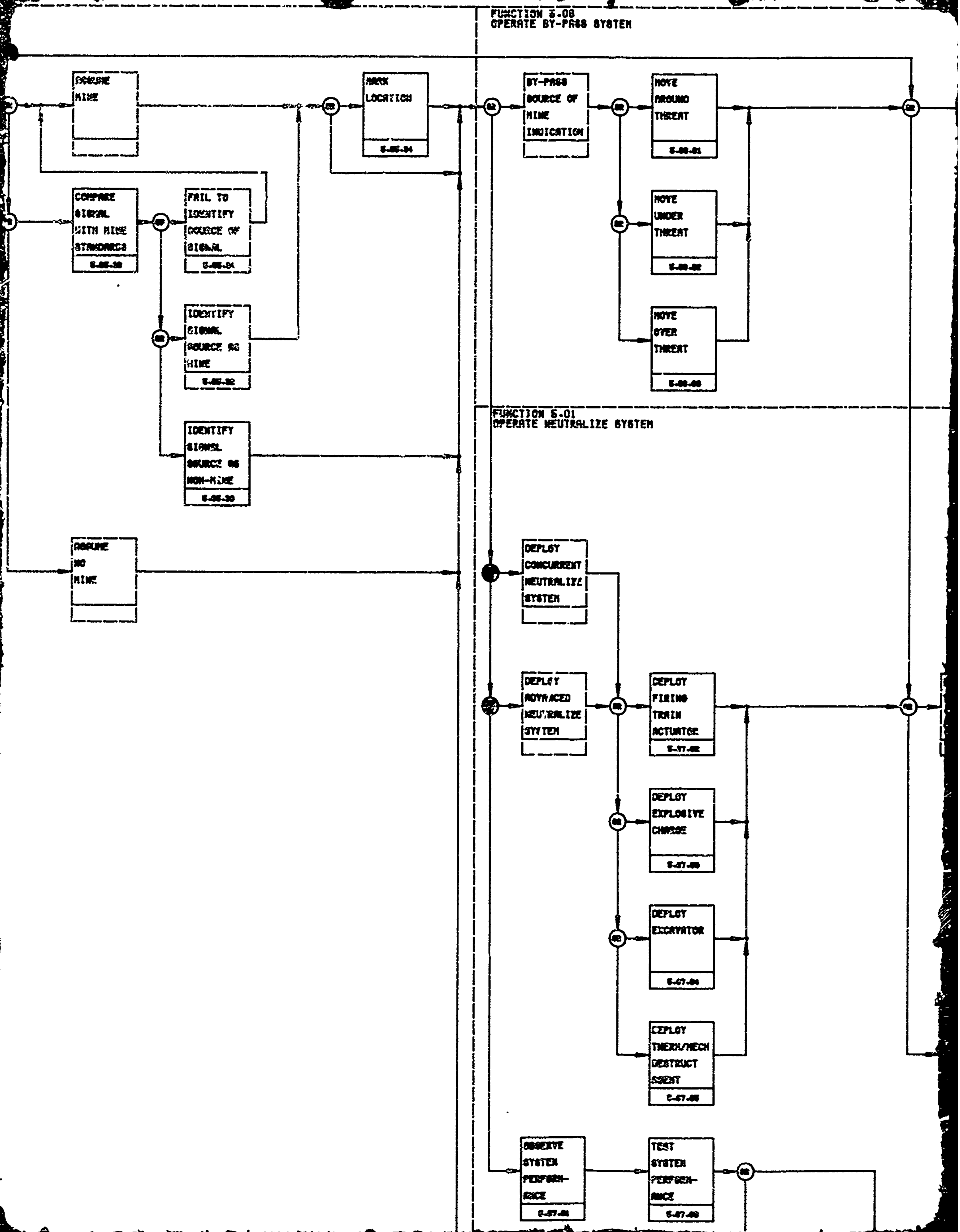
1. FUNCTION 7.01. IDENTIFY THREAT TYPE. AS PER FM 20-32.
2. DOTTED BOXES DENOTE SOFT FUNCTIONS OR IDENTIFIERS.
3. FROM THIS POINT ON ANY FUNCTION CAN LEAD DIRECTLY TO FUNCTION 5.18. ACTIVATE MINE FIRING TRAIN. VIA DEFICIENCY IN EFFECTIVENESS OF COUNTERMINE SYSTEM.
4. FUNCTION 5.04. DEPLOY DELIBERATE COUNTERMINE SYSTEM. IS SO IDENTIFIED TO EMPHASIZE THE POSSIBILITY OF UNINTENTIONAL MINE DETECTION AND/OR NEUTRALIZATION AT ANY TIME AFTER DEPLOYMENT OF THE TOTAL SYSTEM.
5. FOR SIMPLICITY. OBSERVE SYSTEM PERFORMANCE. IS LISTED AS A FUNCTION ONLY AT BLOCK 5.07.01 WHILE IN PRACTICE. THIS FUNCTION IS NECESSARY WITH ALL OF THE PRINCIPAL SYSTEM FUNCTIONS.
6. OUTPUT TO MINE SYSTEM.
7. FUNCTION 4.04. SYSTEM ELEMENTS ARE DEFINED AS HARDWARE. FACILITIES. PERSONNEL. PROCEDURAL DATA. COMPUTER PROGRAMS. AND ANIMALS.
8. FUNCTION 4.05. INCUR DAMAGE TO MANEUVER. DENOTES RESTRICTIONS UPON THE USE OF GROUND FOR TACTICAL MOVEMENT.



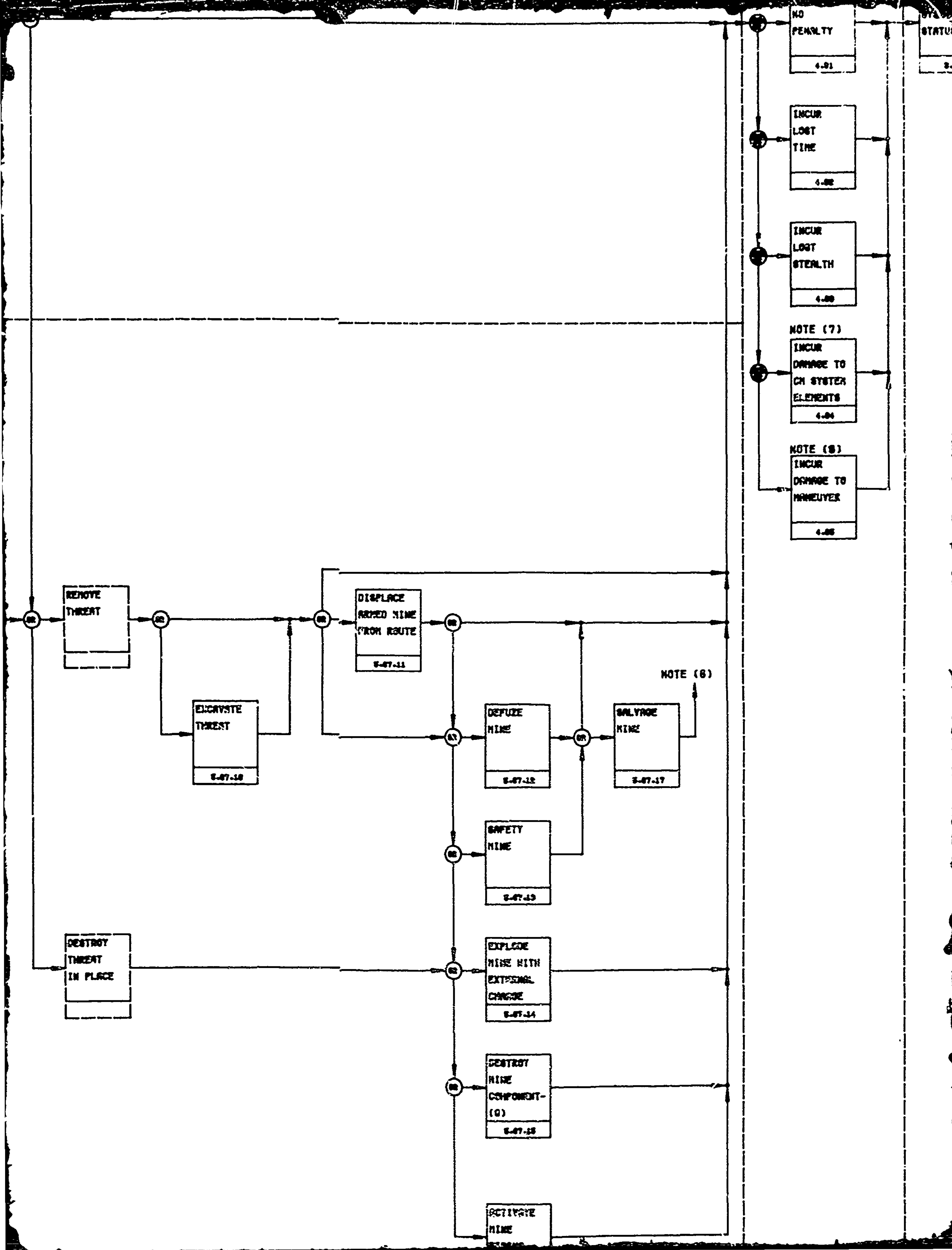
NCTION 6.02
LECT BY-PASS/
UTRALIZE SYSTEM
SELECT MINE NEUTRALIZE SYSTEM
SELECT ADVANCE NEUTRALIZE SYSTEM
SELECT CONCURRENT NEUTRALIZE SYSTEM
SELECT REMOTE NEUTRALIZE SYSTEM
SELECT ON-SITE NEUTRALIZE SYSTEM
SELECT THREAT DESTRUCT SYSTEM
SELECT THREAT REMOVAL SYSTEM
SPECIFY HARDWARE FOR CM MISSION
SPECIFY FACILITIES FOR CM MISSION
SPECIFY PERSONNEL FOR CM MISSION
SPECIFY SOFTWARE FOR CM MISSION
SPECIFY ANIMALS FOR CM MISSION
ASSEMBLE DETECT SYSTEM
ASSEMBLE NEUTRALIZE SYSTEM
SELECT MINE BY-PASS SYSTEM
SELECT MOVING AROUND THREAT
SELECT MOVING OVER THREAT
SELECT MOVING UNDER THREAT

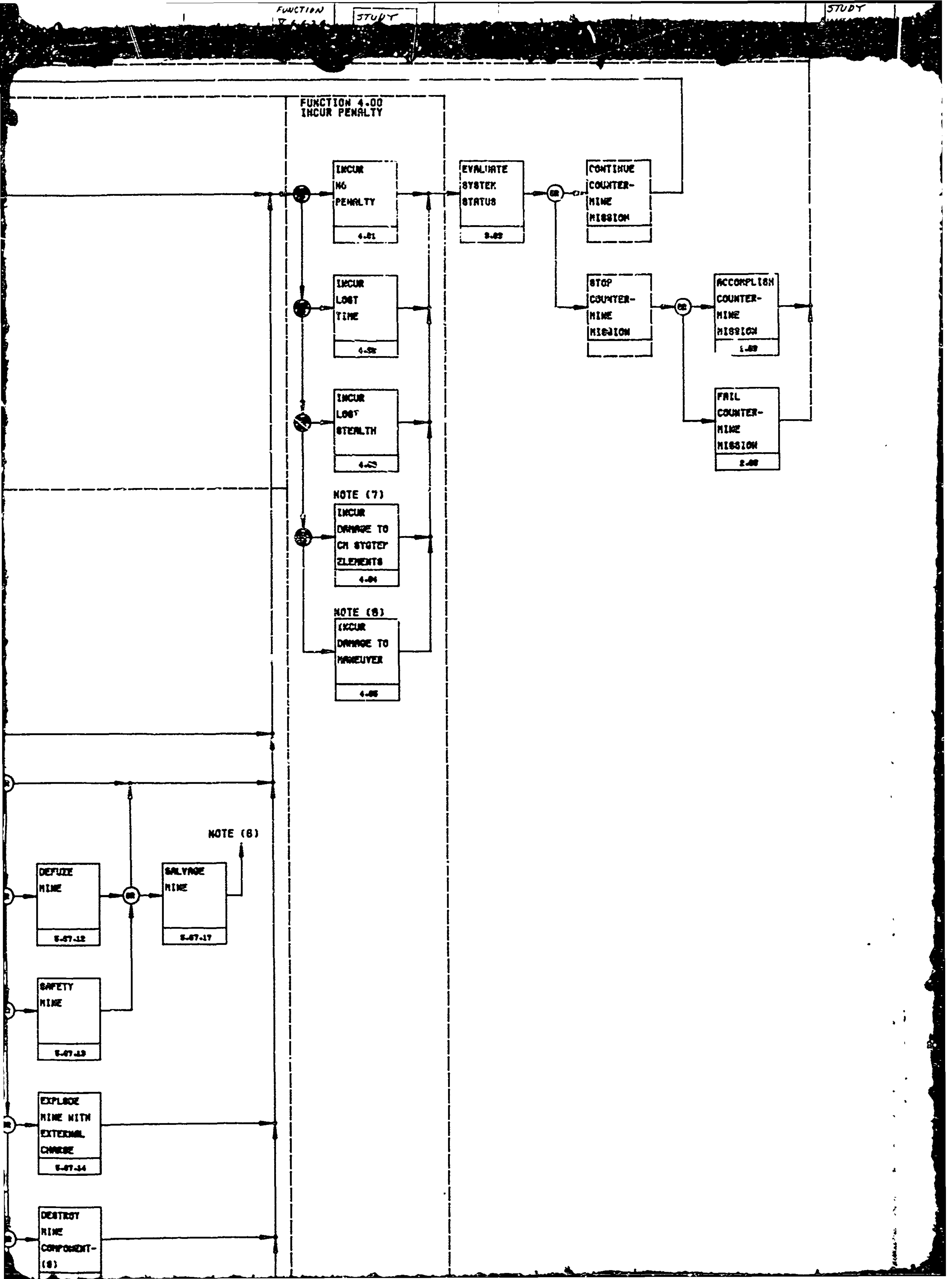


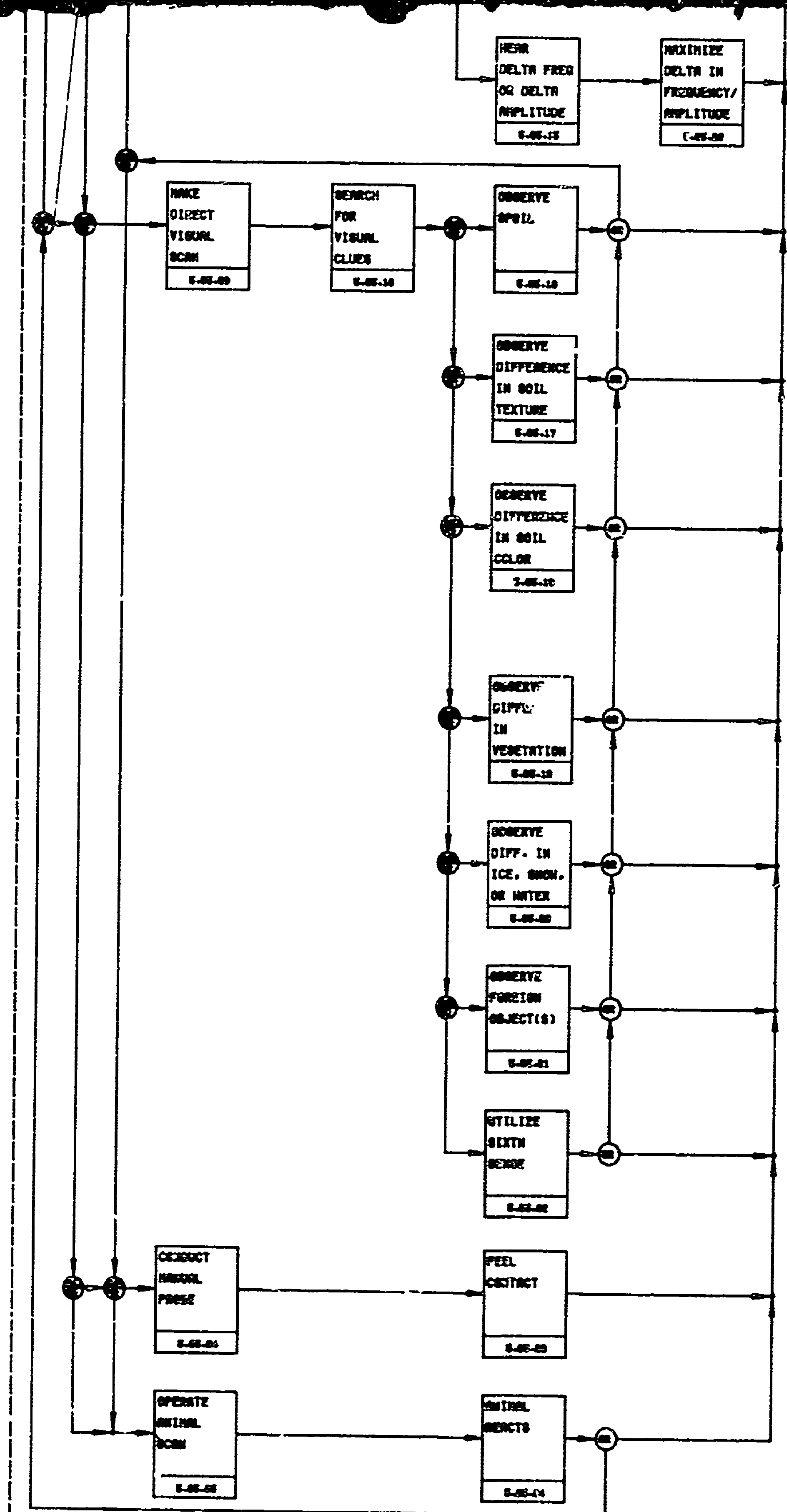
(NEW MISSION)
FUNCTION
OPERATE DETECTION SYSTEM
NO DETECTION SYSTEM
TRAVEL TO THREAT SITE
OR
DEPLOY DELIBERATE CM SYSTEM
NOTE (4)
NOTE (3)
DETONATE EXPLOSIVE DEVICE
OBSERVE REACTION
SEE AND/OR HEAR EXPLOSION
EXAMINE SITE
OBSERVE MINE CRATER
OPERATE INSTRUMENT
OBSERVE FOR VISUAL OUTPUT
MAXIMIZE OUTPUT
OBSERVE ANOMALY
OBSERVE METER DEFLECTION
OBSERVE INDICATOR ON LIGHT
LISTEN FOR AUDIO OUTPUT
HEAR TONE
MAXIMIZE TONE
HEAR DELTA FREQ OR DELTA AMPLITUDE
MAXIMIZE DELTA IN FREQUENCY/ AMPLITUDE
MAKE DIRECT VISUAL SCAN
SEARCH FOR VISUAL CLUES
OBSERVE SPOIL
OBSERVE DIFFERENCE IN SOIL TEXTURE
OBSERVE DIFFERENCE



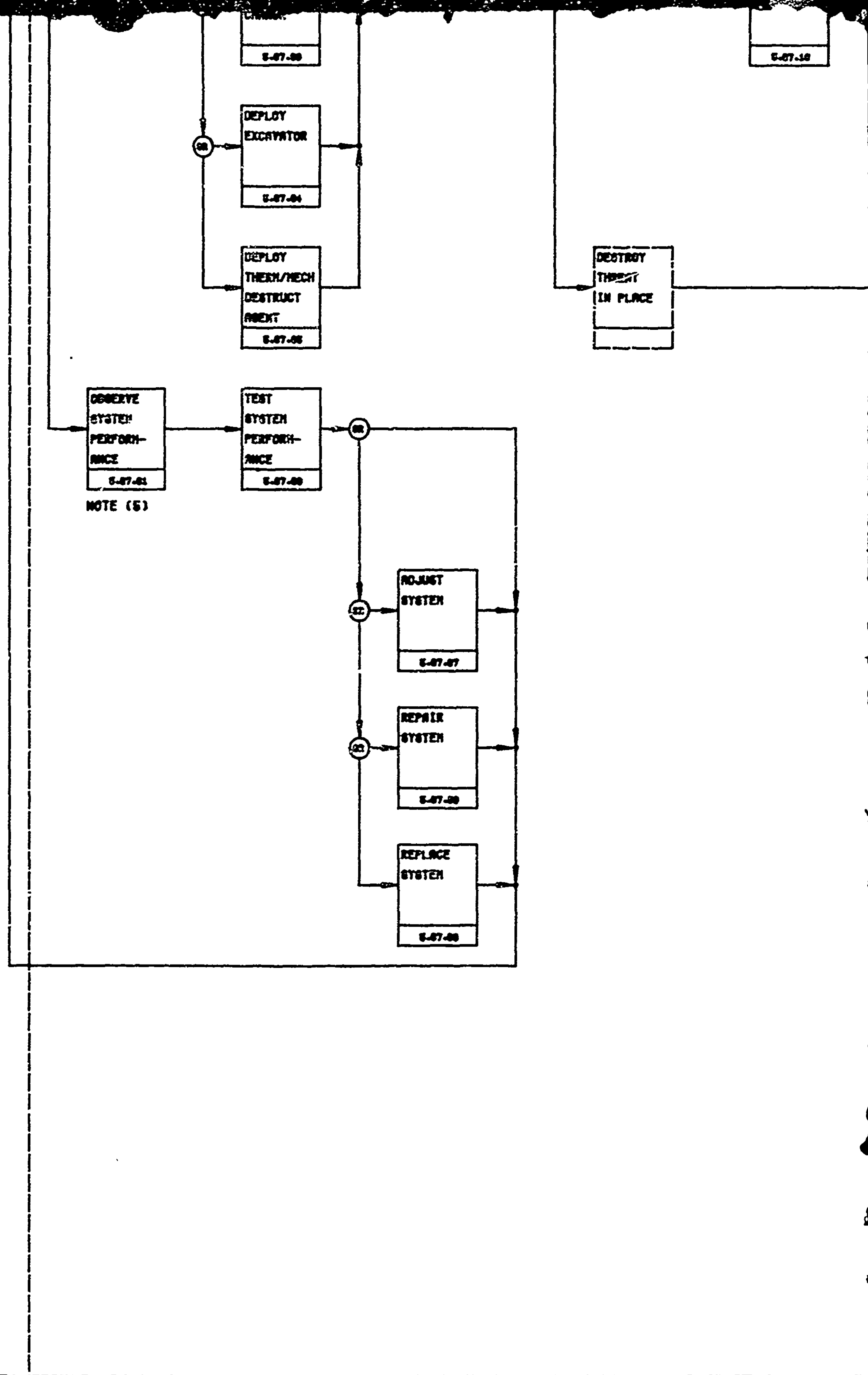
FUNCTION 5.06
OPERATE BY-PASS SYSTEM
FUNCTION 5.01
OPERATE NEUTRALIZE SYSTEM
ASSUME MINE
MARK LOCATION
COMPARE SIGNAL WITH MINE STANDARDS
FAIL TO IDENTIFY SOURCE OF SIGNAL
IDENTIFY SIGNAL SOURCE AS MINE
IDENTIFY SIGNAL SOURCE AS NON-MINE
ASSUME NO MINE
BY-PASS SOURCE OF MINE INDICATION
MOVE AROUND THREAT
MOVE UNDER THREAT
MOVE OVER THREAT
DEPLOY CONCURRENT NEUTRALIZE SYSTEM
DEPLOY ADVANCED NEUTRALIZE SYSTEM
DEPLOY FIRING TRAIN ACTUATOR
DEPLOY EXPLOSIVE CHARGE
DEPLOY EXCAVATOR
DEPLOY THERM/MECH DESTRUCT AGENT
OBSERVE SYSTEM PERFORMANCE
TEST SYSTEM PERFORMANCE


NO PENALTY
4.01
STATUS
INCUR LOST TIME
4.02
INCUR LOST STEALTH
4.03
NOTE (7)
INCUR DAMAGE TO CM SYSTEM ELEMENTS
4.04
NOTE (8)
INCUR DAMAGE TO MANEUVER
4.05
REMOVE THREAT
EXCAVATE THREAT
5.07.10
DISPLACE ARMED MINE FROM ROUTE
5.07.11
DEFUZE MINE
5.07.12
NOTE (6)
SALVAGE MINE
5.07.17
SAFETY MINE
5.07.13
DESTROY THREAT IN PLACE
EXPLODE MINE WITH EXTERNAL CHARGE
5.07.14
DESTROY MINE COMPONENT-(S)
5.07.15
ACTIVATE MINE


FUNCTION
STUDY
STUDY
FUNCTION 4.00
INCUR PENALTY
INCUR NO PENALTY
4.01
EVALUATE SYSTEM STATUS
OR
CONTINUE COUNTER-MINE MISSION
STOP COUNTER-MINE MISSION
OR
ACCOMPLISH COUNTER-MINE MISSION
FAIL COUNTER-MINE MISSION
INCUR LOST TIME
INCUR LOST STEALTH
NOTE (7)
INCUR DAMAGE TO CM SYSTEM ELEMENTS
4.04
NOTE (8)
INCUR DAMAGE TO MANEUVER
NOTE (6)
DEFUZE MINE
OR
SALVAGE MINE
SAFETY MINE
EXPLODE MINE WITH EXTERNAL CHARGE
DESTROY MINE COMPONENT-(S)



HEAR DELTA FREQ OR DELTA AMPLITUDE
MAXIMIZE DELTA IN FREQUENCY/ AMPLITUDE
MAKE DIRECT VISUAL SCAN
SEARCH FOR VISUAL CLUES
OBSERVE SPOIL
OBSERVE DIFFERENCE IN SOIL TEXTURE
OBSERVE DIFFERENCE IN SOIL COLOR
OBSERVE DIFF. IN VEGETATION
OBSERVE DIFF. IN ICE, SNOW, OR WATER
OBSERVE FOREIGN OBJECT(S)
UTILIZE SIXTH SENSE
CONDUCT MANUAL PROBE
FEEL CONTACT
OPERATE ANIMAL SCAN
ANIMAL REACTS



DEPLOY
EXCAVATOR
5-07-04
DEPLOY
THERM/MECH
DESTRUCT
AGENT
5-07-05
5-07-10
DESTROY
THREAT
IN PLACE
OBSERVE
SYSTEM
PERFORM-
ANCE
5-07-01
NOTE (5)
TEST
SYSTEM
PERFORM-
ANCE
ADJUST
SYSTEM
5-07-07
REPAIR
SYSTEM
REPLACE
SYSTEM

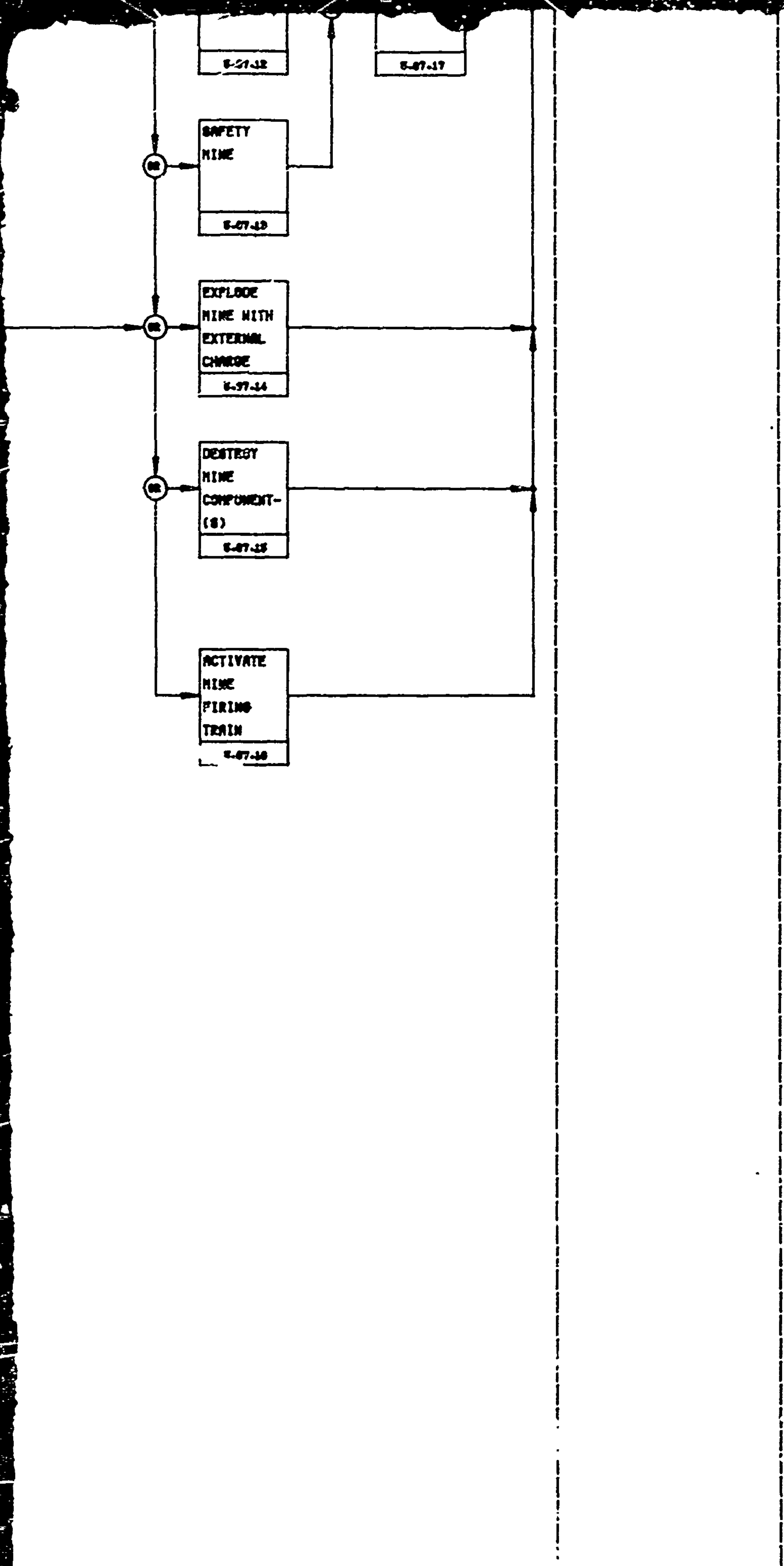


Fig. 7. Countermine mobility systems study function flow block diagram (second level).

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SYSTEMS ENGINEERING AND COMPUTATION SUPPORT OFFICE
COUNTERMINE MOBILITY SYSTEMS STUDY
FUNCTION FLOW BLOCK DIAGRAM OF COUNTERMINE SYSTEM
SECOND LEVEL
10 FEBRUARY 1972

Finally, an additional lower level of detail for system functions is given in Fig. 7. The primary value of these function flow block diagrams thus far in the study has been to provide a disciplined checklist for system elements.

These diagrams will next be used in Parts II and III of this study for guiding the development of performance and design requirements allocation for alternative conceptual systems.

6. **Barrier Minefield Model and Countermine System Breaching Data.**

a. **Dismounted Breaching Operations and Associated Time, Labor and Materiel Costs (Blue).**

Threat Model

A deliberate barrier minefield was laid out on paper (Fig. 8) using a scale of 1 inch = 10 meters. The dimensions of the barrier were approximately 300 meters deep by 406 meters wide. A density of 1 antitank, 4 antipersonnel fragmentation, and 8 antipersonnel blast mines (M15, M16, and M14) per meter was selected from FM 17-1, Table 4-5.[15] A density of 1-2-2 was used in the irregular outer edge (IOE) of the field. It was assumed that the mines were buried and suitably camouflaged. At this point in the study, it is not regarded as unrealistic to use a Blue minefield for a Red threat model, but a sensitivity analysis will be performed with foreign minefield models in a later phase of the study.

Operations Model

To be consistent with field manual data, it was first assumed that breaching was to be accomplished under conditions of average visibility and moderate enemy activity with normal U. S. countermeasures including screening of enemy observation and counter battery fires against hostile artillery or other weapons covering the barrier. Then, it was also assumed that deliberate overt breaching was to be accomplished along straight-line paths that were drawn somewhat randomly but roughly perpendicular to the barrier. Mine fuzing was not specified, and detection by either instrument or manual probing was assumed to have an effectiveness of unity, i.e., to be 100% effective.

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15. "Armor Operations," FM 17-1, October 1966.

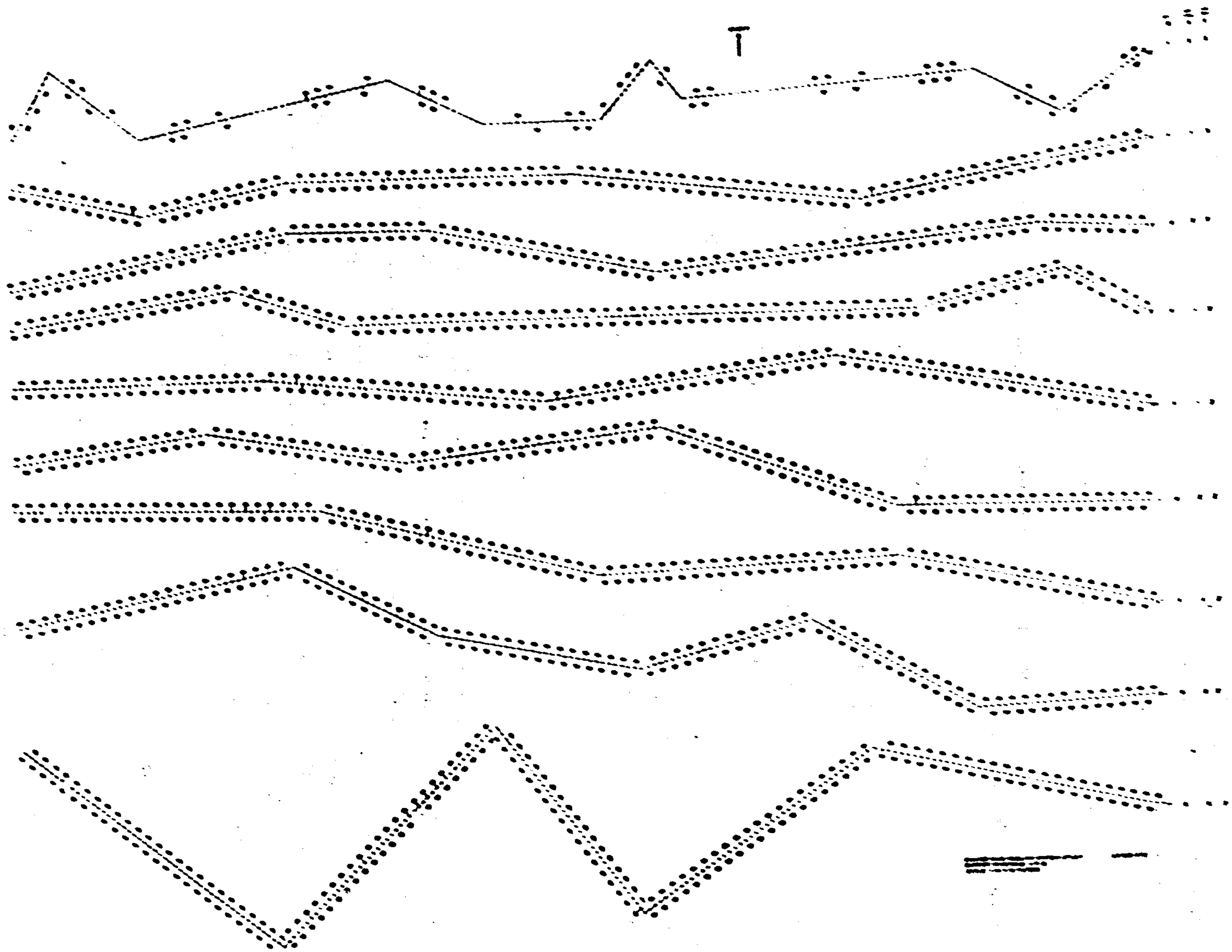

Fig. 8. Deliberate barrier minefield (Drawing 001).

Personnel for the breaching operations were defined by FM 20-32, Table 5-1.[16] Equipment was defined by FM 5-25,[17] FM 5-34,[18] FM 101-10-1,[19] and SB 700-2,[20] with the latter document taking precedence for currency as of 1 September 1971.

With the objective of attempting to bracket a wide variety of conditions by exercising the model under "best" and "worst" condition, 14 different paths were taken through the barrier minefield model. When each path line drawn through the barrier was observed or judged to have touched a cluster, it was assumed that at least one mine was detected. A summary of the model breaching encounter data is presented in Table I. Paths are shown in Fig. 9.

With these basic encounter data, a family of breaching mission examples was postulated; and time, labor, and materiel cost ranges were computed for each. The breaching mission examples are as follows:

Mission Examples	Path Width (meters)	Breaching Method
1	1	Detector and Detonate in Place
2	8	Detector and Detonate in Place
3	1	Manual Probe and Detonate in Place
4	8	Manual Probe and Detonate in Place
5	1	Bangalore Torpedo + Detect + Detonate in Place
6	6	Blind Detonate using M157 (Snake)
7	6	Blind Detonate using M173 (Rocket)
8	8	Bangalore Torpedo + Detect + Detonate in Place

16. "Landmine Warfare," FM 20-32, August 1966.

17. "Explosives and Demolitions," FM 5-25, May 1967.

18. "Engineer Field Data," FM 5-34, December 1969.

19. "Staff Officers' Field Manual Organization, Technical, and Logistical Data Unclassified Data," FM 101-10-1, January 1966.

20. "Army Adopted/Other Selected Items and List of Reportable Items," DA Supply Bulletin SB 700-2, 1 September 1971.

Table I. Summary of Barrier Minefield Breaching Encounter Model Data (From Drawing 001)

Encounter Number	Distance Traveled to Encounter Mine Cluster (meters)													
	Path													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	68	68	69	31	36	61	63.5	58	58	36	66	85.5	65	119.5
2	13	13.5	12	5	31	29.5	22	54.5	25.5	27	11.5	11	6	26
3	27.5	21.5	27	24	26.5	20.5	27.5	38	20	5	5	5	27.5	9
4	19	74	14.5	33	17	18	21.5	41.5	20	12	17	25	5.5	23
5	5	5	65.5	11	15	22	18.5	5.5	22	20.5	5.5	5	18.5	8.5
6	41	23	35.5	22	29	43.5	34	27	4.5	26	23	13	58	36.5
7	22	5	5	65.5	5.5	100	100	64.5	22.5	5	22.5	31	35	9
8	5.5	38	31	28	37.5	–	–	13	32.5	13.5	27	114.5	19	17.5
9	47	31	100	80	18.5	–	–	100	57.5	15.5	24	6	21.5	12
10	18.5	5.5	–	100	60.5	–	–	–	8	24	93.5	100	71	41.5
11	5.5	100	–	–	5.5	–	–	–	100	114.5	5.5	–	24	55
12	100	–	–	–	100	–	–	–	–	5.5	100	–	11.5	28
13	–	–	–	–	–	–	–	–	–	100	–	–	4.5	5.5
14	–	–	–	–	–	–	–	–	–	–	–	–	4.5	11
15	–	–	–	–	–	–	–	–	–	–	–	–	66	5.5
16	–	–	–	–	–	–	–	–	–	–	–	–	8	100
17	–	–	–	–	–	–	–	–	–	–	–	–	100	–

Average = 401.04 meters to breach
= 10.4 mine (cluster) encounters

Note:
1. All paths begin at about the same distance from the IOE.
2. A distance of 100 meters without an encounter is assumed to signify being out of the minefield.
3. Path J, Encounter 11, Path L, Encounter 8, and Path N, Encounter 14, would signify casualties because detection had been discontinued after 100 meters without a mine encounter while still in the minefield.

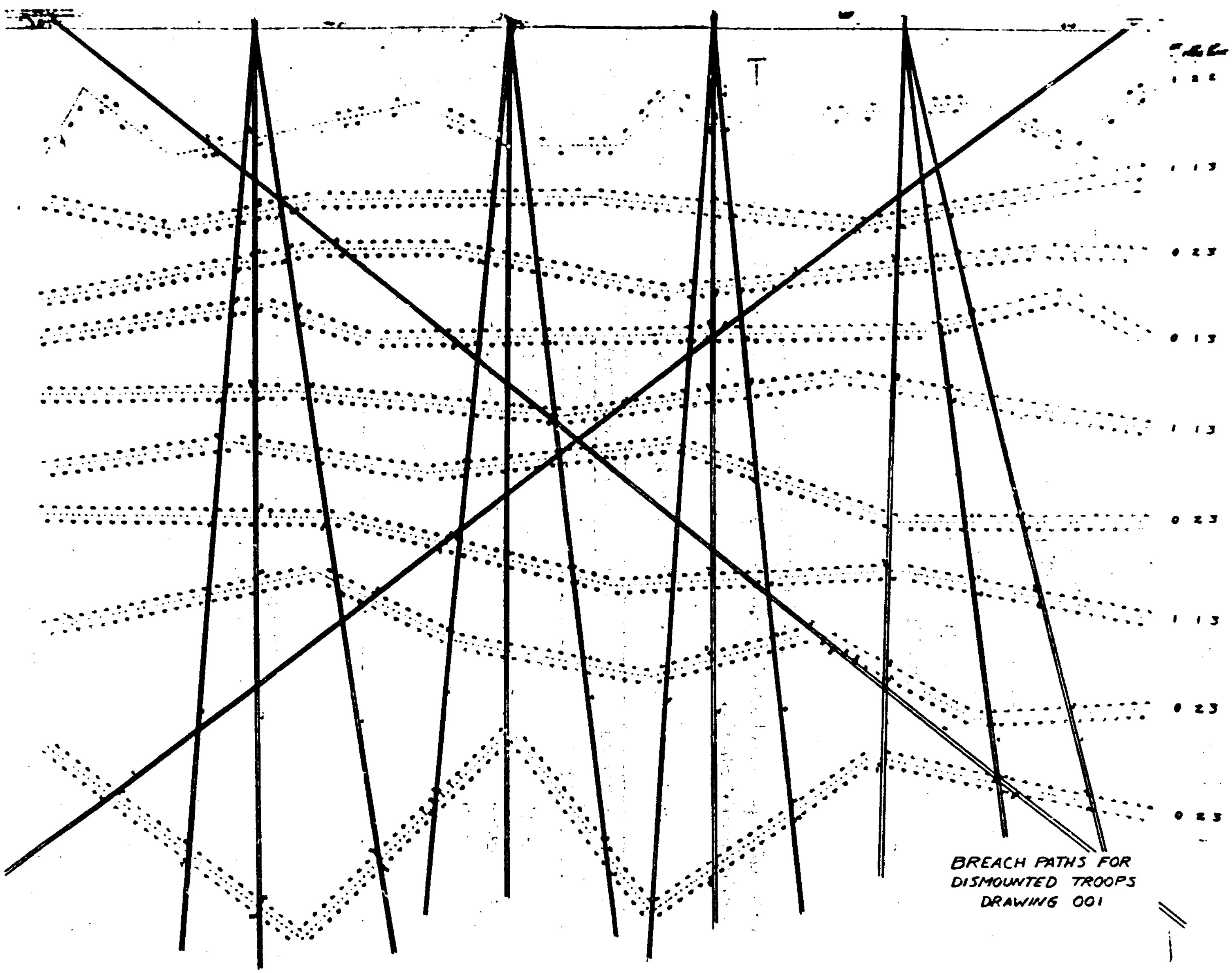

Fig. 9. Breach paths for dismounted troops (Drawing 001).

(1) **Example 1.**

Clear a 1-meter-wide path utilizing a mine detector such as the AN/PRS-7 and demolition charges such as the M5A1, M112, or M118. A breach party of 8 men is postulated (Table II).[21]

Table II. Breach Party Composition (Example 1)

Detector Operator	1
Mine Marker/Tape Layer	1
NCO	1
Demolition Men	2
Relief Detector Operator	1
Radio Operator	1
Reserve (OIC)	1
	8

The time to accomplish detection is next computed for a range of detection speeds selected to more or less bracket the real-world range of potential field conditions (Table III).

Table III. Detection Speed, Traverse Time, and Labor (Example 1)

Detection Speed (Meters/Second)	Time to Traverse Barrier (Seconds)	Time to Traverse Barrier (Hours)	Detection Labor (Manhours)
0.01	40100	11.14	11.14x8 = 89.1
0.05	8020	2.23	2.23x8 = 17.8
0.10	4010	1.11	1.11x8 = 8.88
0.20	20[illegible]	0.56	0.56x8 = 4.48
1.00	401	0.11	0.11x8 = 0.88

The time to accomplish destruction of the mines encountered by detonation in place is also computed for a range of conditions (Table IV).

[21]"Landmine Warfare," FM 20-32, August 1966.

Table IV. Charge Placement Time, Traverse Time, and Labor (Example 1)

Breach Party Charge Placement Speed (Meters/Second)		Time to Traverse Barrier (Hours)	Breach Labor (Manhours)
0.133	(5 min each)	$\frac{401/0.133}{3600} = 0.838$	0.838x8 = 6.70
0.0666	(10 min each)	$\frac{401/0.0666}{3600} = 1.67$	1.67x8 = 13.4
0.0333	(20 min each)	$\frac{401/0.0333}{3600} = 3.35$	3.35x8 = 26.8
0.0222	(30 min each)	$\frac{401/0.0222}{3600} = 5.02$	5.02x8 = 40.2

Then, assuming that breaching time will be dominated by the slowest operation, the relationships of detection speed, charge placement speed, and total breaching time and labor are illustrated in Figs. 10 and 11. Note that the AN/PRS-7 mine detector technical manual recommends a detector head sweep rate corresponding to a detection speed of 0.05 meter/second for a path 1-meter wide.[22] This point is located on Figs. 10 and 11 for reference. For additional comparison, FM 5-34[23] and FM 101-10-1[24] provide an average detection labor value of 27 to 33 manhours per 100 meters of advance for a lane 8 meters wide assuming 1 detector man and 1 relief man:

$$\frac{27}{100} = \frac{\frac{27}{2} \times \frac{400}{100}}{8} = 6.75 \text{ hours}$$

and

$$\frac{33}{100} = \frac{\frac{33}{2} \times \frac{400}{100}}{8} = 8.25 \text{ hours}$$

These points are also located on Fig. 10 to provide perspective for the other calculated values.

---

[22] "Operators, Organizational and Direct Support, Maintenance Manual," Detecting Set, Mine, Portable, Metallic and Nonmetallic (Litton Systems MDL AN/PRS-7).

[23] "Engineer Field Data," FM 5-34, December 1969.

[24] "Staff Officers' Field Manual Organization, Technical, and Logistical Data Unclassified Data," FM 101-10-1, January 1966.

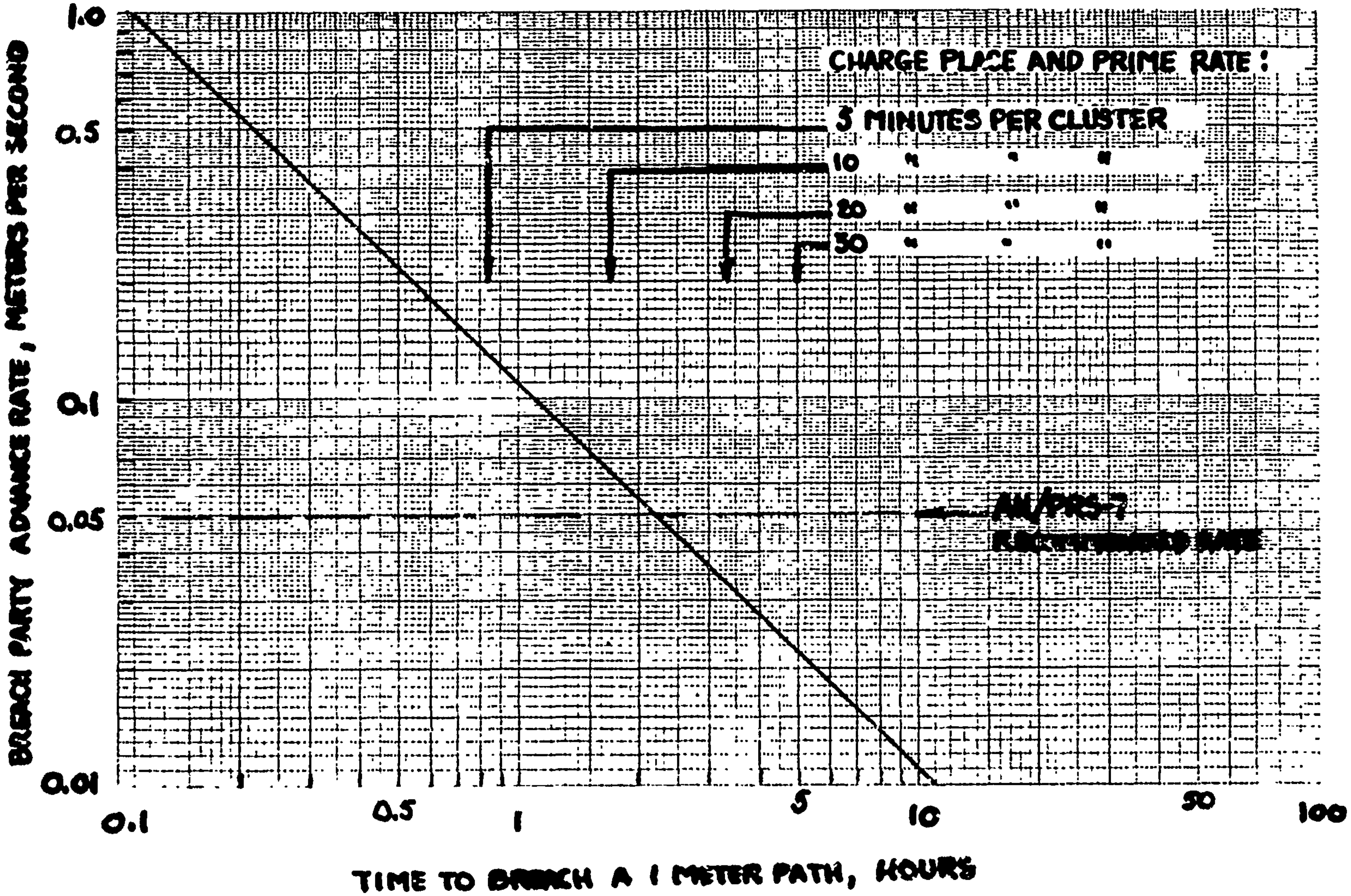

Fig. 10. Plot of breach party advance rate vs time to breach (Example 1).

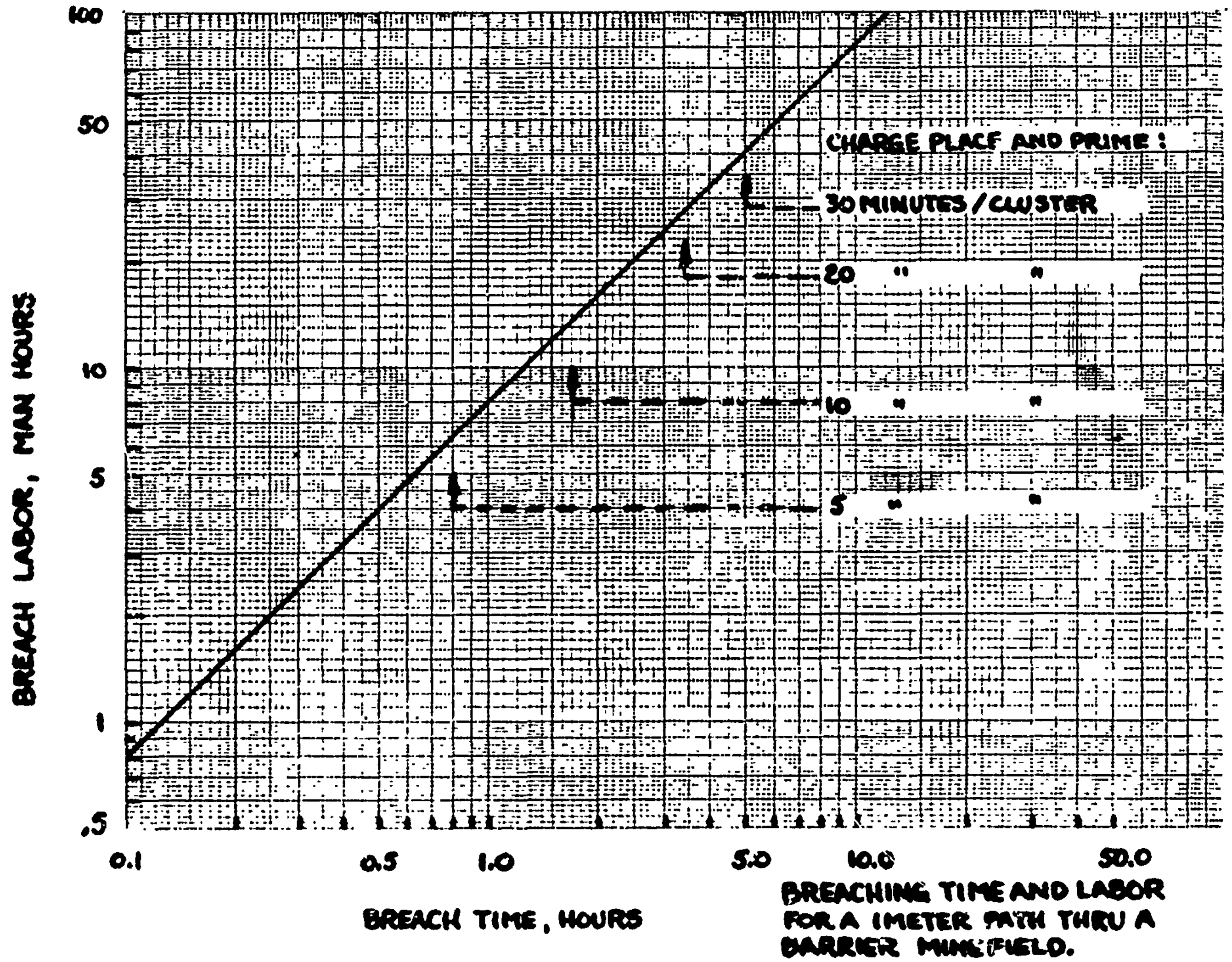

Fig. 11. Plot of breach labor vs breach time (Example 1).

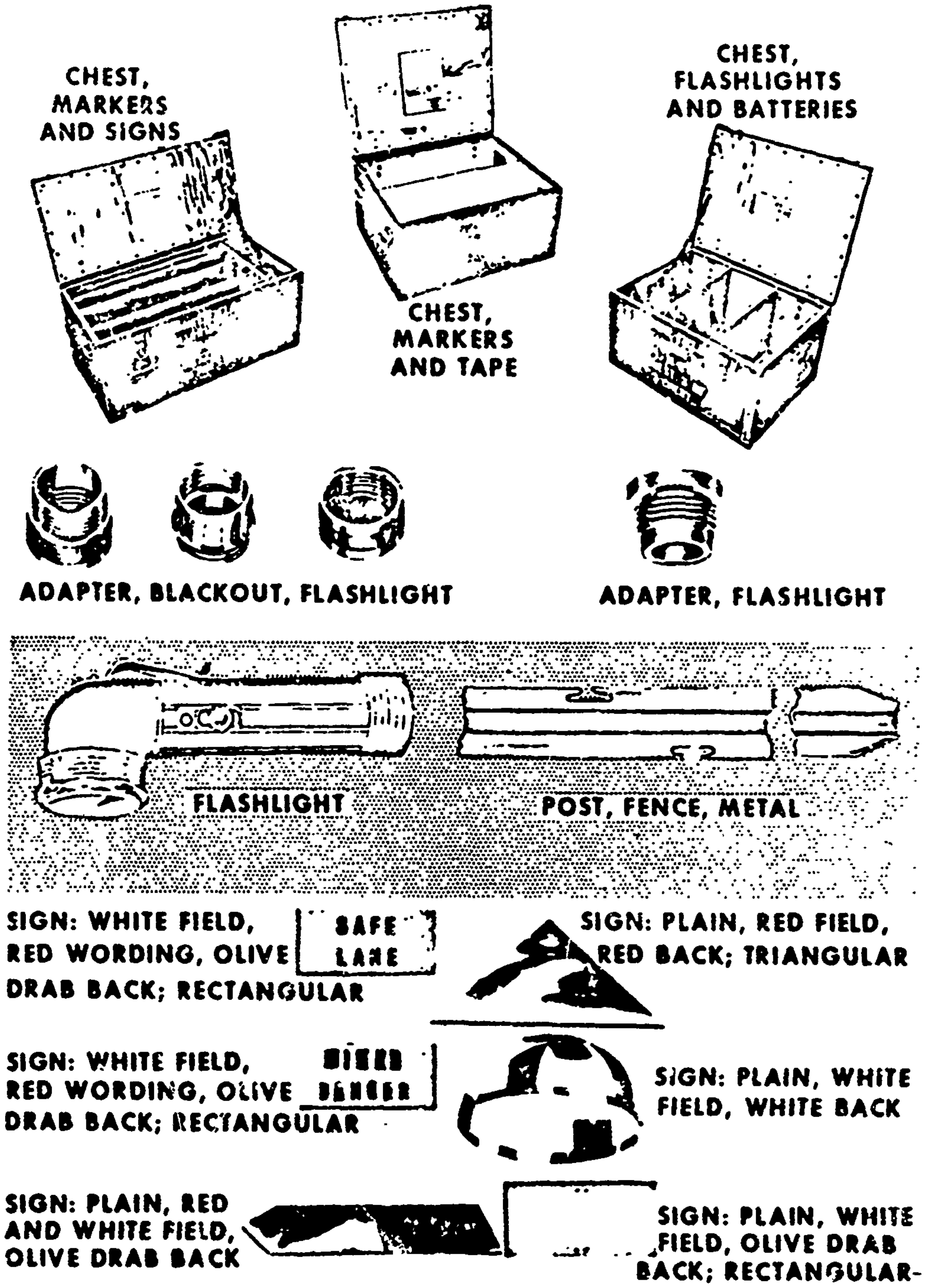

Fig. 12. Minefield marking set.

The breaching materiel cost range for Example 1 is estimated as follows:

Function	Item	Price Ea	No.	Subtotal Price
Clear vegetation	Flame thrower	$327-1347	1	$327 – 1347
Detect	Mine Detector	350-1136	2	700 – 2272
Mark Mines and Lane	Minefield Marking Kit (Fig. 12)	465- 465	1	465 – 465
Detonate mines	Demo Set	197- 197	1	197 – 197
	Charge Demo	1- 1	20	20 – 20
				$1709 – 4301

The basic data for these and subsequent cost estimations is presented in Appendix A, Table A-I.

(2) **Example 2.**

Clear an 8-meter-wide path utilizing a mine detector such as the AN/PRS-7 and demolition charges such as the M5A1, M112, or M118. In this example, it is necessary to use the organization shown in Table V.[25]

Table V. Breach Platoon Composition (Example 2)

Personnel	O	NCO	EM	
Officer in charge	1	–	–	
Platoon Sergeant	–	1	–	
Breaching party 1	–	1	7	
Breaching party 2	–	1	7	
Breaching party 3	–	1	7	
Support party	–	1	7	
Total	1	5	31	37

FM 20-32 also directs that such a breaching operation be conducted by parties similar to that shown in Table II but that each party must maintain a 100-meter distance from other parties. It is postulated that three platoons will be used in this example and that each platoon will stand at the barrier until its assigned breaching

[25]"Landmine Warfare," FM 20-32, August 1966.

paths are simultaneously detonated. The complete breaching organization is then as shown in Table VI.

Table VI. Breach Organization (Example 2)

Platoon 1	Party 1	
	Party 2	
	Party 3	
	Support Party	
		37
Platoon 2	Party 1	
	Party 2	
	Party 3	
	Support Party	
		37
Platoon 3	Party 1	
	Party 2	
	Support Party	
		21

To develop and maintain 100-meter spacing between parties, Platoons 1 and 2 will be at the barrier for a time that is equivalent to traversing 400+200=600 meters. Platoon 3 will be at the barrier for a time that is equivalent to traversing 400+100=500 meters. The relationships between breach party speed, platoon time at the barrier, and breaching time are shown in Table VII.

But, as discussed in Example 1, breaching in these particular cases consists of two separate and distinct operations that are performed sequentially, i.e., detection and then detonation in place. This, in turn, leads to the complete breaching operation being dominated by the rate at which the slowest operation is accomplished. To determine the area of dominance, the above calculation of detection is repeated in Table VIII for detonate-in-place time relationships.

Table VII. Relationship of Breach Party Mine Detection Speed to Platoon Time at the Barrier and Breach Time (Example 2)

Breach Party Speed (Meters/Second)	Time at the Barrier (Hours)			Breach Time (Hours)
	Platoon 1	Platoon 2	Platoon 3	
0.01	$\frac{600/0.01}{3600} = 16.7$	16.7	$\frac{500/0.01}{3600} = 13.9$	47.3
0.05	$\frac{600/0.05}{3600} = 3.34$	3.34	$\frac{500/0.05}{3600} = 2.78$	9.5
0.10	$\frac{600/0.10}{3600} = 1.67$	1.67	$\frac{500/0.10}{3600} = 1.39$	4.7
0.20	$\frac{600/0.20}{3600} = 0.834$	0.834	$\frac{500/0.20}{3600} = 0.691$	2.4
1.00	$\frac{600/1}{3600} = 0.167$	0.167	$\frac{500/1}{3600} = 0.139$	0.47

Table VIII. Relationship of Breach Party Demolition Charge Placement and Priming Speed to Platoon Time at the Barrier and Breach Time (Example 2)[a]

Breach Party Speed (Meters/Second)	Time at the Barrier (Hours)			Breach Time (Hours)
	Platoon 1	Platoon 2	Platoon 3	
0.133[b]	$\frac{600/0.133}{3600} = 1.25$	1.25	$\frac{500/0.133}{3600} = 1.04$	3.54
0.0666[c]	$\frac{600/0.0666}{3600} = 2.50$	2.50	$\frac{500/0.0666}{3600} = 2.09$	7.09
0.0333[d]	$\frac{600/0.0333}{3600} = 5.01$	5.01	$\frac{500/0.0333}{3600} = 4.17$	14.2
0.0222[e]	$\frac{600/0.0222}{3600} = 7.51$	7.51	$\frac{500/0.0222}{3600} = 6.26$	21.3

(a) From Table I, 10 mine clusters/400M=40M/cluster.

(b) At 5 minutes per cluster, rate=40/300=0.133M/Sec.

(c) At 10 minutes per cluster, rate=40/600=0.0666M/Sec.

(d) At 20 minutes per cluster, rate=40/1200=0.0333M/Sec.

(e) At 30 minutes per cluster, rate=40/1800=0.0222M/Sec.

The calculation shown in Table IX is then made to determine breach party speed vs breach labor relationships.

Table IX. Relationship of Breach Party Speed to Breach Labor (Example 2)

Breach Party Speed (Meters/Second)	Labor to Breach (Manhours)			OIC	Total
	Platoon 1	Platoon 2	Platoon 3		
0.01	37x16.7=618	618	21x13.9=292	47	1575
0.05	37x3.34=123	123	21x2.78=58	9.5	315
0.10	37x1.67=61.8	61.8	21x1.39=29	4.7	158
0.20	37x0.834=30.9	30.9	21x0.691=15	2.4	79
1.00	37x0.167=6.18	6.18	21x0.0139=2.9	0.47	15

Table X presents limits imposed by the demolition charge placement and priming time requirements.

Table X. Relationship of Breach Party Demolition Charge Placement and Priming Time to Breach Labor (Example 2)

Breach Party Speed (Meters/Second)	Labor to Breach (Manhours)			OIC	Total
	Platoon 1	Platoon 2	Platoon 3		
0.133	37x1.25=46.3	46.3	21x1.04=21.8	3.54	118
0.0222	37x7.51=278	278	21x6.26=131	21.3	708

The relationships calculated for this example are shown in Figs. 13 and 14.

To complete Example 2, materiel cost range is estimated as follows:

Function	Item	Price Ea	No.	Subtotal Price
Clear Vegetation	Flame Thrower	$327–1347	8	$2616–10,776
Detect	Mine Thrower	350–1136	16	5600–18176
Mark Mines & Lanes	Minefield Marking Kit	465–465	16	7440–7440
Detonate Mines	Demo Set	197–197	8	1576–1576
	Charge Demo	1– 1	160	160– 160
				$17392–38128

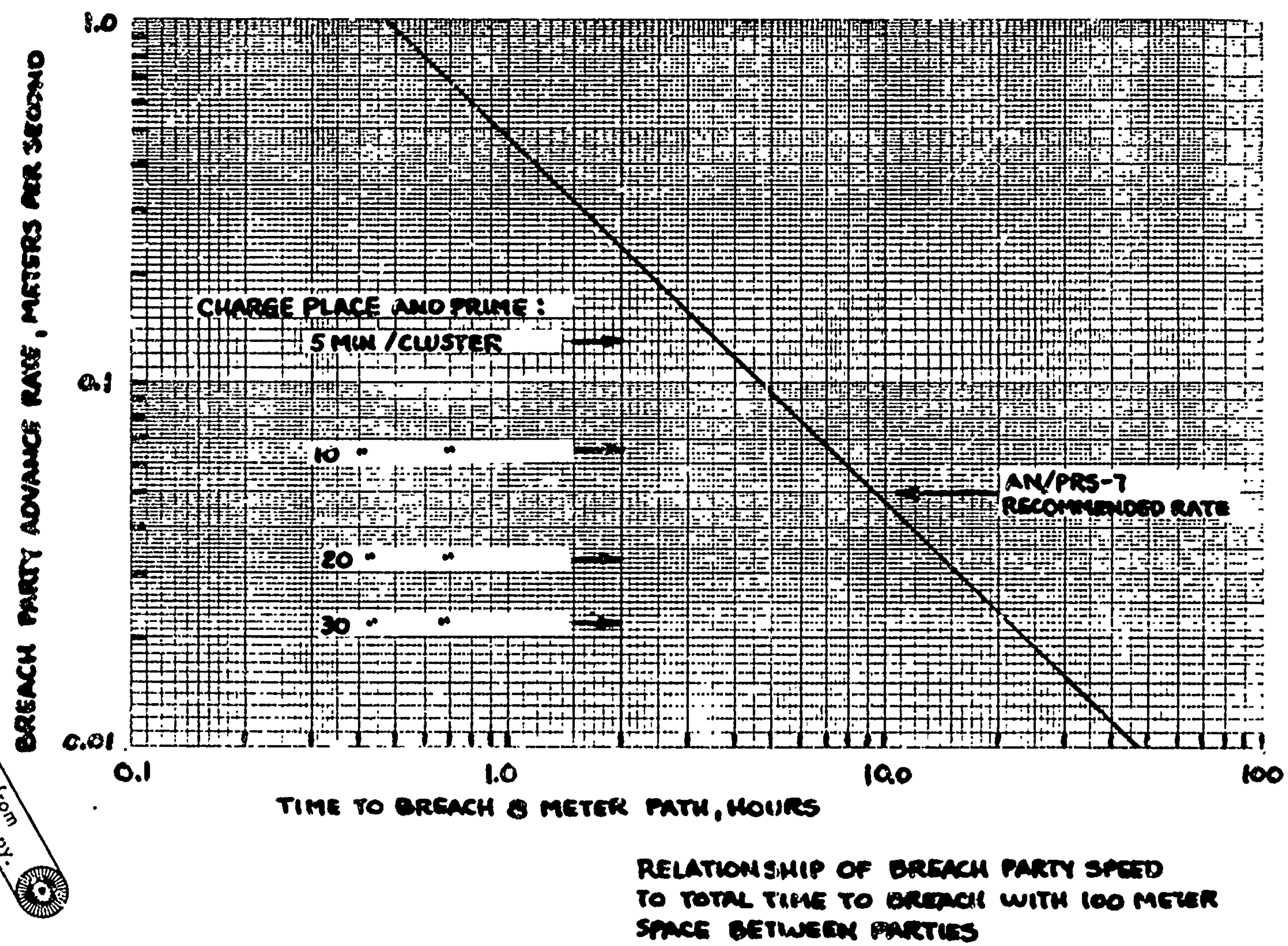

Fig. 13. Plot of breach party advance rate vs breach time (Example 2).

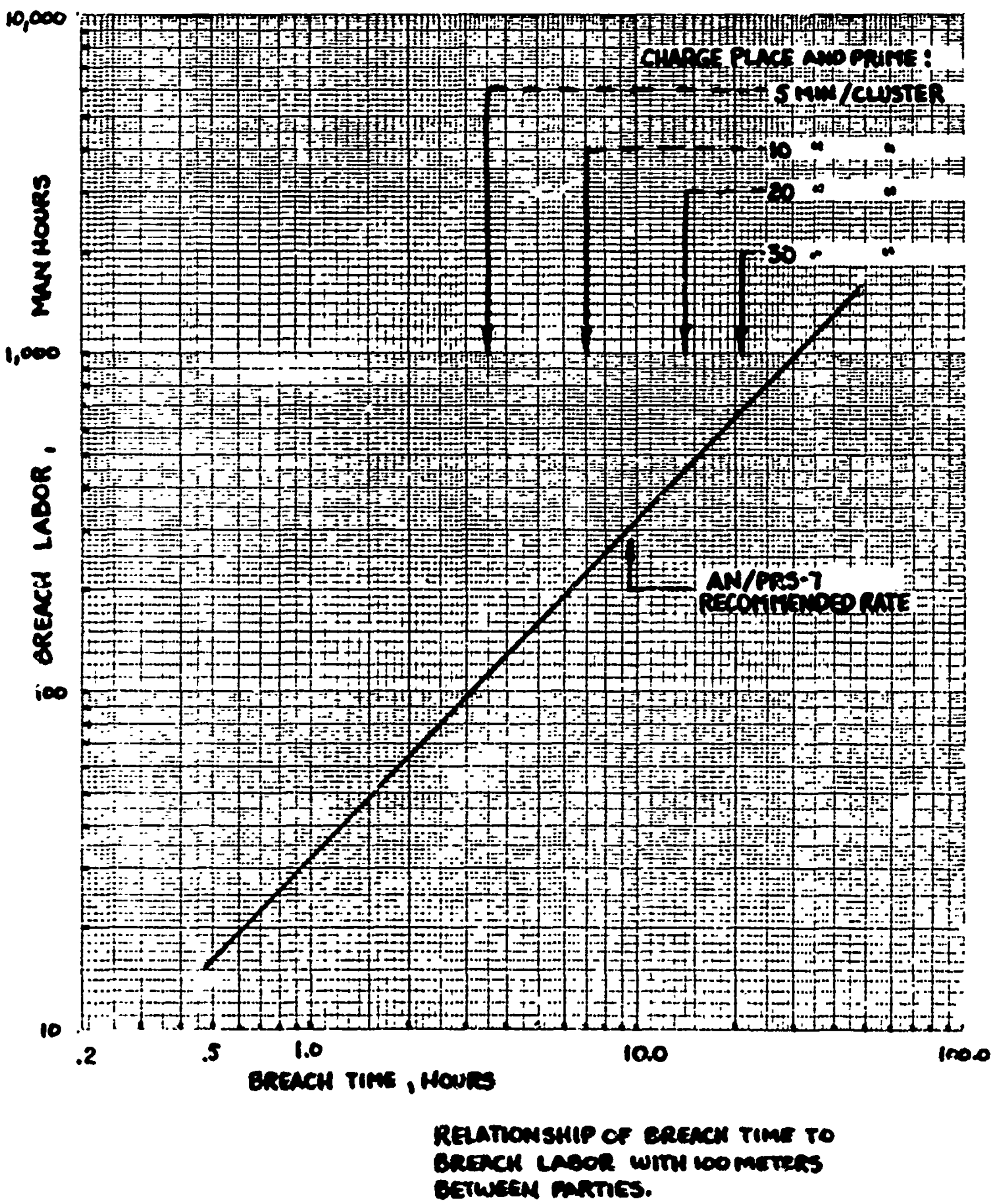

Fig. 14. Plot of breach labor vs breach time (Example 2).

(3) Example 3.

Clear a 1-meter-wide path by manual probing and destruction in place of mines using demolition charges such as the M5A1, M1?2, or M118.

Basic data for this example are derived from FM 5-34, p. 87,[26] which gives the relationships shown in Table XI.

Table XI. Probing and Removal Standard Data (Example 3)

a	Location by Probing	16-22 MH/100M	(1-Meter Path)
b	Removal by Explosives	220-247 MH/100M	(8-Meter Path)

From the context of FM 5-34, it is reasonable to assume that item a in Table XI refers to one man for 16 to 22 hours. Assume also, then, the use of an 8-man party, location by probing for 400 meters requires from 4 x 16 = 64 hours to 4 x 22 = 88 hours. Probing labor would range from 8 x 64 = 512 manhours to 8 x 88 = 704 manhours.

Applying the same general interpretation of the Table XI data, the time for removal by explosives from a 400-meter path, 1-meter-wide, ranges from $\frac{220}{8} \times 4 = 110$ hours to $\frac{247}{8} \times 4 = 124$ hours. Corresponding labor is 110 x 8 = 880 manhours to 124 x 8 = 992 manhours.

As in the case of Examples 1 and 2, breaching time is dominated by charge placement and priming time.

The breaching materiel cost range for Example 3 is estimated as follows:

Function	Item	Price Ea	No.	Subtotal Price
Clear Vegetation	Flame Thrower	$327–1347	1	$327–1347
Mark Mines & Lanes	Minefield Marking Kit	465–465	1	465–465
Detonate Mines	Demo Set	197–197	1	197–197
	Charge Demo	1– 1	20	20– 20
				$1009–2029

[26] "Engineer Field Data," FM 5-34, December 1969.

(4) **Example 4.**

Clear an 8-meter-wide vehicular path by manual probing and removal of mines by detonation in place using demolition charges such as the M5A1, M112, or M118. This example is similar to Example 3 which was for a 1-meter path through the barrier. Referring to the data presented in Table XI, breaching is dominated by demolition charge placement and priming time and ranges from 110 to 124 hours per 1-meter lane. In this example, however, 8 breaching parties are required, and each party must maintain a spacing of 100 meters from the next party.

By using the breaching platoon listed in Table V, the breaching organization listed in Table VI, and an abbreviated calculation similar to that used in Example 2, the information shown in Tables XII and XIII emerges.

Table XII. Relationship of Breach Party Speed, Time at the Barrier, and Breach Time (Example 4)

Breach Party Speed (Meters/Second)	Time at Barrier (Hours) Platoon 1	Platoon 2	Platoon 3	Breach Time (Hours)
$\frac{401}{110 \times 3600} = 0.0010$	$\frac{600/0.001}{3600} = 166$	166	$\frac{500/0.001}{3600} = 139$	471
$\frac{401}{124 \times 3600} = 0.00089$	$\frac{600/0.00089}{3600} = 187$	187	$\frac{500/0.00089}{3600} = 156$	530

Table XIII. Relationship of Breach Party Speed, Time at the Barrier. and Breach Labor (Example 4)

Breach Party Speed (Meters/Second)	Labor to Breach (Manhours) Platoon 1	Platoon 2	Platoon 3	OIC	Total
0.0010	37x66=6142	6142	21x139=2919	471	15700
0.00089	37x187=6919	6919	21x156=3276	530	17600

The breaching materiel cost range for Example 4 is estimated as follows:

Function	Item	Price Ea	No.	Subtotal
Clear Vegetation	Flame Thrower	$327–1347	8	$2616–10776
Mark Mines & Lanes	Minefield Marking Kit	465–465	8	3720–3720
Detonate Mines	Demo Set	197–197	8	1576–1576
	Charge Demo	1– 1	160	160–160
				$8072–16232

(5) **Example 5.**

Clear a 1-meter-wide path by means of blind neutralization utilizing the bangalore torpedo M1A1/M1A2 without previous detection and follow by detection to locate and then destroy in place unexploded mines in the breach path.

The bangalore torpedo (Fig. 15) consists of 10 sections, each 5 feet long, for a total length of approximately 15 meters. According to FM 20-32, p. 87,[27] from 3.5 to 4.5 manhours per 100 meters are required for this device to clear a 1-meter path. This would include assembly, transportation into the barrier, priming, and firing time. Assume first that an 8-man party conducts this operation and that the time for a 400-meter breach path is 4 x 3.5 to 4.5 = 14 to 18 hours and breach labor = 8 x 14 to 8 x 18 = 112 to 144 manhours.

Assume next that a detector sweep is performed at the standard rate of 0.05 meter/sec for the AN/PRS-7 detector, breach time is increased by $\frac{400/0.05}{3600}$ = 2.22 hours and breach labor by 2.22 x 8 = 17.8 manhours.

Then, assuming that 50% of the original mines are detected after the bangalore torpedo action, 0.5 x 10 = 5 mines remain to be destroyed in place. Using the midpoint of 15 minutes to place and prime each demolition charge, that time is $5 \times \frac{15}{60}$ = 1.25 hours and labor is 1.25x8 = 10 manhours. Since this is less than the detect time, detect time will dominate.

[27] "Landmine Warfare," FM 20-32, August 1966.

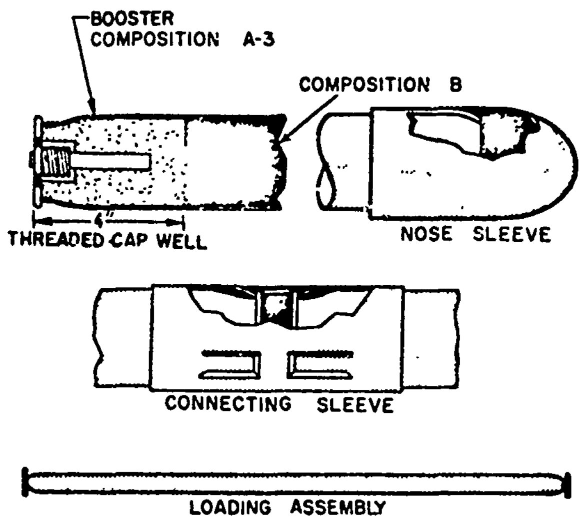

Fig. 15. M1A1 bangalore torpedo.

Summarizing:

	Breach Time (Hours) Low	Breach Time (Hours) High	Breach Time (Manhours) Low	Breach Time (Manhours) High
Bangalore Torpedo	14	18	112	144
Detection and Detonate in Place	2.22	2.22	17.8	17.8
	16.2	20.2	130	162

The breaching materiel cost range for Example 5 is estimated as follows:

Function	Item	Unit Price	No.	Subtotal Price
Blind Detonate	Bangalore Torpedo	$106–106	27	2862–2862
Detect	Detector	350–1136	2	700–2272
Mark Mines & Path	Minefield Marking Kit	465–465	1	465–465
Detonate Mines	Demoset	197–197	1	197–197
	Charge Demo	1–1	20	20–20
				$4244–5816

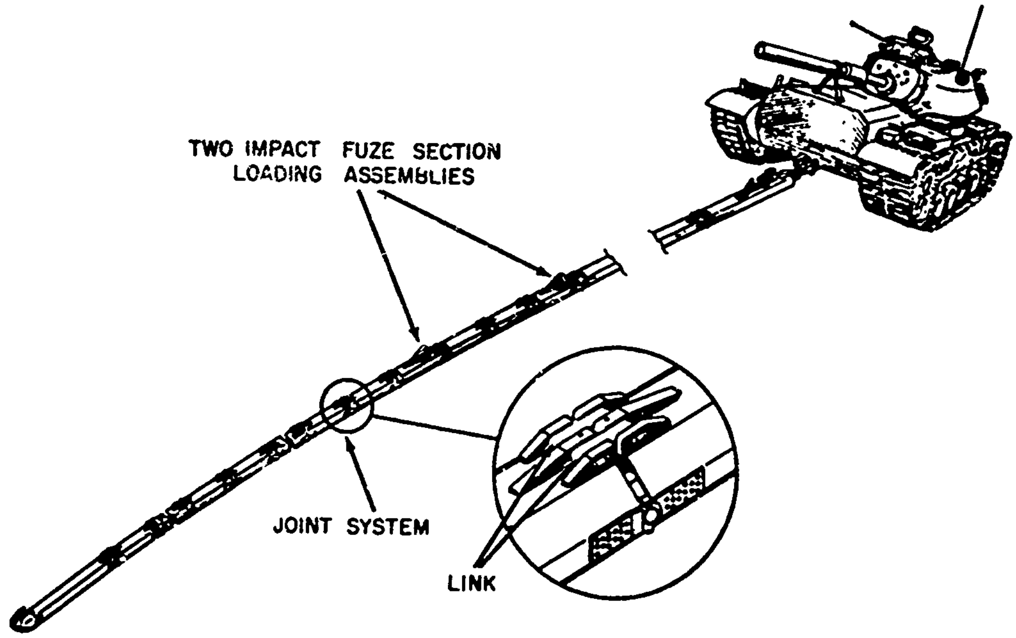

Fig. 16. M-157 projected demolition charge kit.

(6) Example 6.

Clear a 6-meter-wide vehicle path by means of blind neutralization utilizing the demolition kit projected charge M157F (Snake) (Fig. 16). This kit weighs 11,000 pounds and consists of 79 sections that must be assembled at the barrier. By detonation, the device clears a lane approximately 100 meters long by 6 meters wide by 1½ meters deep. A tank is required to push the snake into place and then it is detonated by bullet impact fuzing (FM 17-36, p. 21[28]). Approximately 8 manhours are required for assembly and 8 manhours, to clear a 100-meter lane (FM 20-32, p. 87[29]).

Assume first that the breaching organization is the platoon of Table V plus a tank and its crew of 4 men. A total of 4 snakes is required, and the snakes are assembled concurrently in 1 hour:

Assembly time = 1 hour
Assembly labor = 1 (37+4) = 41 manhours.

28. "Divisional Armored and Air Cavalry Units," FM 17-36, November 1968.

29. "Landmine Warfare," FM 20-32, August 1966.

Assume next that 0.5 hour is required to position and detonate each snake:

Time = 4 x 0.5 = 2 hours
Labor = 2 (37 + 4) = 82 manhours.

For the completed breaching mission:

Breaching time = 1 + 2 = 3 hours
Breaching Labor = 41 + 82 = 123 manhours.

The breaching materiel cost range for Example 6 is estimated as follows:

Function	Item	Unit Price	No.	Subtotal Price
Position Snake	M60 Tank	$147475–217680	1	$147475–217680
Detonate Mines	M157 Snake	10786– 10786	4	43144– 43144
Mark Path	Minefield Marking Kit	465– 465	1	465– 465
				$191084–261289

(7) Example 7.

Clear a 6-meter-wide vehicle path by means of blind neutralization utilizing the demolition kit projected charge M173 (Fig. 17). This kit requires a vehicle to tow the sled-like kit up to the minefield where a rocket then pulls a line charge out to approximately 90 meters to clear a lane 90 meters long by 6 meters wide.

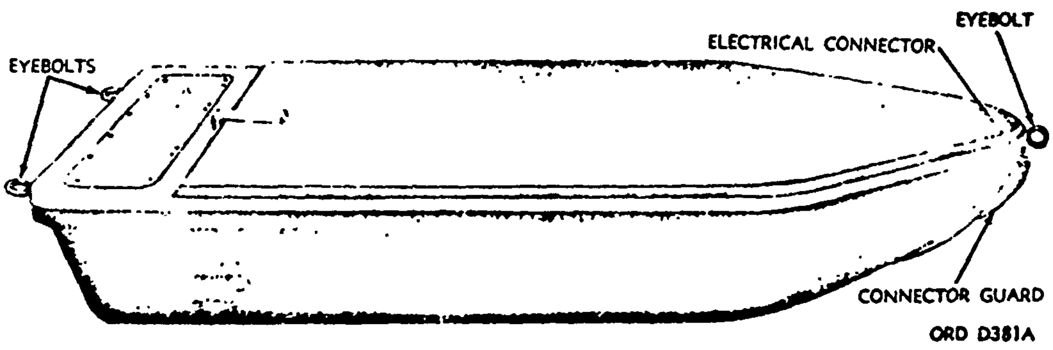

Fig. 17a. Projected charge demolition kit M173.

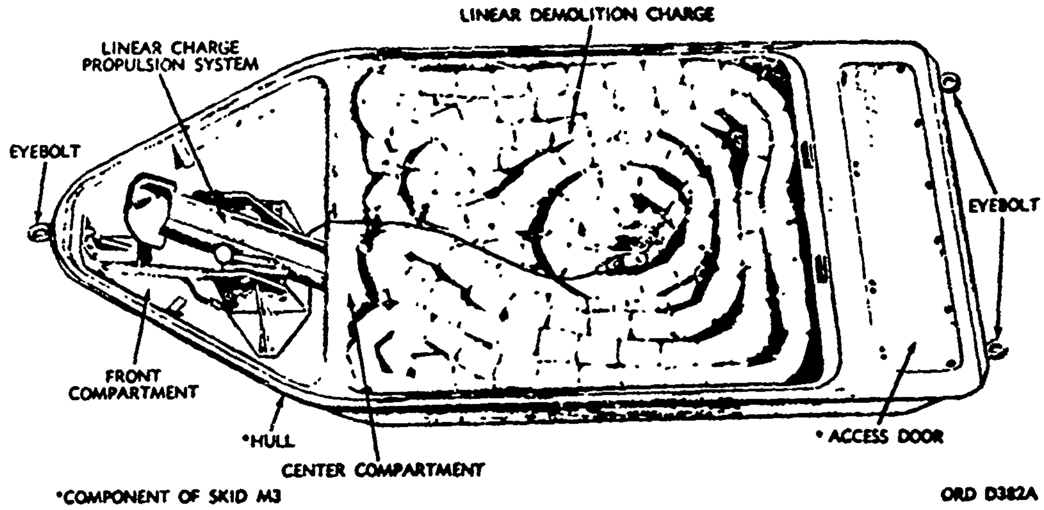

Fig. 17b. Projected charge demolition kit M173 with main cover removed.

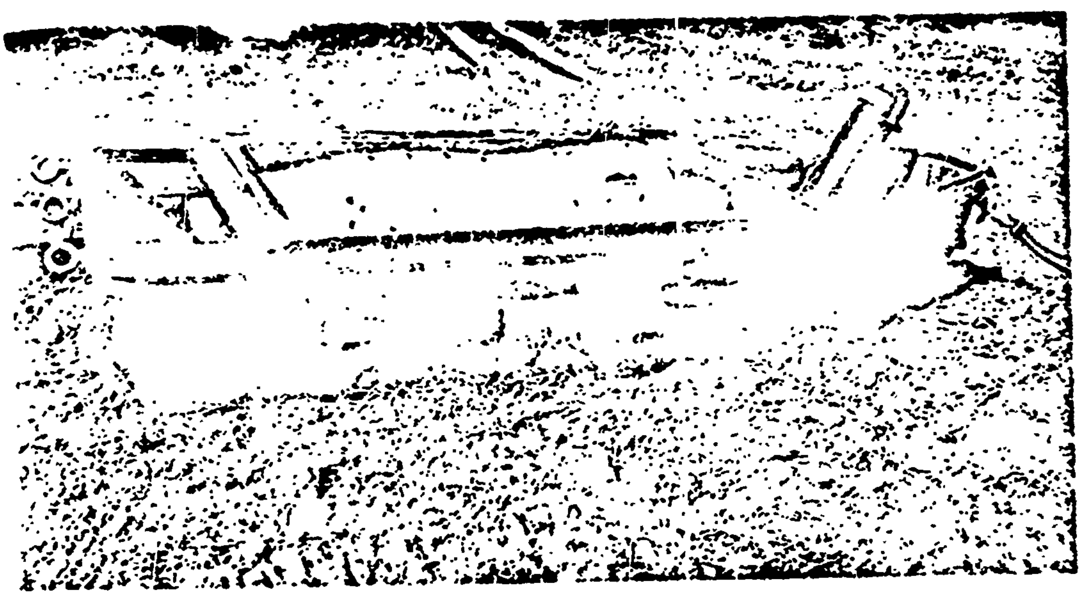

Fig. 17c. M173 rocket-projected line charge.

Assume first that the breaching organization consists of 8 men as per Table II plus a tank and its crew of 4, and that 5 kits are required and prepared concurrently in 1.0 hour:

Preparation time = 1.0 hour
Preparation labor = 1 (8 + 4) = 12 manhours.

Assume next that each kit requires 0.25 hour to position and fire:

Position and fire time = 5 x 0.25 = 1.25 hours
Position and fire labor = 1.25 (8 + 4) = 15 manhours.

Then, for the completed breaching mission:

Breaching time = 1 + 1.25 = 2.25 hours
Breaching labor = 12 + 15 = 27 manhours.

The breaching materiel cost range for Example 7 is estimated as follows:

Function	Item	Unit Price	No.	Subtotal
Position Demo Kit	M-60 Tank	$147475–217680	1	$147475–217680
Detonate Mines	M173 Demo Kit	8137– 8137	5	40675– 40675
Mark Path	Minefield Marking Kit	465– 465	1	465– 465
				$188615–258820

(8) **Example 8.**

Clear an 8-meter-wide path by means of blind neutralization utilizing the bangalore torpedo M1A1/M1A2 without previous detection and follow by detection to locate and then destroy unexploded mines in the breaching path.

This operation and the supporting assumptions are similar to Example 5 which was for a 1-meter path. For 8 meters, however, it is necessary to use the organization of Table V and Table VI and to develop and maintain a spacing of 100 meters between breaching parties. The calculations shown in Tables XIV and XV are then made by the method used in Example 2.

Table XIV. Relationship of Breach Party Bangalore Speed to Time at the Barrier, and Breach Time (Example 8)

Breach Party Speed (Meters/Sec)	Time at the Barrier (Hours)			Bangalore Time (Hours)
	Platoon 1	Platoon 2	Platoon 3	
400/18x3600=0.006	$\frac{600/.006}{3600} = 27.8$	27.8	$\frac{500/.006}{3600} = 23.1$	78.7
400/14x3600=0.008	$\frac{600/.008}{3600} = 20.8$	20.8	$\frac{500/.008}{3600} = 17.4$	59.0

Table XV. Relationship of Bangalore Time to Breach Labor (Example 8)

Breach Party Speed (Meters/Sec)	Labor to Breach (Manhours)				
	Platoon 1	Platoon 2	Platoon 3	OIC	Total
0.006	37x27.8=1030	1030	37x23.1=855	78.7	2990
0.008	37x20.8= 770	770	37x17.4=644	59.0	2240

Assume that the subsequent detect time and the detect labor range from 3.54 to 21.3 hours and 118 to 708 manhours as per Tables VIII and IX. Finally, assume that the demolition charge placement time and the demolition labor also range from 3.54 to 21.3 hours. The following totals are thus obtained:

	Time		Labor	
Bangalore Torpedo Operations	59.0	– 78.7 hours	2290	– 2290 manhours
Detection and Charge Placement Operations	1.75	– 23.7	53	354
	60.8	102.4	2349	2644

The breaching materiel cost range for Example 8 is estimated as follows:

Function	Item	Unit Price	No.	Subtotal Price
Blind Detonate	Bangalore Torpedo	$106–106	216	$22896–22896
Detect	Detector	350–1136	16	5600–18176
Mark Mines & Paths	Minefield Marking Kit	465–465	8	3720– 3720
Detonate Mines	Demo Set	197–197	1	197– 197
	Charge Demo	1– 1	160	160– 160
				$32573–45149

(9) **Summary.**

The relationships between breach time, breach labor, and breach materiel cost just calculated for 8 examples are presented in Figs. 18 and 19. A comparison of these penalties associated with breaching is presented in Table XVI.

Table XVI. Summary of Time, Labor, and Materiel Cost Ranges Directly Associated with Dismounted Breaching Operations Against a Barrier Minefield

Example	Path (meters)	Method	Time (Hours)		Labor (Manhours)		Materiel (Dollars)	
			Low	High	Low	High	Low	High
3	1	Manual Probe and Detonate	110	124	880	992	1009	2029
1	1	Detector and Detonate	0.84	5.02	6.7	40.2	1709	4301
5	1	Bangalore+Detector+Detonate	16.2	20.2	130	162	4244	5816
4	8	Manual Probe and Detonate	471	530	15,700	17,600	8072	16,232
2	8	Detector and Detonate	3.54	47.3	118	1,575	17,392	38,128
6	6	Blind Detonate w/M157 (Snake)	3	–	123	–	191,000	261,000
7	6	Blind Detonate w/M173 (Rocket)	2.25	–	27	–	188,615	258,820
8	8	Bangalore+Detector+Detonate	60.8	102	2349	2,644	32,600	45,200

To complete this brief analysis of dismounted breaching operations against a barrier minefield, time, labor, and materiel cost ratios have been calculated to illustrate the relative advantages to Blue or Red forces (Table XVII). These ratios must be interpreted with caution for only when the value system of Blue and Red is clearly established will the ratios have a tactical interpretation.

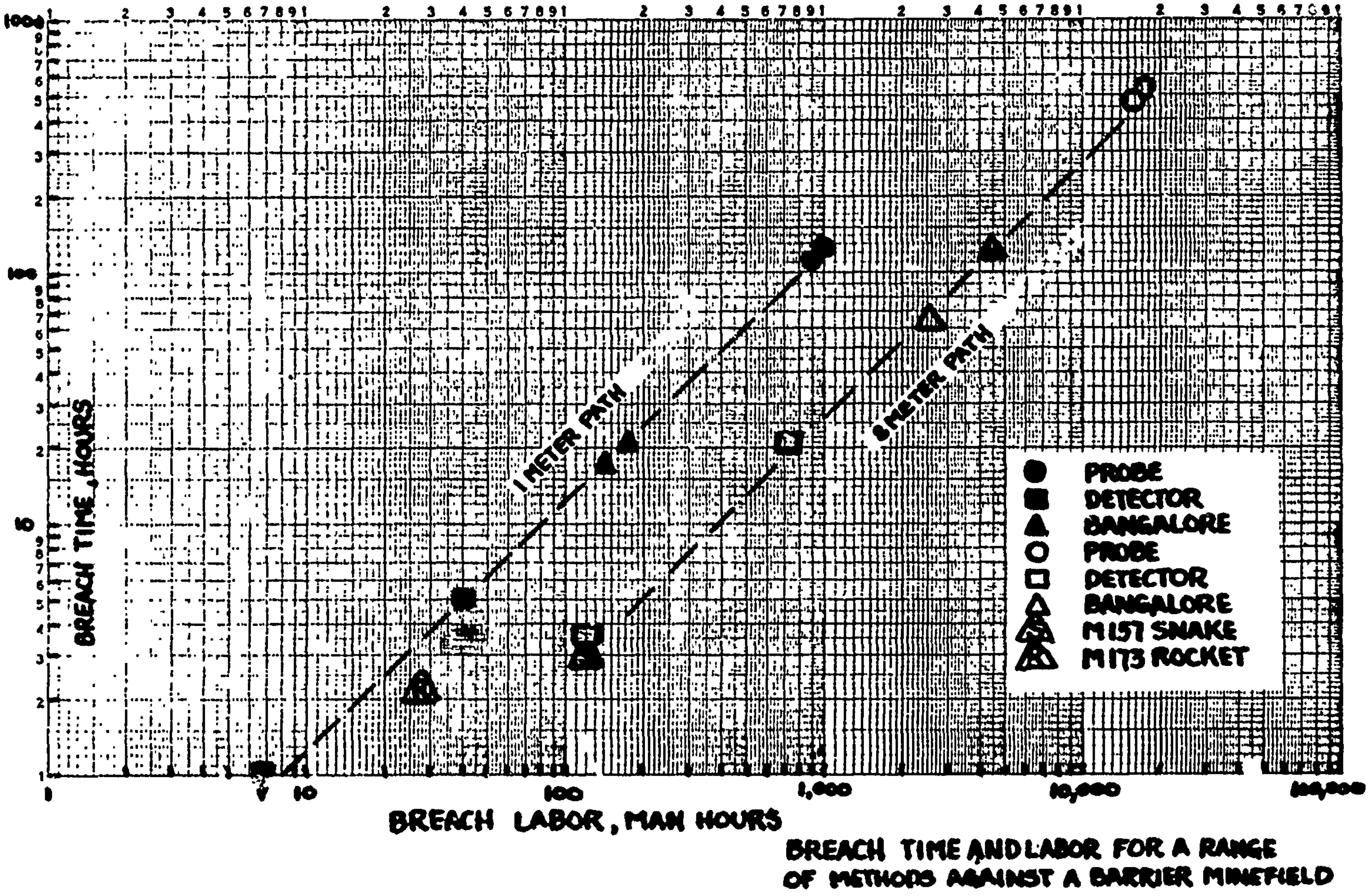

Fig. 18. Plot of breach time vs breach labor for all dismounted examples calculated.

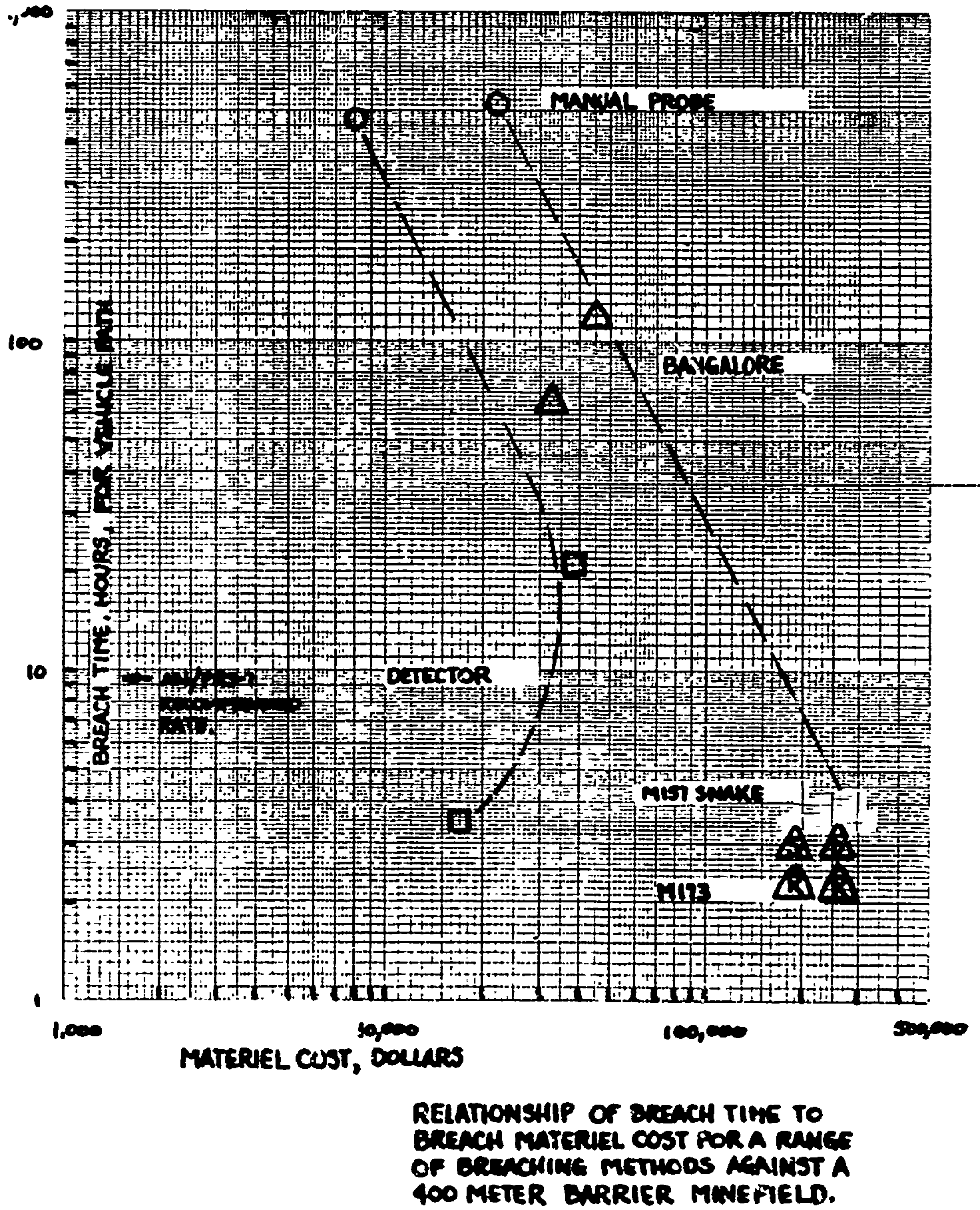

Fig. 19. Plot of breach time vs materiel cost for dismounted examples providing a vehicle lane.

Table XVII. Comparison of Breaching Cost to Barrier Cost Ratio for a Range of Breaching Methods

			Time Cost (Hr)	Labor Cost (MH)	Materiel Cost ($)
1	Detector	(1M)	0.016–0.125	0.007–0.04	0.012–0.064
2	Detector	(8M)	0.067–1.18	0.12–1.66	0.12–0.56
3	Probe	(1M)	2.07–3.10	0.93–1.00	0.007–0.03
4	Probe	(8M)	8.89–13.2	15.5–18.5	0.056–0.24
5	Bangalore	(1M)	0.31–0.51	0.14–0.17	0.029–0.086
6	M157 Snake	(6M)	0.051–0.075	0.13	1.34–3.86
7	M173 Rocket	(8M)	0.042–0.056	0.028	1.32–3.83
8	Bangalore	(8M)	1.15–2.55	2.5–2.8	0.22–0.67
	Barrier		40 – 53	950	67,600–143,000

Note: These data are plotted against breaching time in Figs. 20, 21, and 22.
See Table XXXIV for Cost Data Base.

(10) Discussion of Dismounted Breaching Operations.

To recapitulate briefly, this part of the study (Section 6a) has addressed the problem of determining gross time, labor, and materiel costs associated with breaching a defined barrier minefield with dismounted troops. These breaching operations have been conducted using a simple, uncomplicated scenario with current doctrine and using only type-classified materiel formally in the inventory as of 1 September 1971. No attempt has been made to utilize all of the materiel that might be suitable or to consider field expedients that might be highly effective. The selection of materiel and methods has been arbitrary. but the selection has been made with the objective of bracketing a large body of complex operations. Thus, it has been possible to make some helpful general observations about countermine warfare and its associated costs.

For example, Fig. 10 presents a log-log plot of breach party advance rate in meters per second against breach time in hours for a 1-meter path through the defined barrier minefield. This operation is conducted by a prescribed 8-man breaching party using an AN/PRS-7 mine detector and destruction-in-place of mines by use of small demolition charges. Also positioned on the figure are a range of times assumed necessary for the placement and priming of demolition charges and the recommended AN/PRS-7 sweep rate. This figure illustrates the fact that the time required to breach the barrier is highly sensitive to the *rate of the slowest operation*. In this particular case, the detector can complete its mission in about 2.2 hours; but, when 30 minutes

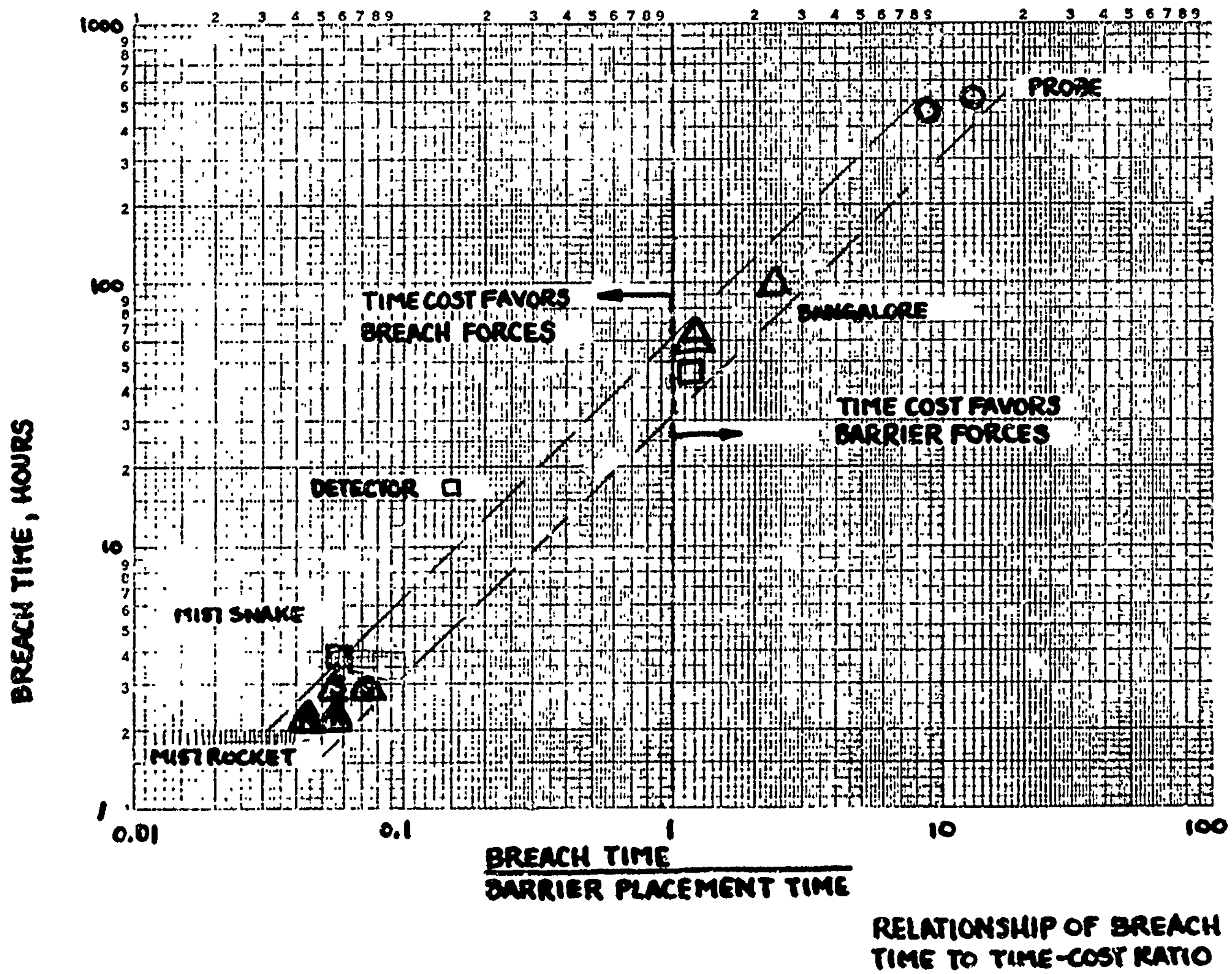

Fig. 20. Plot of breach time vs breach to barrier time ratio.

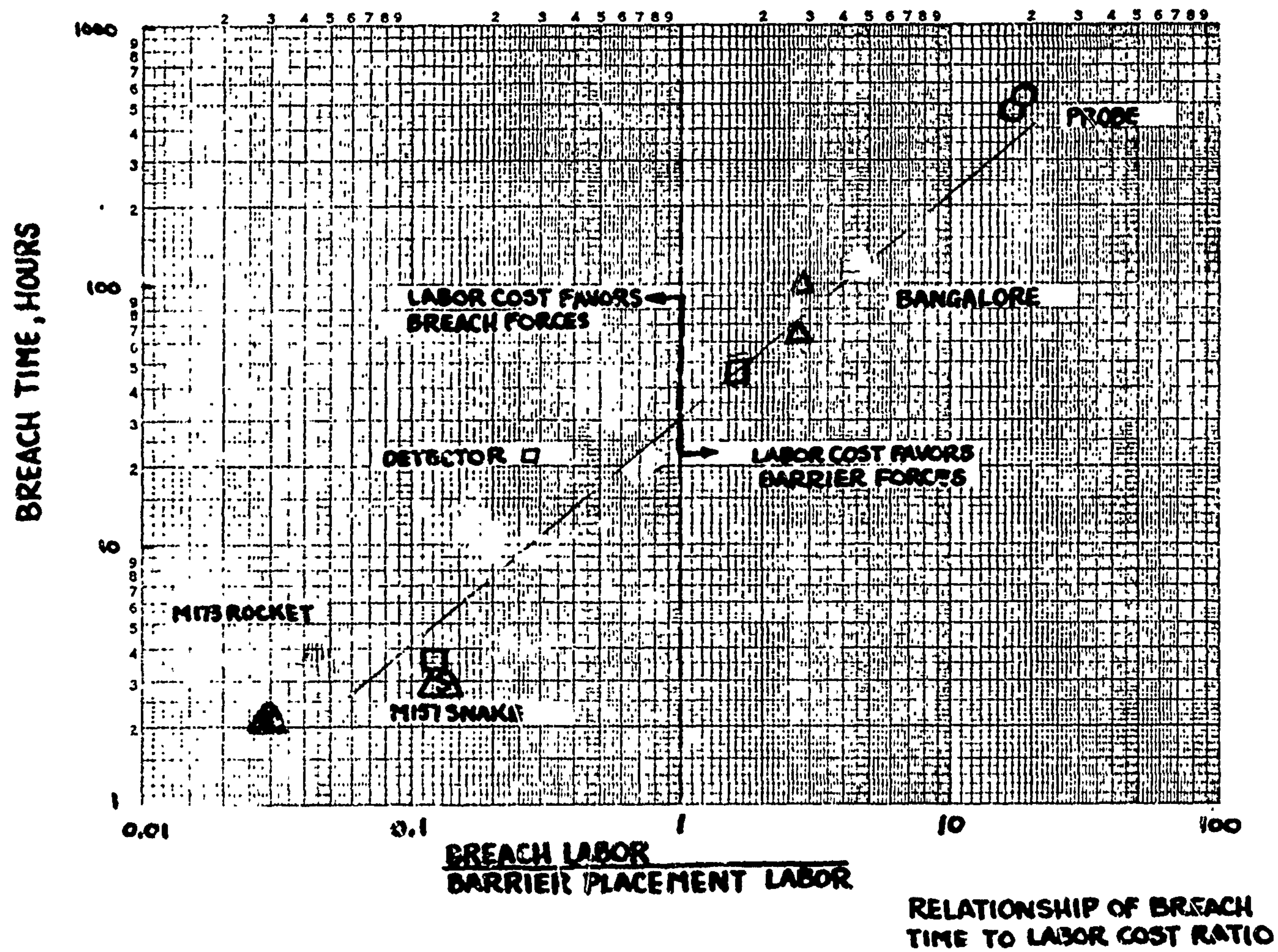

Fig. 21. Plot of breach time vs breach to barrier labor ratio.

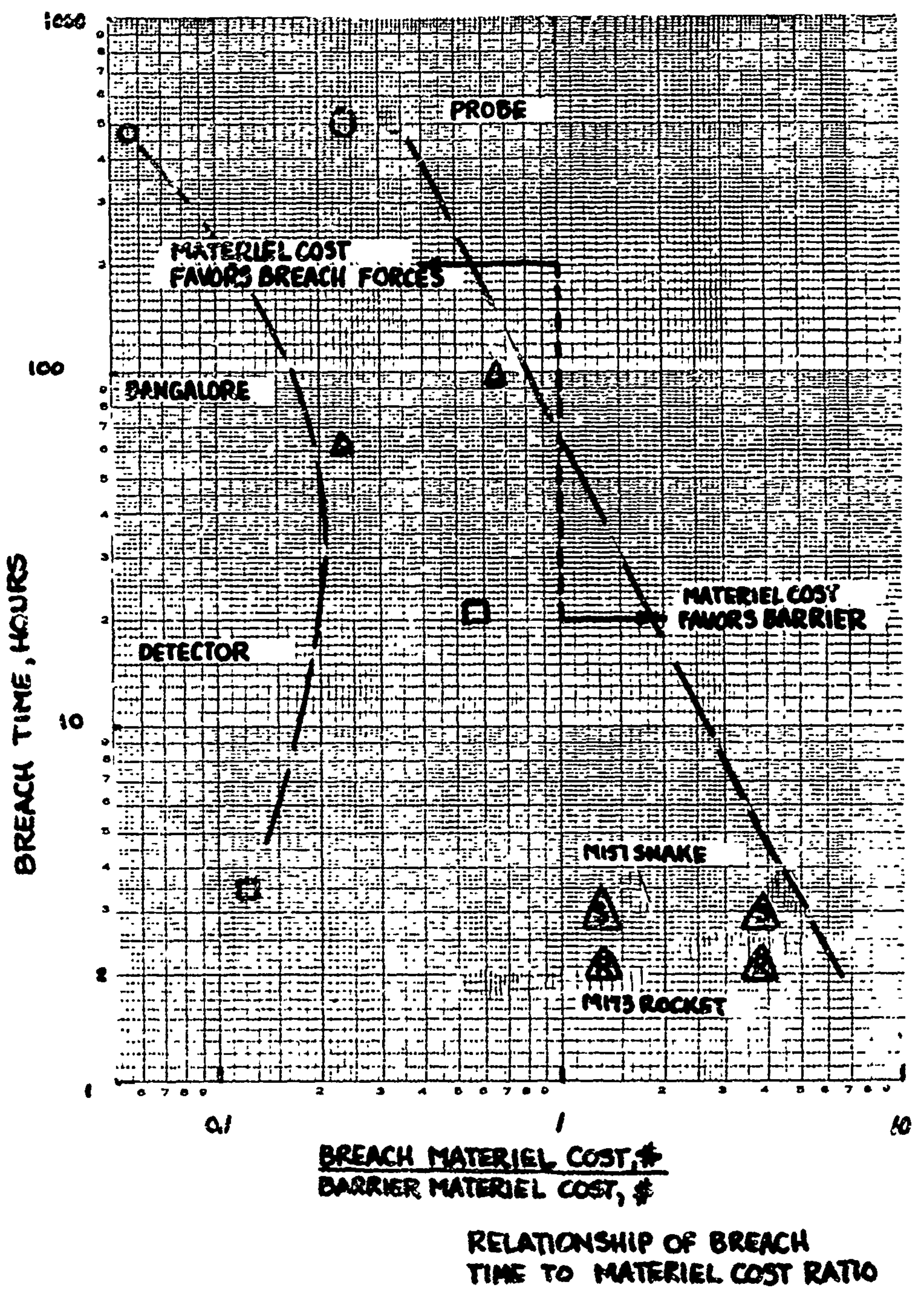

Fig. 22. Plot of breach time vs breach to barrier materiel cost ratio.

is required for placement and priming of each demolition charge, the complete breach mission will require 5 hours.

In Fig. 11, breach time in hours is plotted against breach labor in manhours for the same range of breach party advance rates. The impact of charge placement and priming time upon total breaching labor is again illustrated.

For Fig. 13, a log-log plot of breach party advance rate in meters per hour against the time in hours required to breach is presented for an 8-meter path through the minefield. In this case, 8 breaching parties are utilized and a spacing of 100 meters is maintained between each party. Breach time using the AN/PRS-7 detector advance rate has now gone up to 10 hours. The increase in breach labor is illustrated in Fig. 14.

Breaching time and breaching labor relationships are summarized in Fig. 18 for a range of breaching materiels and breaching methods. On initial inspection, it is somewhat surprising that the log-log relationship for both the 1-meter lane and the 8-meter lane breach times are not only linear with breach labor but also parallel to each other This is of particular interest when the wide diversity of breaching materiel and methods is considered. On inspection, however, it is evident that the 1-meter path has an intercept value of about 8 manhours at 1 hour. This relationship originates with the 8-man breaching party that has the 1-lane missions. Correspondingly, for the 8-lane breach mission, the 1-hour intercept has a value of approximately 37 manhours; and this originates from the 37-man breaching platoon used in the calculations.

A significant exception to these general relationships occurs when the M173 demolition kit projected charge (rocket) is employed. Here, the small amount of preparation and charge placement time provides disproportionately large savings in breach time and breach labor.

Figures 20, 21, and 22 present log-log plots of breaching time against the ratio of breaching cost to barrier cost. In Fig. 20, time cost in hours is considered. As expected, the projected charges, M157 and M175, are highly effective on a time-cost ratio basis. It is intuitively obvious that casualties and casualty rate will increase in a non-linear fashion with respect to breaching operations time and breaching operations labor. The exact relationship would be highly dependent upon a large number of details covered by a specific breaching scenario. Generalizations relative to casualties must therefore be treated carefully and in a specific tactical mission context. Generalizations relative to casualties are nevertheless useful in comparing systems. For example, it is stated that casualties to covering fire double when a force is delayed 5 minutes and are multiplied by a factor of 12 for a 1-hour delay.[30] The use of time as *one* measure of countermine system effectiveness is thus supported.

Time ratio, i.e., time to breach/time to emplace barrier is, however, another matter entirely because the tactical outcome of a given encounter will be determined by a complex interaction of Blue to Red resources ratio. About the best generalization here is that low ratios of time, labor, materiel, and casualties favor Blue. Figure 22, for example, presents breach time against the ratio of breach materiel cost to barrier materiel cost. The projected charges, M157 and M175, in this instance are not materiel cost effective to the breach force; but, with their associated short exposure time of personnel, casualties would be low (see Appendix A).

In addition to the costs of time, labor, materiel dollars, and casualties associated with minefield breaching operations, there is also a cost of energy expended which arises from the use of explosives and motor fuels. This energy cost carries with it a logistics burden because the energy source requires transportation and storage system elements. Further, the minefield itself depends upon chemical energy for its functions so that an examination of Blue countermine and Red mine energy relationships may provide some additional insight and perspective.

Table XVIII presents the energy content of three U. S. mines.

Table XVIII. Energy Content of Three U. S. Mines

Mine	Type	Charge	Charge Wt (lb)	Btu/lb	Btu/mine
M15	AT	Comp B	22	2050	45,100
M16	AP, Frag	TNT	1.0	2100	2,100
M14	AP, Blast	Tetryl	0.06	1800	108

Table XIX presents the energy content and energy density of three U. S. minefields.

50. "Family of Scatterable Mines," Phase II Report, Vol 1, 70826, ACN 17852, CDC Engineering Agency, 1 Feb 72.

Table XIX. Energy Content and Energy Density of Three Standard U. S. Minefields

	Mine	Density	Mines/100M	Mines/406M	Btu	Total Btu	Btu/M	AT Energy (%)
1.	M15	1	164	666	30.040,000			
	M16	1	164	666	1,399,000			
	M14	1	164	666	71,930			
						31,511,000	259	95
2.	M15	1	164	666	30,040,000			
	M16	4	623	2330	5,313,000			
	M14	8	1213	4925	531,900			
						35,885,000	195	84
3.	M15	3	459	1864	84,066,000			
	M16	4	623	2530	5,313,000			
	M14	8	1213	4925	531,900			
						89,911,000	738	93

Then, to examine the breaching energy requirements, Table XX presents selected explosive components and their energy content.

Table XX. Energy Content of U. S. Countermine Materiel

Component	Charge Wt (lb)	Btu/lb	Btu
Charge Demo	1	2100	2,100
Bangalore M1A1/M1A2	9	2050	18,450
M157 (Snake)	3200	2050	6,560,000
M173 (Rocket)	1720	2050	3,526,000

These values are then used to calculate the breaching energy associated with the examples of breaching described earlier in this section (Table XXI).

The data from Table XXI are then combined with data from Table XVI, and the relationships of energy expended in breaching to breaching time for a 6- to 8-meter vehicular path are shown in Fig. 23. Also shown are the energy densities of three minefields as calculated in Table XIX and the breach time of 9.5 hours which corresponds to the recommended rate for the AN/PRS-7 mine detector.

Then, assuming that breaching labor in manhours at the minefield site is of interest due to its probable direct relationship to potential breaching casualties, the breach energy versus breach labor relationships is presented in Fig. 24. Again, as in the previous figure, the breach labor for using the AN/PRS-7 detector at its recommended rate is shown for reference and orientation.

The last two figures appear to demonstrate that an exponential relationship exists between breaching energy expended and both breach time and breach labor. Although the relationship may be intuitively obvious, this exploratory quantitative study of energy in mine-countermine systems begins to come to grips with some of the more fundamental aspects of mine warfare. For example, a rough extrapolation on Fig. 22 concludes that a 400-meter minefield of 1-4-8 density may be breached with existing technology in 1 hour if 90,000 Btu/meter^2 can be delivered to the breach path. Then, extrapolating from Fig. 24, breach labor can approach 10 manhours or less by the same 90,000 Btu/meter^2 of applied energy. This 90,000 Btu is equivalent to roughly 90,000/2000=45 pounds of detonating explosive or 90,000/18,000=5 pounds of a hydrocarbon fuel utilizing atmospheric oxygen for its combustion. Thus, with the above guidelines, a 400- x 8-meter breach path can be accomplished with 400 x 8 x 45 = 144,000 pounds of detonating explosive or 400 x 8 x 5 = 16,000 pounds of hydrocarbon fuel.

Table XXI. Energy Density of Breaching Examples

Example	Component	Btu (ea)	No.	Btu Total	Area Breached. M²	Btu/M²
1	Charge Demo	2,100	20	42,000	400	105
2	" "	2,100	160	336,000	3200	105
3	" "	2,100	20	42,000	400	105
4	" "	2,100	160	336,000	3200	105
5	Bangalore	18,450	27	498,150		
	Charge Demo	2,100	20	42,000		
				540,000	400	1,350
6	M157 Snake	6,560,000	4	26,240,000		
	Tank Fuel	18,000[a]	–	4,680,000[b]		
				31,000,000	2400	12,883
7	M173 Rocket	3,526,000	5	17,630,000		
	Tank Fuel	18,000[a]	–	2,340,000[c]		
				19,970,000	2400	8,320
8	Bangalore	18,450	216	3,985,000		
	Charge Demo	2,100	160	336,000		
				4,321,200	3200	1,350

(a) Btu/lb.
(b) 2 Hours at 20 GPH = 2x20x6.5x18000 = 4,680,000 BTU (M-60).
(c) 1 Hour at 20 GPH = 2x20x6.5x18000 = 2,340,000 BTU.

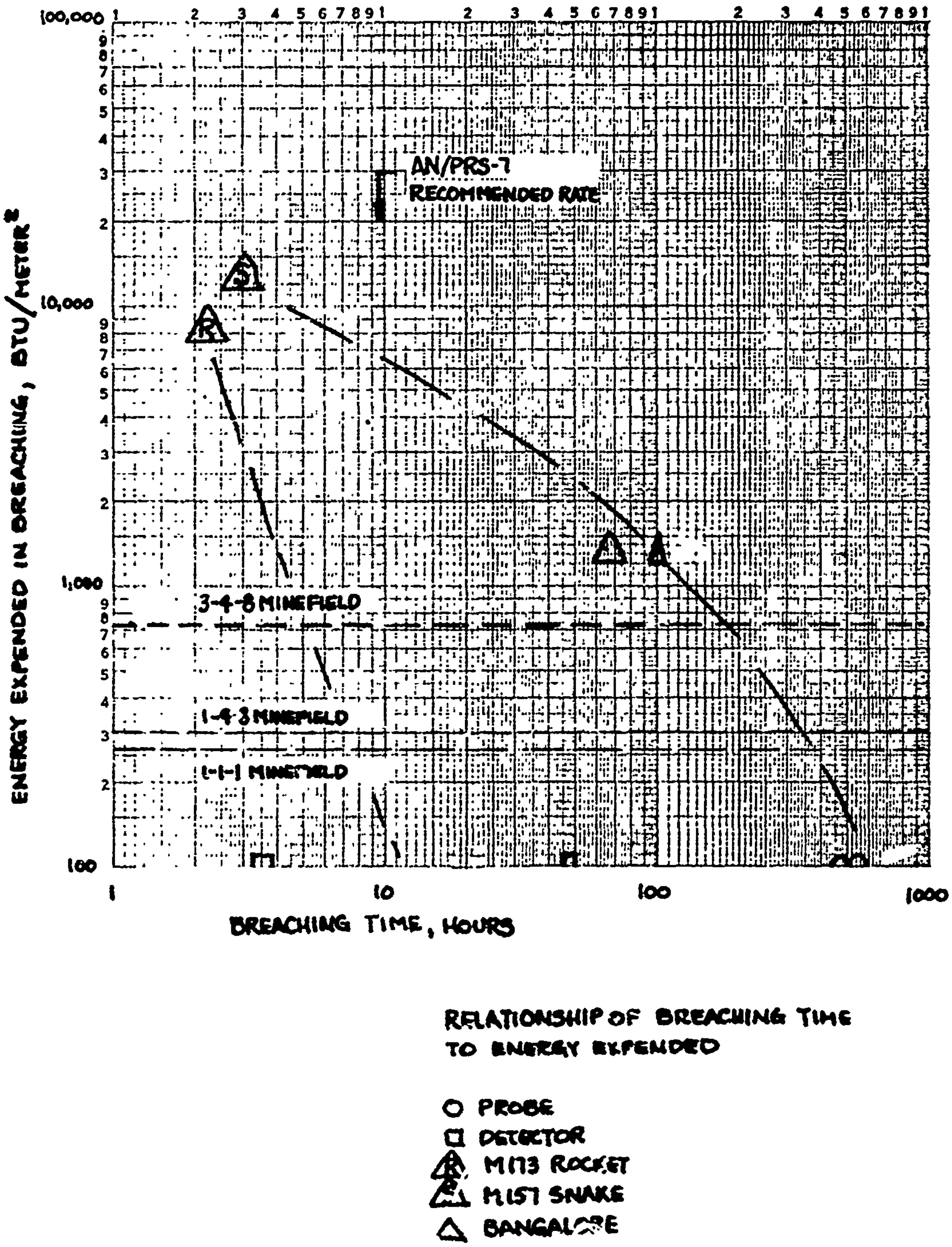

Fig. 23. Plot of breach energy vs breach time.

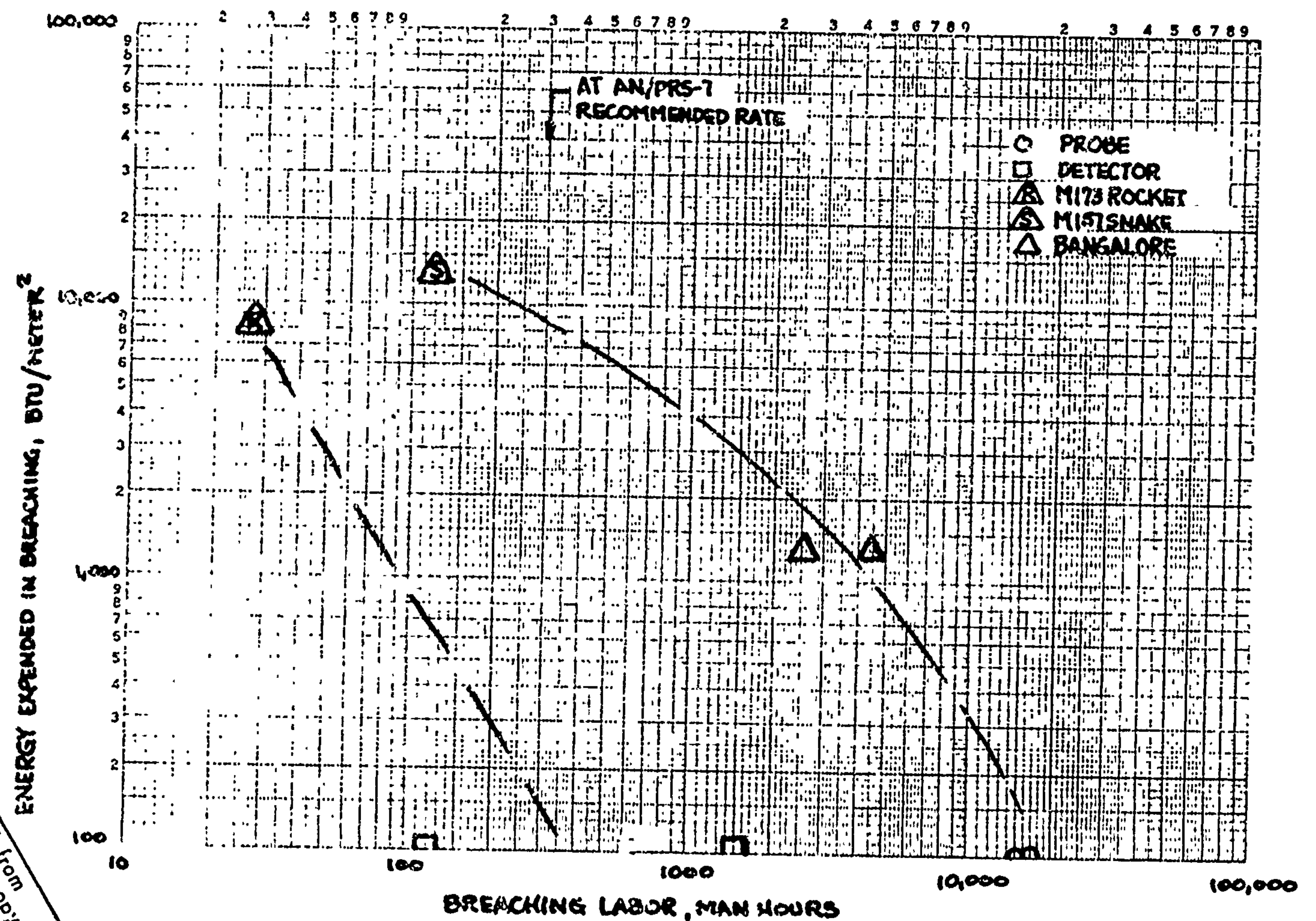

Fig. 24. Plot of breach energy vs breach labor.

Because this report is directed to the preparation of a system description for use as a standard of comparison with alternative conceptual approaches, it is not appropriate to go further into the matter of conceptual mine-countermine energy relationships at this time. The rough interpretative calculations presented in the preceding paragraph are intended only to demonstrate the potential utility of energy source, energy density, energy rate, and energy logistics considerations and analysis.

(11) Integrated Logistics Support (ILS)

Only that part of ILS dealing with weight and volume of equipment is considered in this phase of the study in order to compare, in a general way, the degree of logistical burden imposed by various countermine breaching techniques. There has been no attempt made, at this point, to apportion or determine use factors for use items as tanks (required to position "snakes," for example). All required equipment must be shipped from Conus to the theater of operations as well as transported or moved to the minefield site. Tables B-V and B-VI in Appendix B list the dimensions and weights of countermine equipment and armored vehicles discussed. Most of the dimensions, weights, and cubes for those tables were taken from TB 55-46-2.[31] Those figures in parentheses in Table B-V were gathered from applicable technical manuals.

The total weights and total volumes of necessary equipment for each of the eight examples described in Section 6a are shown in Tables XXII, XXIII, and XXIV. Where possible, a range of weights and volumes is given. These data are plotted in Figs. 25 and 26 against breach time.

Depending on the equipment required, the total weight of the necessary items, in the eight examples discussed, can range from a low of slightly less than 1,000 pounds to a high of nearly 142,000 pounds. Even in the cases which do not require the use of a tank to position equipment, the total weight (Example 8) may be as high as 23 tons with a volume requirement of over 1,000 cu ft.

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31. "Standard Characteristics (Dimensions, Weight, and Cube) for Transportability of Military Vehicles and Equipment," TB 55-46-2, Department of the Army, June 1971.

Table XXII. Logistics: Weight and Volume of Breaching Materiel (Examples 1 and 2)

Equipment	No.		Lb Total Wt	Cu Ft Total Vol
Example 1				
Flamethrower	1		87	8.8
Mine Detector	2		42–66	3.4–4.0
Minefield Mk. Kit	1		854	26.3
Demo Set	1		6–42	0.3–5.1
Charge Demo	20		20–25	0.2
		Total	1009–1074	39.0–44.4
Example 2				
Flamethrower	8		696	70.4
Mine Detector	16		336–528	27.2–32.0
Minefield Mk. Kit	16		13664	420.8
Demo Set	8		48–336	2.4–40.8
Charge Demo	160		160–200	1.6
		Total	14904–15424	522.4–565.6

Table XXIII. Logistics: Weight and Volume of Breaching Materiel
(Examples 3, 4, and 5)

Equipment	No.		Lb Total Wt	Cu Ft Total Vol
Example 3				
Flamethrower	1		87	8.8
Minefield Mk. Kit	1		854	26.3
Demo Set	1		6–42	0.3–5.1
Charge Demo	20		20–25	0.2
		Total	967–1,008	35.6–40.4
Example 4				
Flamethrower	8		696	70.4
Minefield Mk. Kit	8		6,832	210.4
Demo Set	8		48–336	2.4–40.8
Charge Demo	160		160–200	1.6
		Total	7,736–8,064	284.8–323.2
Example 5				
Bangalore Torpedo	27		4,752	94.5
Detector	2		42–66	3.4–4.0
Minefield Mk. Kit	1		854	26.3
Demo Set	1		6–42	0.3–5.1
Charge Demo	20		20–25	0.2
		Total	5,674–5,739	124.7–130.1

Table XXIV. Logistics: Weight and Volume of Breaching Materiel
(Examples 6, 7, and 8)

Equipment	No.	Lb Total Wt	Cu Ft Total Vol
Example 6			
M60 Tank	1	93,000–97,000	3,330.7–3,472.1
M157 Snake	4	44,000	933.2
Minefield Mk. Kit	1	854	26.3
	Total	137,854–141,854	4,290.2–4,431.6
Example 7			
M60 Tank	1	93,000–97,000	3,330.7–3,472.1
M173 Demo Kit	5	15,500	569.0
Minefield Mk. Kit	1	854	26.3
	Total	109,354–113,354	3,926.0–4,067.4
Example 8			
Bangalore Torpedo	216	38,016	756.0
Mine Detector	16	336–528	27.2–32.0
Minefield Mk. Kit	8	6,832	210.4
Demo Set	1	6–42	0.3–5.1
Charge Demo	160	160–200	1.6
	Total	45,350–45,618	995.5–1,005.1

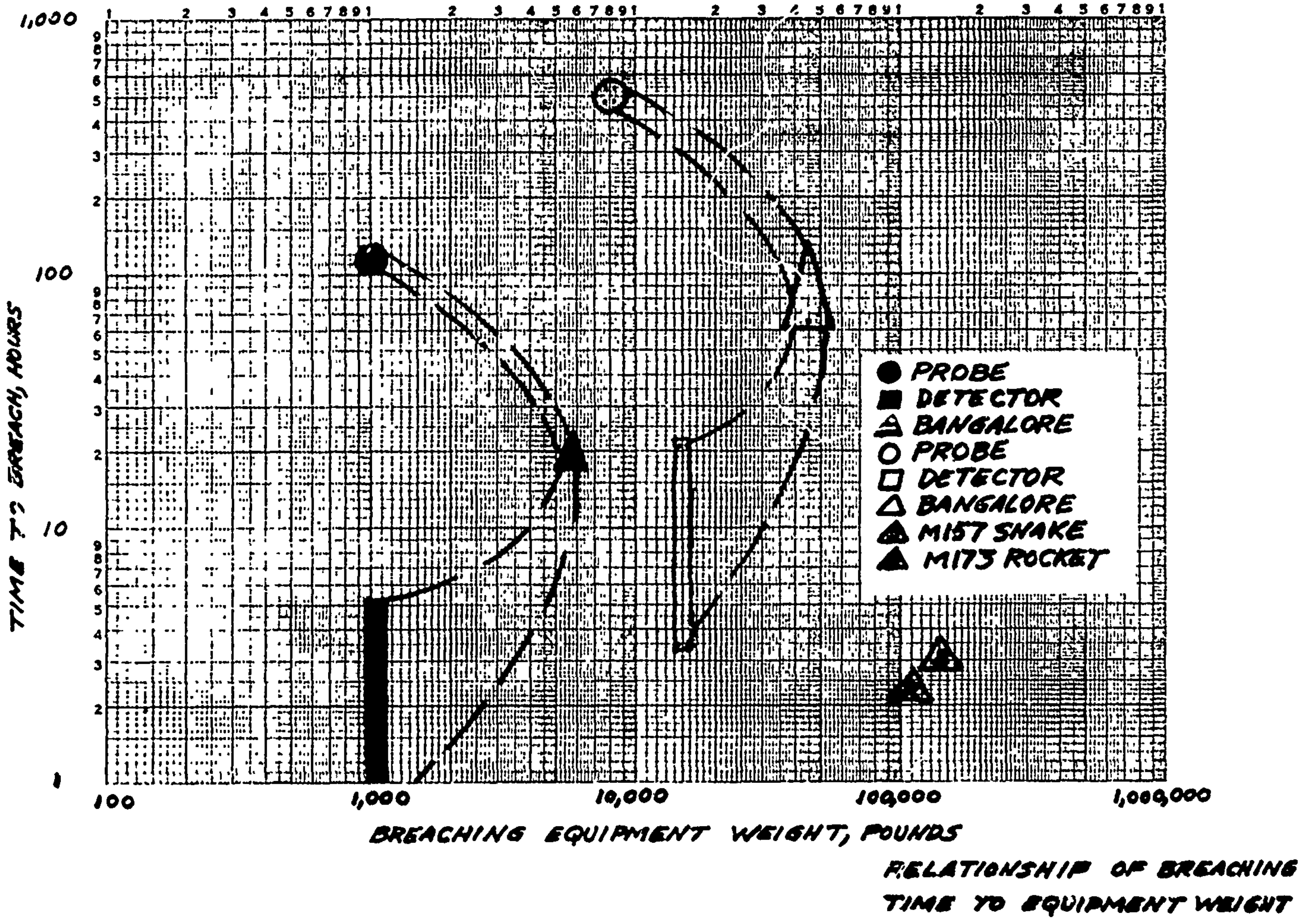

Fig. 25. Plot of breach time vs breach materiel weight.

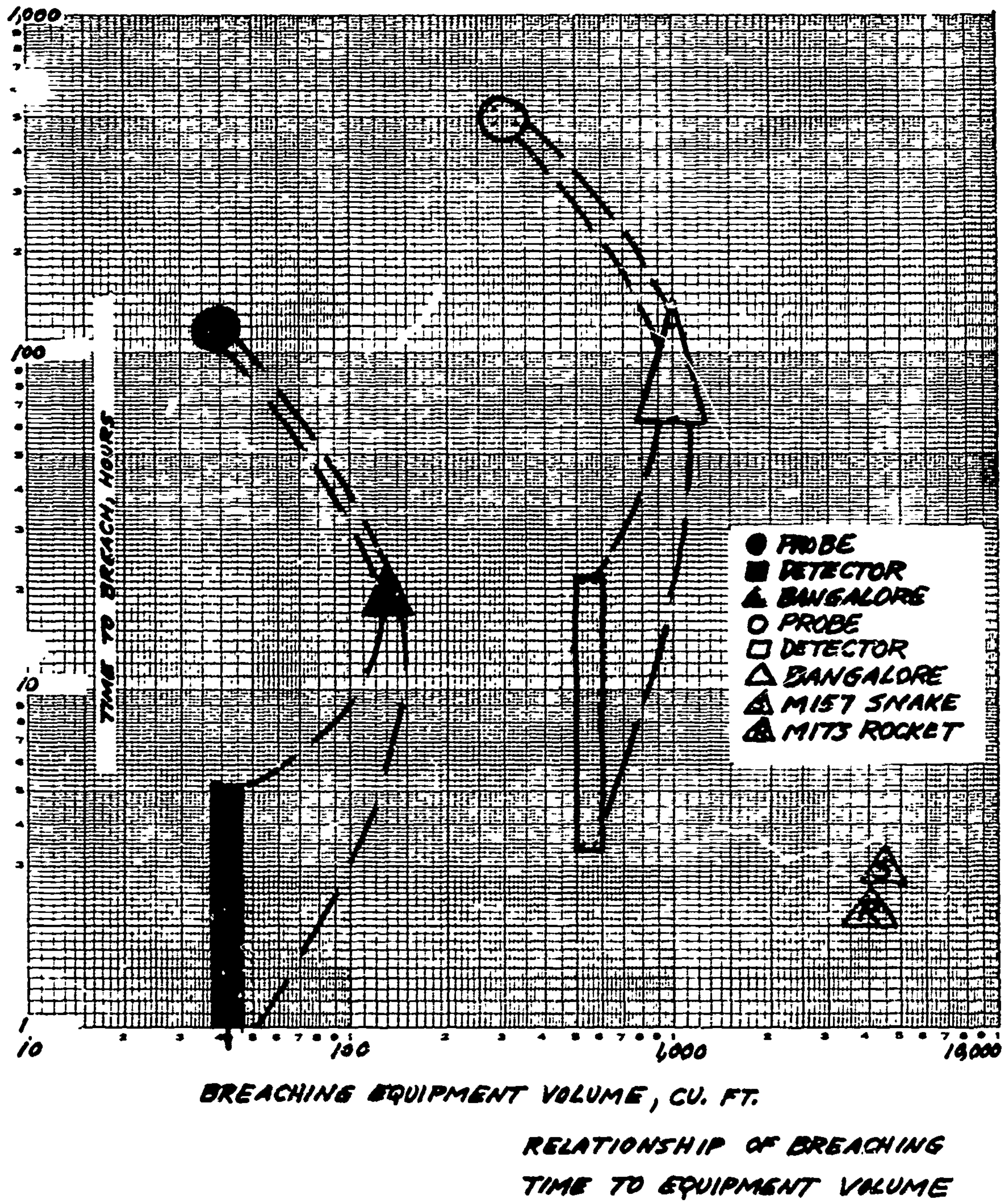

Fig. 26. Plot of breach time vs breach materiel volume.

b. Armored Vehicle Breaching Operations and Associated Time, Labor, and Materiel Costs.

Armored breachings, for purposes of this study, are breaching techniques in which no attempt has been made at route preparation before the vehicle enters the minefield. These techniques, referred to as bulling,[32] are primarily oriented toward situations and tactical operations where time saving is essential and personnel exposure is to be minimized. Two bulling techniques are evaluated. The first technique makes no attempt to recover immobilized vehicles but subsequent vehicles simply go around and leave the vehicles in the minefield until the breaching operation is completed. The second technique is aimed at minimizing losses during bulling by removing immobilized vehicles from the safe path before proceeding. These techniques were evaluated by conducting models of vehicles through the same model minefield used earlier in this study.

The model minefield used in this report, a 1-4-8 density deliberate-barrier type, has been described earlier. Three types of armored vehicles were considered: the M60 full-tracked combat tank (2350-678-5773);[33] the M551 armored reconnaissance/airborne assault vehicle, full-tracked (2350-873-5408);[34] and the M113 full-tracked armored personnel carrier (2320-629-1294).[35]

Twelve straight-line paths of advance through the model minefield were randomly selected for each of the three vehicle types. Clear plastic scale models, with marked track widths, were run through the minefields with the right side of the vehicle parallel to and touching the path line. Whenever a vehicle tread contacted an anti-tank mine location, a hit was recorded; and a scale-model vehicle outline was taped in place and numbered. When the breach was considered without vehicle removal, the next vehicle followed in the tracks of the previous one until it was one vehicle length behind the hit vehicle. A turn to the right or left was determined by a random change device, and the active vehicle was run alongside the immobilized vehicle and turned back to the original path. If the second vehicle also struck a mine in the same strip, the same procedure was again followed including the use of the random device to determine right or left (Figs. 27, 28, 29, and 30).

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[32] W. G. Comeyne, "Antitank Effectiveness of the U. S. Army Standard Minefield Pattern," USAMERDC Report 1979, April 1970.

[33] "Tank, Combat, Full Tracked: 105-MM Gun, M60 w/c (2350-678-5773)," TM 9-2350-215-10, Department of the Army, February 1965.

[34] "Armored Reconnaissance/Airborne Assault Vehicle," Department of the Army, February 1965.

[35] "Carrier, Personnel, Full Tracked: Armored, M113 (2320-629 1294)," TM 9-2300-224-10, Department of the Army, November 1961.

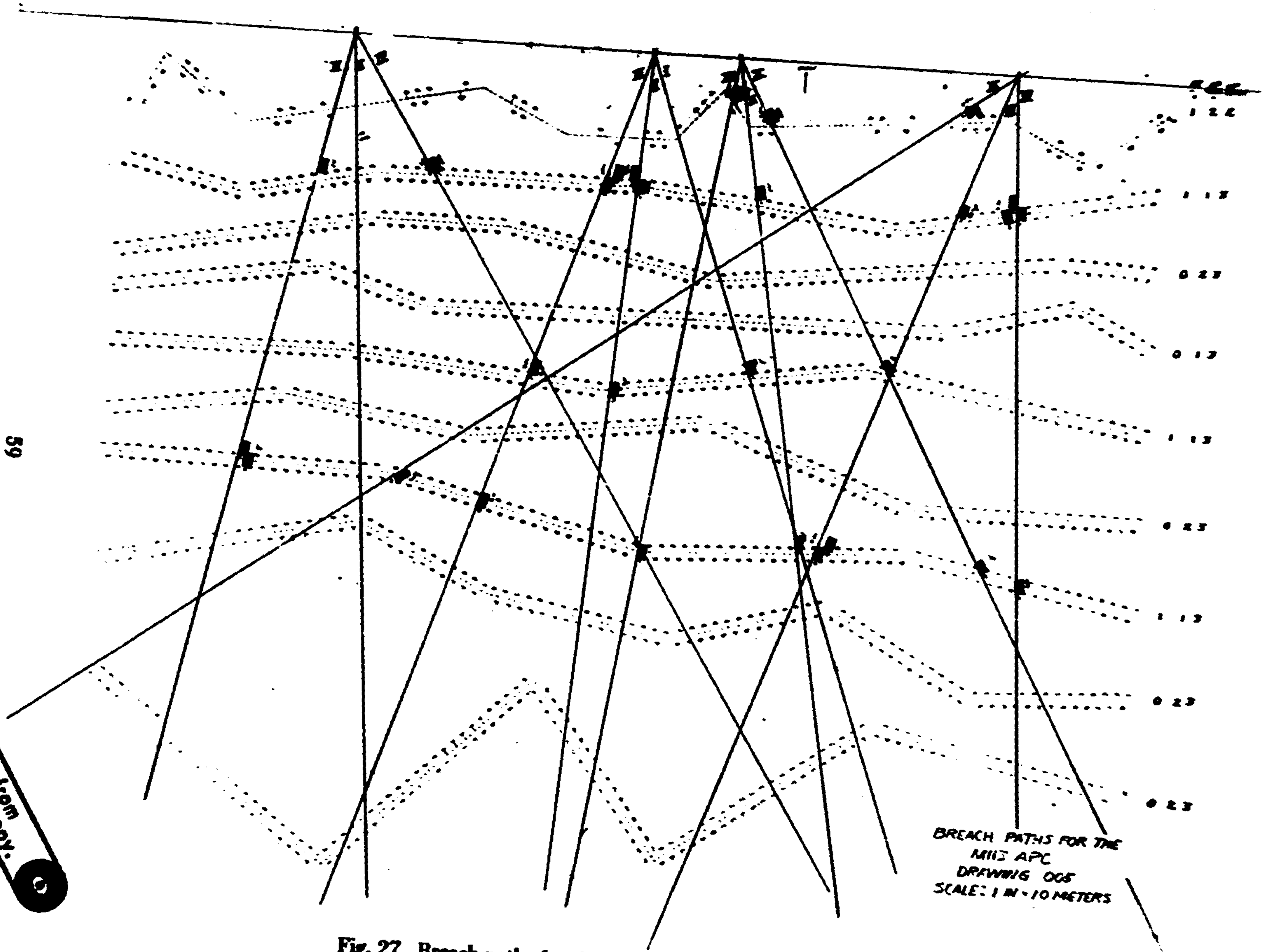

Fig. 27. Breach paths for the M113 full-tracked armored personnel carrier.

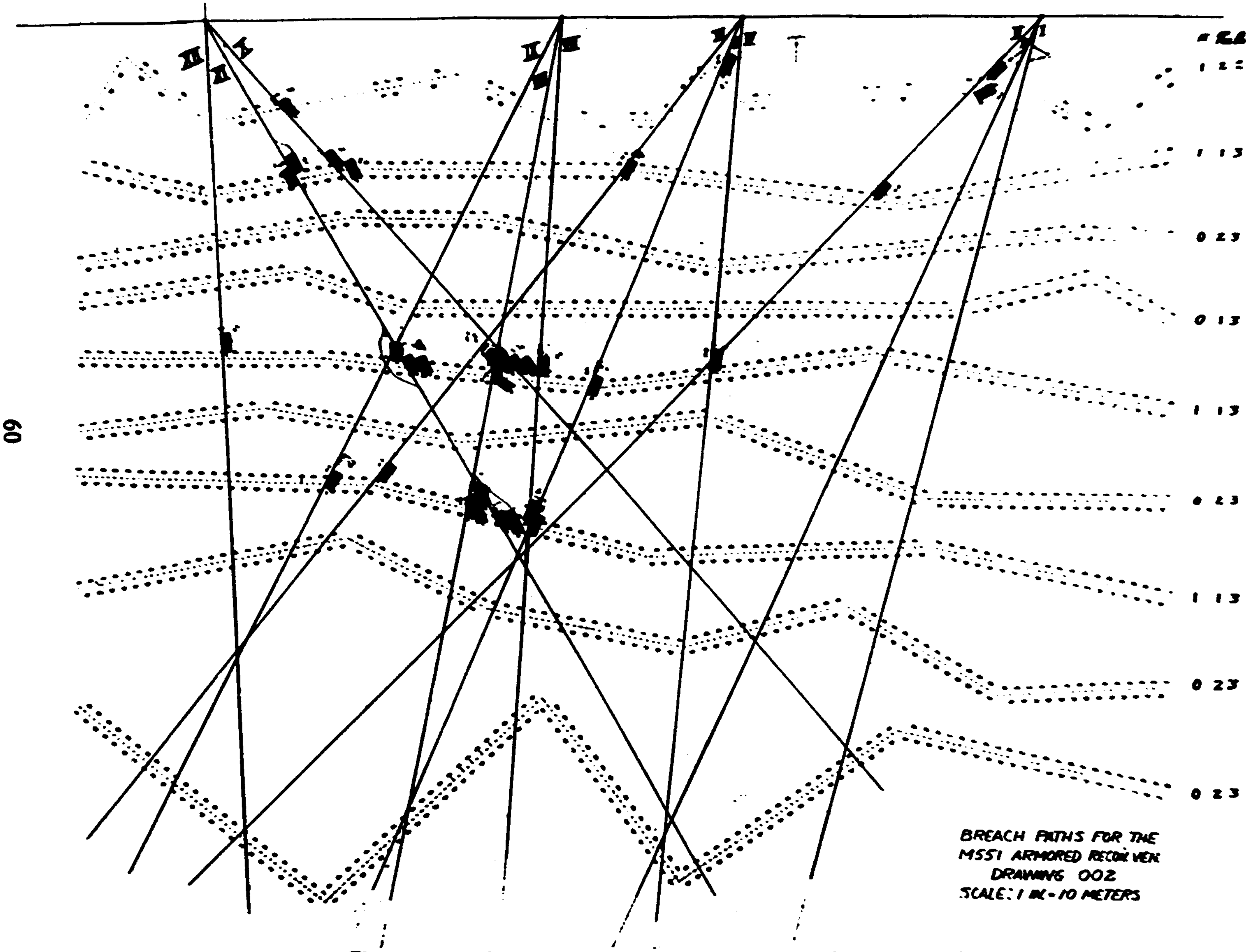

Fig. 28. Breach paths for the M551 armored recon/AB assault vehicle.

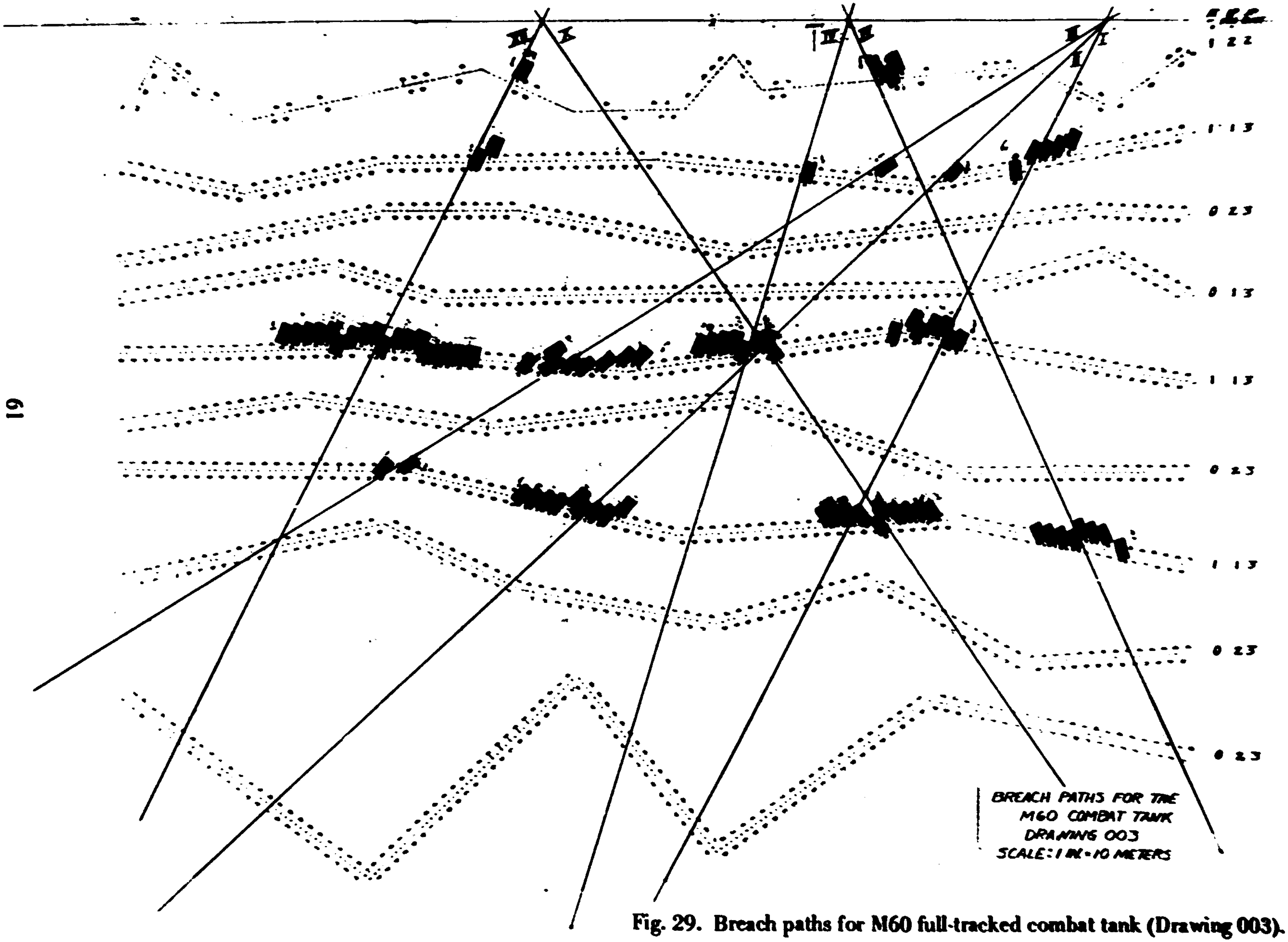

Fig. 29. Breach paths for M60 full-tracked combat tank (Drawing 003).

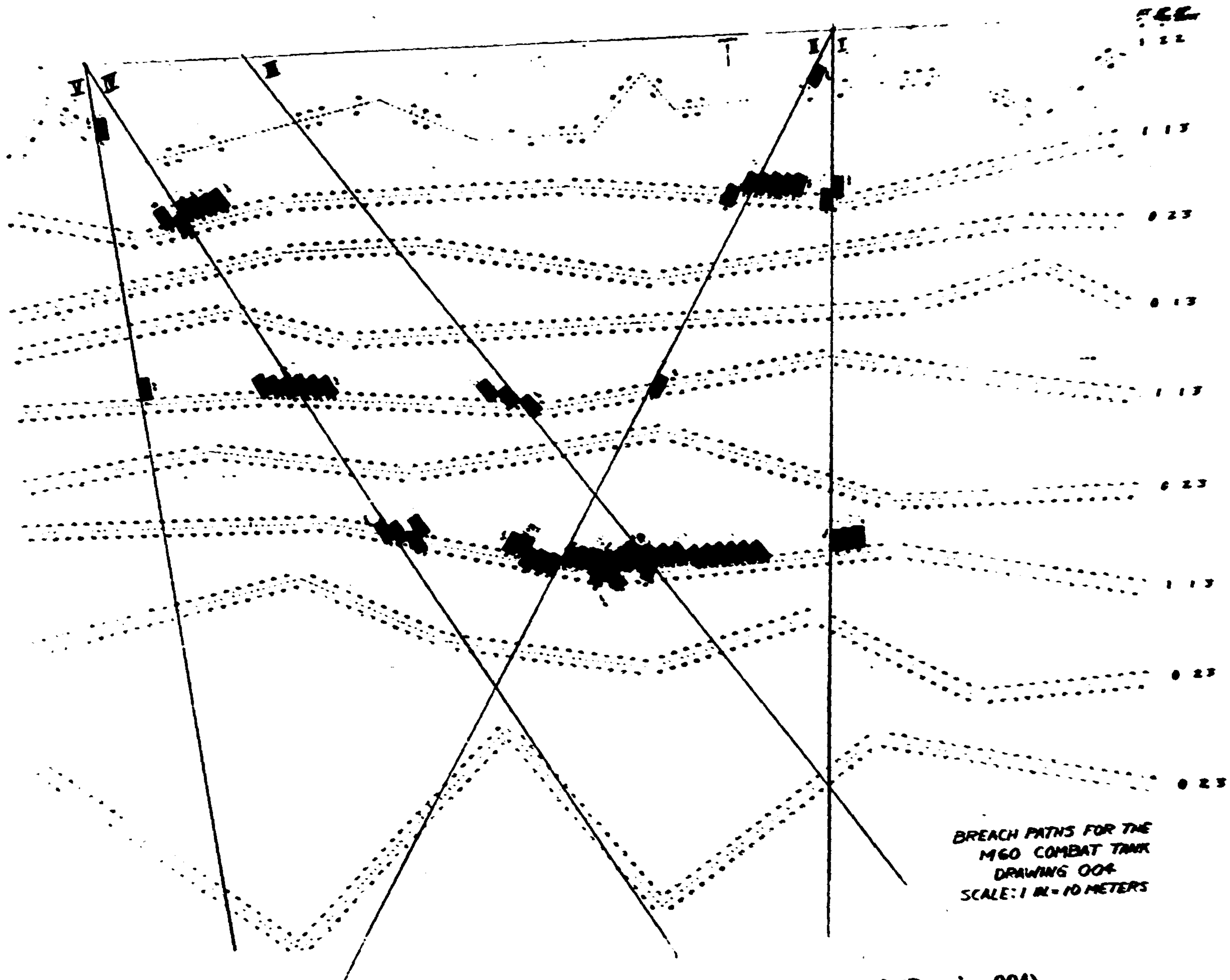

Fig. 30. Breach paths for M60 full-tracked combat tank (Drawing 004).

Another major consideration was the difference in vehicle losses that might occur if each immobilized vehicle was removed from the path before the next vehicle passed that spot. The same vehicles and paths were used, but it was not necessary to go around immobilized vehicles; and the mine that hit a vehicle was, of course, considered neutralized. In both this case and the previous one, all anti-tank mines were assumed 100% effective, i.e., no duds, etc. It was also assumed that no vehicle damage would be incurred from anti-personnel mines.

The same range of vehicle speeds traversing the minefield was used for all three types of vehicles. The slowest speed was 5 miles per hour and the fastest, 25 miles per hour. Where vehicle removal was a consideration, a range of hook-up times was employed. The fast time was 5 minutes and the slow time, 30 minutes. In both cases, the vehicle was pulled out of the field at 5 miles per hour. In order to insure a wide range of time, the slow hook-up time was used with slow traverse and the fast hook-up, with the fast traverse.

Figures 27, 28, 29, and 30 show the paths of advance and the location of immobilized M60, M551, and M113 vehicles. Corresponding losses are shown in Tables XXV, XXVI, and XXVII.

All three types of vehicles studied suffered fewer losses with vehicle removal than without vehicle removal. The M60 showed the greatest vehicle savings. The average traverse time of the minefield rose approximately one order of magnitude for all three types of vehicles when vehicle removal was used. The human casualty rate, because of increased time in the minefield and because of exposure during vehicle hook-up, would undoubtedly go up with removal.

At this time, insufficient data exist to show the exact relationship of track width and track separation to hits taken in traversing a minefield. The present gross model is not sufficiently sensitive to allow a parametric study of the relationship between track geometry and hit probability. In later parts of this study, an effort will be made to construct computer models of minefields, mobility vehicles, and the interaction of the vehicles with the minefields. Parametric studies of the vulnerability of both the vehicles and the minefields will be made.

Figure 31 shows traverse time vs vehicle speed for all three types of vehicles with and without vehicle removal. Since only two points were available for each curve, the straight-line (Log-Log) representatives of the relationships may or may not be valid. The same observation also applies to Fig. 32 which shows a vehicle-removal relationship. This figure indicates by the rather drastic difference in slope of the M60 curve and the other two curves that vehicle removal may be of considerably greater interest for the M60.

Table XXV. Comparison of M113 Traverse Time and Vehicle Losses Without and With Vehicle Removal (Dwg. 005: Fig. 27)

Lane No.	Vehicle Losses		Minimum Time to Traverse (25 mph)		Maximum Time to Traverse (5 mph)	
	No. of Vehicles		Time in Hours		Time in Hours	
	W/o Removal	W/Removal	W/o Removal	W/Removal	W/o Removal	W/Removal
I	1	1	.010	.109	.053	.566
II	3	2	.012	.202	.063	1.080
III	4	3	.019	.314	.093	1.633
IV	1	1	.010	.100	.049	.556
V	0	0	.008	.008	.038	.038
VI	3	2	.017	.206	.083	1.089
VII	4	2	.016	.214	.080	1.100
VIII	3	2	.019	.213	.096	1.104
IX	2	2	.018	.223	.091	1.129
X	3	3	.017	.313	.086	1.632
XI	2	2	.013	.209	.064	1.093
XII	2	2	.012	.204	.061	1.087
Total	28	22	.063	2.315	.857	12.107
Average	2.3	1.8	.014	.193	.071	1.009

Table XXVI. Comparison of M551 Traverse Time and Vehicle Losses Without and With Vehicle Removal (Dwg. 002: Fig. 28)

Lane No.	Vehicle Losses		Minimum Time to Traverse (25 mph)		Maximum Time to Traverse (5 mph)	
	No. of Vehicles		Time in Hours		Time in Hours	
	W/o Removal	W/Removal	W/o Removal	W/Removal	W/o Removal	W/Removal
I	0	0	.007	.007	.036	.036
II	0	0	.008	.008	.042	.042
III	3	3	.014	.284	.071	1.590
IV	1	1	.011	.011	.055	.570
V	4	4	022	.426	.111	2.180
VI	2	2	.016	.217	.079	1.114
VII	1	1	.010	.109	.049	.565
VIII	2	2	.012	.220	.077	1.115
IX	1	1	.012	.119	.062	.586
X	8	3	.034	.302	.174	1.616
XI	9	3	.044	.321	.217	1.648
XII	1	1	.0[illegible]	.109	.052	.567
Total	32	21	.200	2.133	1.025	11.629
Average	2.7	1.8	.017	.178	.085	.969

Table XXVII. Comparison of M60 Traverse Time and Vehicle Losses Without and With Vehicle Removal (Dwgs. 003 and 004: Figs. 29 and 30)

Lane No.	Vehicle Losses		Minimum Time to Traverse (25 mph)		Maximum Time to Traverse (5 mph)	
	No. of Vehicles		Time in Hours		Time in Hours	
	W/o Removal	W/Removal	W/o Removal	W/Removal	W/o Removal	W/Removal
I	12	2	.039	.204	.196	1.090
II	10	3	.074	.327	.368	1.664
III	11	6	.075	.707	.374	3.377
IV	11	3	.051	.324	258	1.649
VI	8	2	.031	.202	.156	1.083
X	11	4	.067	.465	.336	2.246
XII	21	3	.071	.290	.355	1.591
I	5	3	.023	.320	.116	1.640
II	21	7	.089	.702	.449	3.726
III	16	3	.096	.352	.480	1.697
IV	16	4	.060	.434	.300	2.198
V	2	2	.011	.197	.057	1.075
Total	134	42	.687	4.524	3.445	23.036
Average	11.2	3.5	.057	.377	.287	1.920

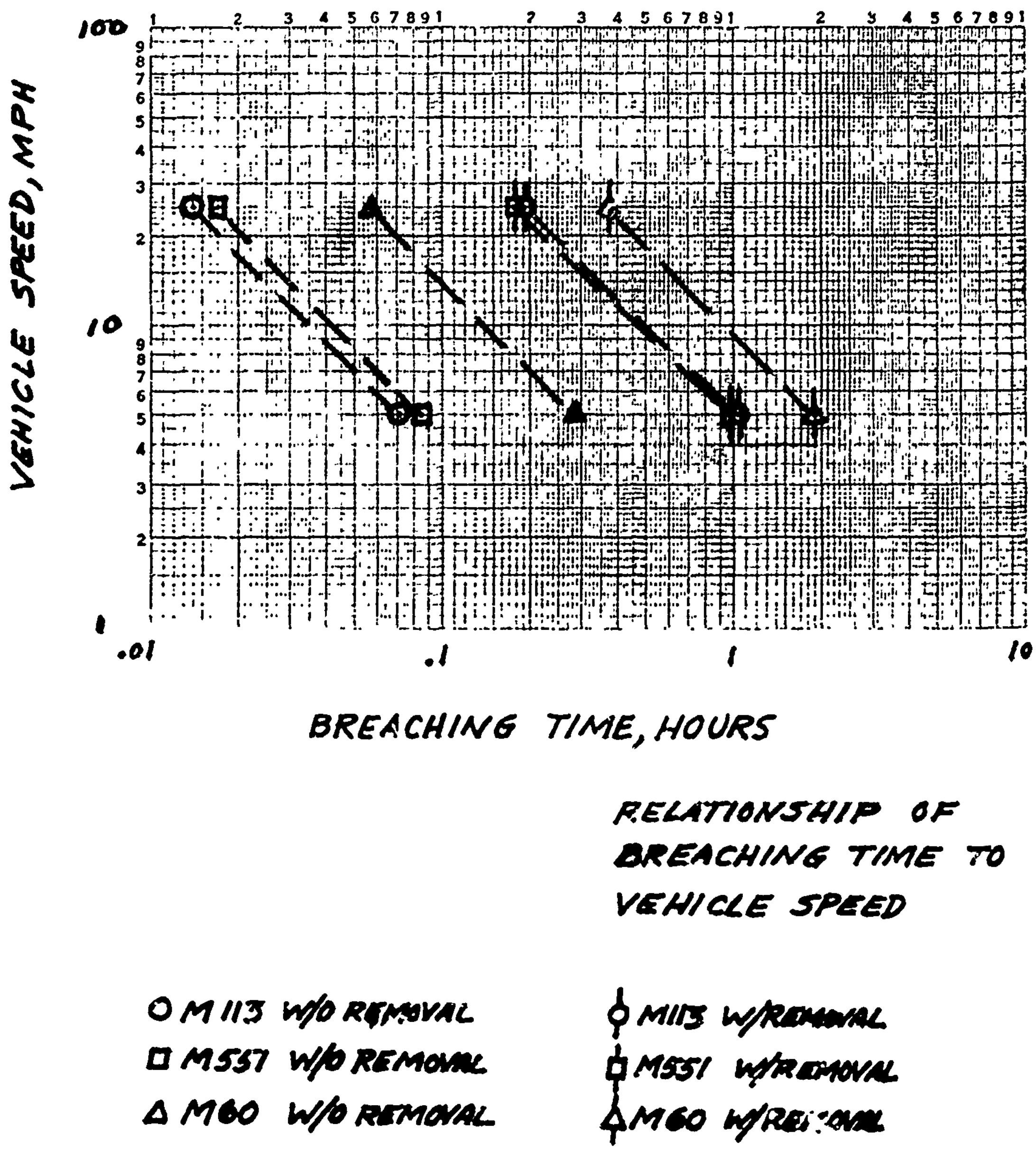

Fig. 31. Plot of vehicle speed vs breaching time.

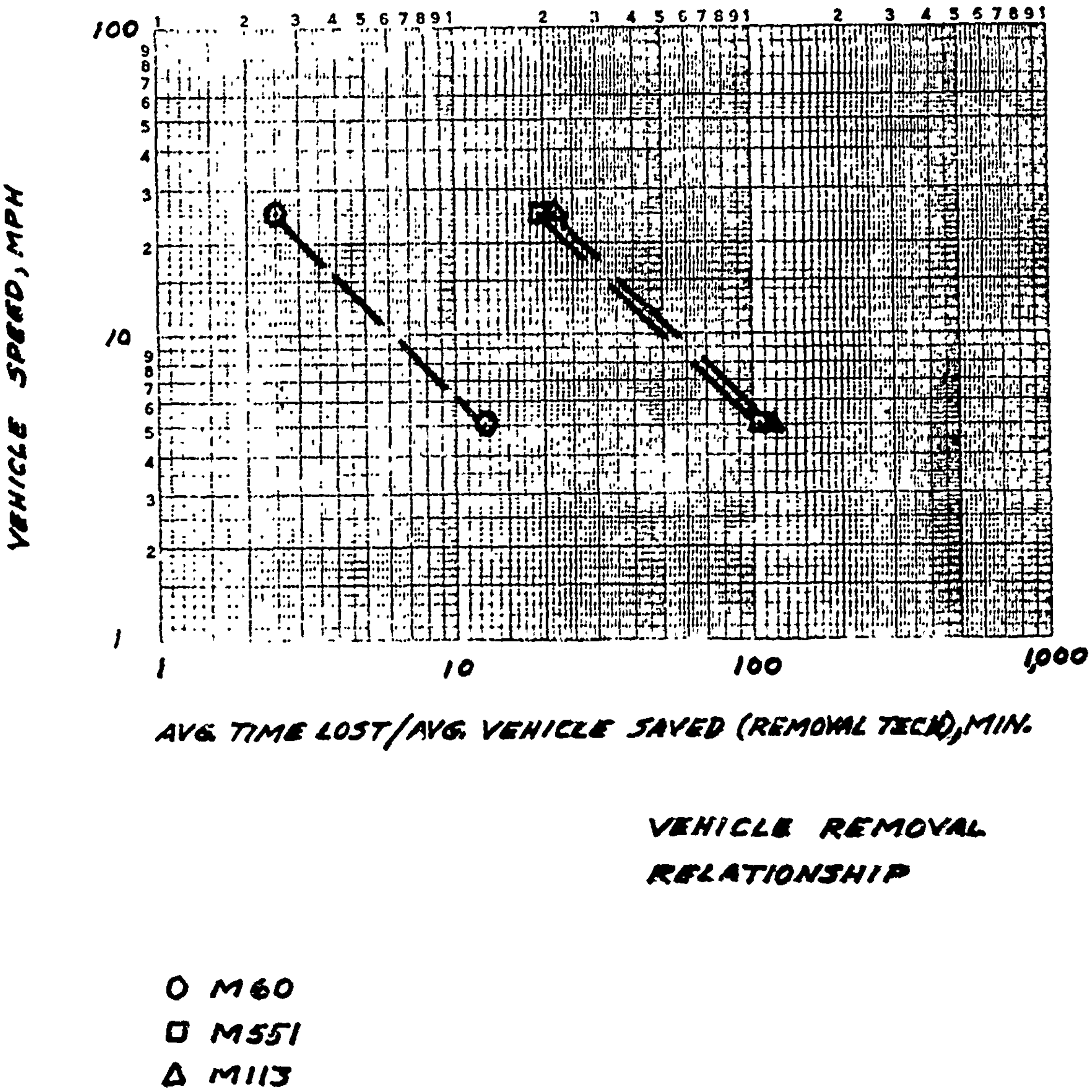

Fig. 32. Plot of vehicle speed vs lost time per vehicle saved.

Table XXVIII. Cost Comparisons

Vehicle	No. Lost Low & High	Cost per Vehicle Low & High	Total Vehicle Loss Cost Low & High (Per Run)	Avg No. Lost	Avg Cost per Vehicle	Total Avg Cost per Traverse
			Without Removal			
M113	0–4	$27,158–$30,566	$0–$122,264	2.3	$28,862	$ 66,383
M551	0–9	$214,670	$0–$1,932,030	2.7	$214,670	$ 579,609
M60	2–21	$147,475–$217,680	$294,950–$4,571,280	11.2	$182,578	$2,044,874
			With Removal			
M113	0–3	$27,158–$30,566	$0–$91,698	1.8	$28,862	$ 51,952
M551	0–4	$214,670	$0–858,680	1.3	$214,670	$386,406
M60	2–7	$147,475–$217,680	$294,950–$1,523,760	3.5	$182,578	$639,023

FM-17-36 shows that the cost of an M60 tank ranges from $147,475 to $217,680, an M113 ranges from $27,158 to $30,566, and an M551 is $214,670.[36] Table XXVIII indicates that, for the example traverses, the vehicle costs per breach can vary from $0 to $4,571,280. The average costs per breach can range from $51,952 to $2,044,874. Comparing vehicle removal with no removal, on an average, the M113 shows a 22% cost reduction, the M551 shows 33%, and the M60 shows 69%. It must be borne in mind, however, that these vehicle cost reductions do not take human casualties or mission delay time into account.

Under combat conditions, it may be necessary to sacrifice armored vehicles in order to satisfy other more pressing demands such as surprise, suppression of covering fires, or other constraints demanding a minimum time loss in traversing a barrier minefield. If such a case exists, the bulling technique offers the fastest possible breaching technique using equipment presently in the inventory. Bulling with immobilized vehicle removal offers a breaching technique which is a compromise between vehicle damage and breaching speed.

The armored traversing also involves a logistics burden for the vehicles immobilized by the minefield. Average values of vehicle losses shown in Tables XXV, XXVI, and XXVII have the total weights and volumes shown in Table XXIX. On the average, the vehicle weights can range from a low of about 18 tons to a high of about 543 tons and the volumes from about 1,700 cu ft to 39,000 cu ft. Although armored penetrations are much faster than dismounted breachings, the logistics problems are magnified many times.

Table XXIX. Armored Vehicles: Weights and Volumes

Vehicle Type	Average Losses	Total Weight (Lb)	Total Volume (Cu Ft)
Without Vehicle Removal			
M113	2.3	45,436–46,288	2,204.8–2,451.0
M551	2.7	80,892	4,177.2–4,813.0
M60	11.2	1,041,600–1,086,400	37,303.8–38,887.5
With Vehicle Removal			
M113	1.8	35,559–36,225	1,725.5–2,074.7
M551	1.8	53,928	2,784.8–3,208.7
M60	3.5	325,500–339,500	11,657.4–12,152.4

36. "Divisional Armored and Air Cavalry Units," FM 17-36, November 1968.

c. Combined Dismounted/Armored Vehicle Breaching Operations and Associated Time, Labor, and Materiel Costs.

The dismounted breaching tactics outlined in Paragraph 6a are, as a group, much more time consuming than the armored breaching techniques discussed in Paragraph 6b. On the other hand, the armored breaching techniques lead to a high penalty in immobilized vehicles. In this paragraph, two combinations of these two breaching techniques are evaluated.

When a suspected minefield must be breached and its nature and extent are unknown, time can be saved if armored breaching tactics are used until the lead vehicle is immobilized. After the lead vehicle is immobilized, two procedures are considered. The first procedure employed dismounted breaching tactics from the point at which the lead vehicle was immobilized to a point 100 meters beyond the last mine encountered.

The second procedure employed dismounted breaching tactics only from 20 meters behind an immobilized vehicle to a point 20 meters in front of the immobilized vehicle. After this path around the vehicle was cleared, armored breaching tactics were used until the new lead vehicle was immobilized. This process was repeated until the minefield was breached.

Models of the M60, M551, and M113 armored vehicles were conducted through the minefield model. The same paths which were used for evaluation of the armored breaching techniques were used for evaluation of the combination techniques. The paths taken through the minefield are shown in Figs. 27 to 30. The results of breaching these minefields are shown in Tables XXX through XXXIII.

There is a finite possibility, as can be seen in Tables XXX through XXXIII, that an armored vehicle can pass through a barrier minefield without being immobilized by a mine. Therefore, either of the combination breaching techniques could breach the minefield as fast as an armored breaching technique. If, however, antivehicular mines are encountered, more time is needed for either of the combination breaching techniques than for the armored breach; but both combination breaches are faster than a dismounted breach. Conversely, the combination breaches will mean more vehicle immobilization than the dismounted breach but less vehicle immobilization than the armored techniques.

The time, labor, and materiel costs shown in Table XXXIII were calculated using the vehicle data shown in Paragraph 6b and the dismounted data shown in Paragraph 6a(4), Example 4.

Table XXX. Time and Vehicle Costs of Breaching a Barrier Minefield with M60A1 Combat Tanks in Combination with Dismounted Mine-Clearing Teams

Path Number	Number of Vehicles Immobilized		Length Swept by Dismounted Personnel in Meters		Breach Time in Hours	
	Long Sweep	Short Sweep	Long	Short	Long Sweep	Short Sweep
3-I	1	2	390	80	9.2	1.9
3-II	1	2	460	80	10.9	1.9
3-III	1	3	470	120	11.1	2.8
3-IV	1	2	380	80	9.0	1.9
3-VI	1	2	340	80	8.1	1.9
3-X	1	2	290	80	6.9	1.9
3-XII	1	2	390	120	9.2	2.8
4-I	1	2	320	80	7.6	1.9
4-II	1	4	410	160	9.7	3.8
4-III	1	2	280	80	6.6	1.9
4-IV	1	3	400	120	9.5	2.8
4-V	1	2	390	80	9.2	1.9
Average	1	2.4	377	93	8.9	2.2

Table XXXI. Time and Vehicle Costs of Breaching a Barrier Minefield with M551 Vehicles in Combination with Dismounted Mine-Clearing Teams

Path Number	Number of Vehicles Immobilized		Length Swept by Dismounted Personnel in Meters		Breach Time in Hours	
	Long Sweep	Short Sweep	Long	Short	Long Sweep	Short Sweep
1-I	0	0	0	0	.05	.05
1-II	0	0	0	0	.05	.05
1-III	1	2	500	80	11.93	1.98
1-IV	1	1	270	40	6.45	1.00
1-V	1	3	420	120	10.03	2.92
1-VI	1	2	380	80	9.00	1.97
1-VII	1	1	240	40	5.69	1.00
1-VIII	1	2	280	80	6.63	1.96
1-IX	1	1	230	40	5.45	1.01
1-X	1	3	410	120	9.71	2.95
1-XI	1	3	390	120	9.23	2.95
1-XII	1	1	280	40	6.63	1.01
Average	.83	1.58	283	60	6.74	1.57

Table XXXII. Time and Vehicle Costs of Breaching a Barrier Minefield with M113 Armored Personnel Carriers in Combination with Dismounted Mine-Clearing Teams

Path	Number of Vehicles Immobilized		Length Swept by Dismounted Personnel in Meters		Breach Time in Hours	
	Long Sweep	Short Sweep	Long	Short	Long Sweep	Short Sweep
5-I	1	1	250	40	5.79	.97
5-II	1	2	320	80	7.39	1.89
5-III	1	3	380	120	8.76	2.80
5-IV	1	1	380	40	8.76	.97
5-V	0	0	0	0	0	0
5-VI	1	2	340	80	7.85	1.89
5-VII	1	2	320	80	7.39	1.89
5-VIII	1	2	370	80	8.54	1.89
5-IX	1	2	500	80	11.52	1.89
5-X	1	3	400	120	9.22	2.80
5-XI	1	2	320	80	7.39	1.89
5-XII	1	2	370	80	8.54	1.89
Average	.92	1.83	329	70	7.60	1.66

Table XXXIII. Time, Labor, and Materiel Costs of Breaching a Barrier Minefield with Armored Vehicles Combined with Dismounted Mine-Clearing Teams

Vehicle	Breach Time (Hr)		Labor (Man Hr)		Material ($)	
	Long Sweep	Short Sweep	Long Sweep	Short Sweep	Long Sweep	Short Sweep
M60	8.9	2.2	329.3	81.4	164867–255808	371332–560560
M551	6.74	1.57	249.4	58.1	195568–216304	356571–377307
M113	7.60	1.66	281.2	61.4	39933–63498	67104–94064

d. Time, Labor, and Materiel Costs Associated with the Installation of a Barrier Minefield.

The laying of deliberate, patterned defensive and barrier minefields follows the doctrine established by FM 20-32.[37] In order to exercise present-day systems, a deliberate barrier minefield has been constructed by carefully following this doctrine. This model minefield has been used to determine relative minefield costs in terms of dollars, time, and manhours. FM 20-32[38] and FM 101-10-1[39] were used to establish the materiel, time, and manhours required, and SB 700-2[40] supplied the materiel unit costs.

The basic structure of the model minefield is:

TYPE: Deliberate barrier

DENSITY: 1-4-8 (AT; AP Frag.; and AP blast respectively)

STRIPS: 8 (Plus IOE)

IOE: 1-2-2

FRONT: 406 Meters

MINE TYPE: AT-M15's, AP Frag.–M16's, AP Blast-M14's.

MINE TOTALS: Includes IOE and 10% Safety Factor (See Table XIX)

MANHOURS: Based on laying rate of 4 AT, or 8 AP Frag., or 16 AP Blast mines per manhour. Includes 20% factor to compensate for minefield siting, marking, and recording.

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[37] "Landmine Warfare," FM 20-32, August 1966.

[38] Ibid.

[39] "Staff Officers' Field Manual Organization, Technical, and Logistical Data Unclassified Data," FM 101-10-1, January 1966.

[40] "Army Adopted/Other Selected Items and List of Reportable Items," DA Supply Bulletin SB 700-2, 1 September 1971.

Standard minefields range in densities from 1-1-1 to 3-4-8, and the model minefield with a 1-4-8 density is a median value. The types of mines used are typical according to FM 101-10-1.[41] The trucks used to transport the crated mines to the site of the minefield are a necessary part of minefield laying. In order to avoid errors in prorating the cost of the trucks, this cost will be included as a range from zero to the full cost. The mine-laying party may vary in size between 33 and 39 persons,[42] so the time duration for laying the field is also a range of values.

Table XXXIV gives the laying costs of the 1-4-8 model minefield.

Table XXXIV. 1-4-8 Model Minefield Laying Costs

Lin	Description	Unit Cost ($)	Materiel Cost ($)	Man-hours	Time Duration (Hr)
M47863	Mine, AT, M15	$ 21.82	$ 14,532	–	–
M46082	Mine, AP Frag, M16	14.97	37,874	–	–
M45945	Mine, AP Blast, M14	2.80	13,790	–	–
M49096	Minefield Marking Set	465.00	465–1,395	–	–
B29395	Barbed Wire, 1000-ft reel	30.00	810	–	–
P21807	Pickets, U-shaped, 6 ft	0.82	166	–	–
X40831	Truck Cargo: 5-ton 6x6 LWB	10,570.00	0–73,990	–	–
	Manpower (1 Off, 7 NCO, 25-31 EM)	–	–	950	39.6–52.8
	TOTAL		$67,637–$142,557	950	39.6–52.8

Effect of Increasing Minefield Density to 3-4-8.

The model minefield for this study has a density of 1-4-8. This density was deliberately chosen as a mid-value between the 1-1-1 and the 3-4-8 minefields listed in Table 4-5 of FM 20-32.[43] It is the intention of the authors to thoroughly investigate the 3-4-8 minefield and to compare it to the previously discussed 1-4-8 minefield. In a similar manner, a less dense minefield will, if time permits, be compared to the other two. These density variations will provide the framework for a sensitivity analysis of density.

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[41] "Staff Officers' Field Manual Organization, Technical, and Logistical Data Unclassified Data," FM 101-10-1, January 1966.

[42] "Landmine Warfare," FM 20-32, August 1966.

[43] Ibid.

Some probable points of interest can be mentioned at this time. Going to a 3-4-8 minefield should have little or no effect on dismounted breaching activities to clear a footpath of anti-personnel mines since the total number of anti-personnel mines is still the same even though there are nine strips instead of eight. The depth of the field does increase—by one strip—and this might add a small increment of time; however, since the major time factor is blowing the mines in-place and since this factor should not change, the total elapsed time should remain relatively constant.

Breaching by means of line charges and bangalore torpedoes should experience little change in time required.

Increasing the anti-tank mine density will, obviously, have a profound influence on armored vehicle losses and the associated costs. Based on the study to date, there is good reason to believe that the losses—both with and without removal—will increase by a factor of three. The time to traverse quite probably will also go up by a factor of three.

The detailed sensitivity analysis planned for a later phase of this study will provide considerably more information as well as a firmer basis for future decisions in the area of countermine techniques.

III. DISCUSSION

7. **General.** The baseline described in this report follows Army doctrine; employs a standard Army minefield; and incorporates only type-classified materiel.

Three basic types of breaching operations were considered: dismounted; armored vehicle traversing; and combined dismounted – armored vehicle.

A total of 14 breaching paths was chosen in a somewhat random manner for dismounted operations, and the following techniques were examined in some detail:

- a. Manual probe and destroy in place
- b. Detect (AN/PRS-7) and destroy in place
- c. Bangalore torpedo plus AN/PRS-7 plus destroy in place
- d. Blind destroy in place via M157 snake
- e. Blind destroy in place via M173 rocket.

These techniques were used to calculate the resources in time, labor, materiel dollars, energy, weight, volume, and vehicles that might be directly associated with breaching. The subject of casualties has also been addressed; but, from the broad range of conditions to be encountered in breaching, quantitative treatment is difficult. As a temporary analytical expedient, a time-casualty relationship has been postulated to indicate the intuitive importance of time at the minefield.

A total of 12 random paths was used to study the resource costs of armored vehicle breaching. Three vehicles were studied separately:

(1) M113 Carrier, Personnel, Full-Tracked; Armored
(2) M557 Armored Recon, Airborne Assault Vehicle
(3) M60 Tank, Combat, Full-Tracked.

Two breaching techniques were used. In each technique a column of vehicles enters the minefield and continues until the lead vehicle is immobilized. Then, either (a) the second vehicle proceeds around the first until it, too, is immobilized and the process is repeated; or (b) each immobilized vehicle is pulled straight back to the point of minefield entry and then the column proceeds along the same track.

Finally, the same random paths were used to study the resource costs of combined dismounted-armored vehicle breaching. The same three armored vehicles were also used with two dismounted techniques:

(1) When the lead vehicle of a column becomes immobilized, dismounted personnel clear a short path around the vehicle; the column then takes this path until the lead vehicle is immobilized and the process is repeated (short sweep).

(2) When the lead vehicle of a column becomes immobilized, dismounted personnel clear a path through the remainder of the minefield (long sweep).

The resource penalties or costs associated with each of these methods of breaching are summarized in Table XXXV. The resources considered are time, labor, materiel dollars, energy, weight, volume, casualties, and armored vehicles. A quantitative estimate was calculated for each resource by means of relatively simple scenarios with emphasis upon the operations cycle of the countermine system. Some consideration of the logistics burden was introduced by including estimates of materiel weight, materiel volume, and energy. Also, energy considerations were introduced in the belief that further analysis of energy and energy rate relationships between the mine and the countermine systems may lead to a better understanding of fundamentals.

There are many ways to graphically present and summarize the relationships that have been developed. Cost in dollars is, by tradition, usually given early analytical attention even though this cost does not usually dominate the final comparison or selection process. Then, for illustration purposes, five graphs are used to show the trends

Table XXXV. Summary of Costs Directly Associated with Several Standard Methods of Breaching a 6-8 Meter Vehicle Lane Through a 1-4-8 Barrier Minefield 400 Meters Deep

Example Breach Method	Time (Hr)		Labor (Manhours)		Materiel ($) 10^3 (a)		Vehicle Loss		Energy 10^3 Btu (b)		Weight 10^3 Lb		Volume 10^2 Ft^3		Casualties (c)	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Dismounted																
4 Manual Probe	471	530	15700	17600	8	16			336		7.7		2.8	3.2	6764	7582
2 Detector	3.5	47	118	1575	17	38			336		15		5.2	5.6	51	679
8 Bangalore	61	102	2349	2644	33	45			3980		45		9.9	10	663	987
6 M157 (Snake)	3		123		191	261			31000		138		43	44	35	51
7 M173 (Rocket)	2.3		27		189	259			20000		109		39	40	6	
Mounted																
9 M113 w/o Removal	0.014	0.371	0.028 (d)	0.14	0	122	0	4	0	37000 (g)	45	46	22	25	0 (j)	8
10 M113 w "	0.19	1.01	0.39	2.02	0	92	0	3	0	29000	35	36	17	21	0	6
11 M551 w/o "	0.018	0.085	0.068 (e)	0.34	0	1932	0	9	0	165000		81	42	48	0	18
12 M551 w "	0.085	0.97	0.34	3.87	0	859	0	4	0	74000	54		28	32	4	8
13 M60 w/o "	0.057	0.29	0.23 (f)	1.15	295	4571	2	21	87000	915000	1041	1086	373	390	4	42
14 M60 w "	0.38	1.92	1.51	7.68	295	1524	2	7	88000	309000	325	339	116	121	4	14
Mounted & Dismounted (i)																
15 M113 Short Sweep	0.6	8.25	22	305	67	94	0	3							9	131
16 M113 Long "	2.9	39	97	1292	40	63	0	1							42	557
17 M551 Short "	0.5	7.1	19	263	356	377	0	3							8	113
18 M551 Long "	2.5	33	83	1112	196	216	0	1							36	479
19 M60 Short "	0.8	11	30	407	371	560	2	4							13	175
20 M60 Long "	3.3	44	111	1481	165	256	1	1							48	638
1-4-8 Minefield (h)	40	53	950		68	142			36000							

(a) Vehicle fuel cost included only when immobilized.
(b) Includes full tank of fuel when lost.
(c) Time, labor, and materiel costs are on the basis of no casualties.
(d) 2-man crew.
(e) 4-man crew.
(f) 4-man crew.
(g) Energy calculations illustrated in Appendix C.
(h) Installation costs.
(i) Tables XXX, XXXI, and XXXII have been adjusted for 0.01 to 1 m/sec sweep rate to be consistent with remainder of calculations.
(j) Casualties in this group are based upon 2 per vehicle immobilized.

and tendencies of the calculations. Each graph presents breaching time range plotted against materiel cost in dollars range. Figure 33 covers the dismounted breaching operations which include the M173 (Rocket), M157 (Snake), Detector, Bangalore, and Manual Probe. Figure 34 covers breaching operations using the M113 alone and in combination with dismounted support. Dismounted breaching is also shown as a breach method to precede the vehicle. Figure 35 covers breaching operations using the M551 alone and in combination with dismounted support. Dismounted breaching is again shown as a breach method to precede the vehicle. Figure 36 covers the M60 in a similar manner. Finally, the average value for each of the above breaching methods is presented in Fig. 37. The empirical equation

$$y = 205{,}900\ x^{-0.426701}$$

where y = materiel cost in dollars
x = breaching time in hours

has been calculated by the least squares method and its derivation is included in Appendix D. The minefield installation time and materiel cost is also shown not only to provide reference but also to emphasize the eventual importance of relative rather than absolute costs.

One of the more obvious generalizations that may be drawn from Fig. 37 is that rapid breaching carries a heavy materiel cost penalty. Further examination of Table XXXV also indicates that breaching time may have similar relationships to labor, casualties, energy, and logistics burden for the range of breaching methods studied. Note at this point also that log-log plots of data tend to present a picture that is quite different from the same data on Cartesian coordinates (Fig. 38).

The resource cost or resource penalty relationships derived from these countermine models should be interpreted and utilized carefully because the real world in which countermine systems must operate is complex indeed. These simple models do not imply a simple world but are only approximations to provide a rational study structure. The quantitative treatment of resources does, however, provide a reasonable yardstick for the objective comparison of systems and subsystems concepts that will follow.

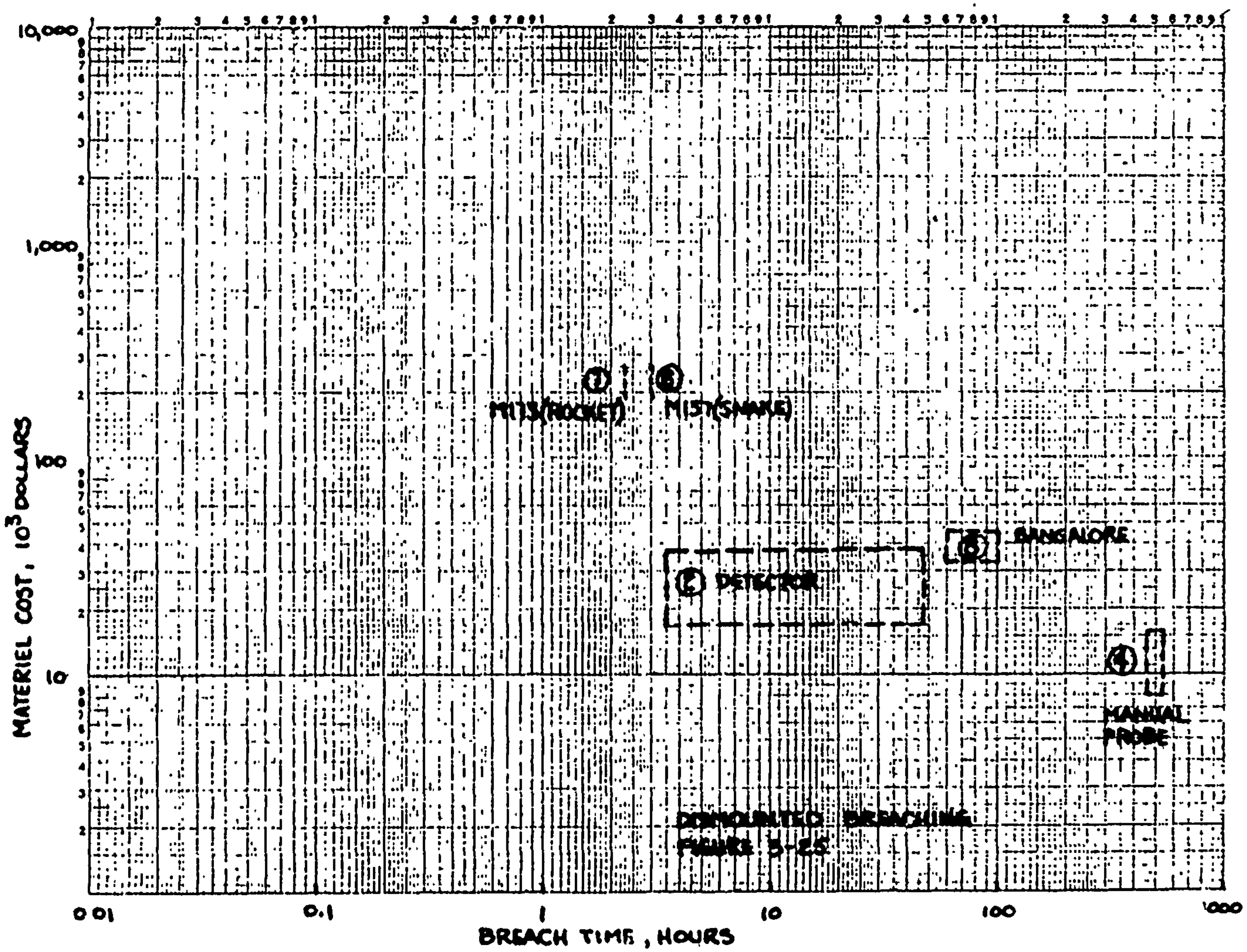

Fig. 33. Dismounted breaching: plot of materiel cost vs breach time.

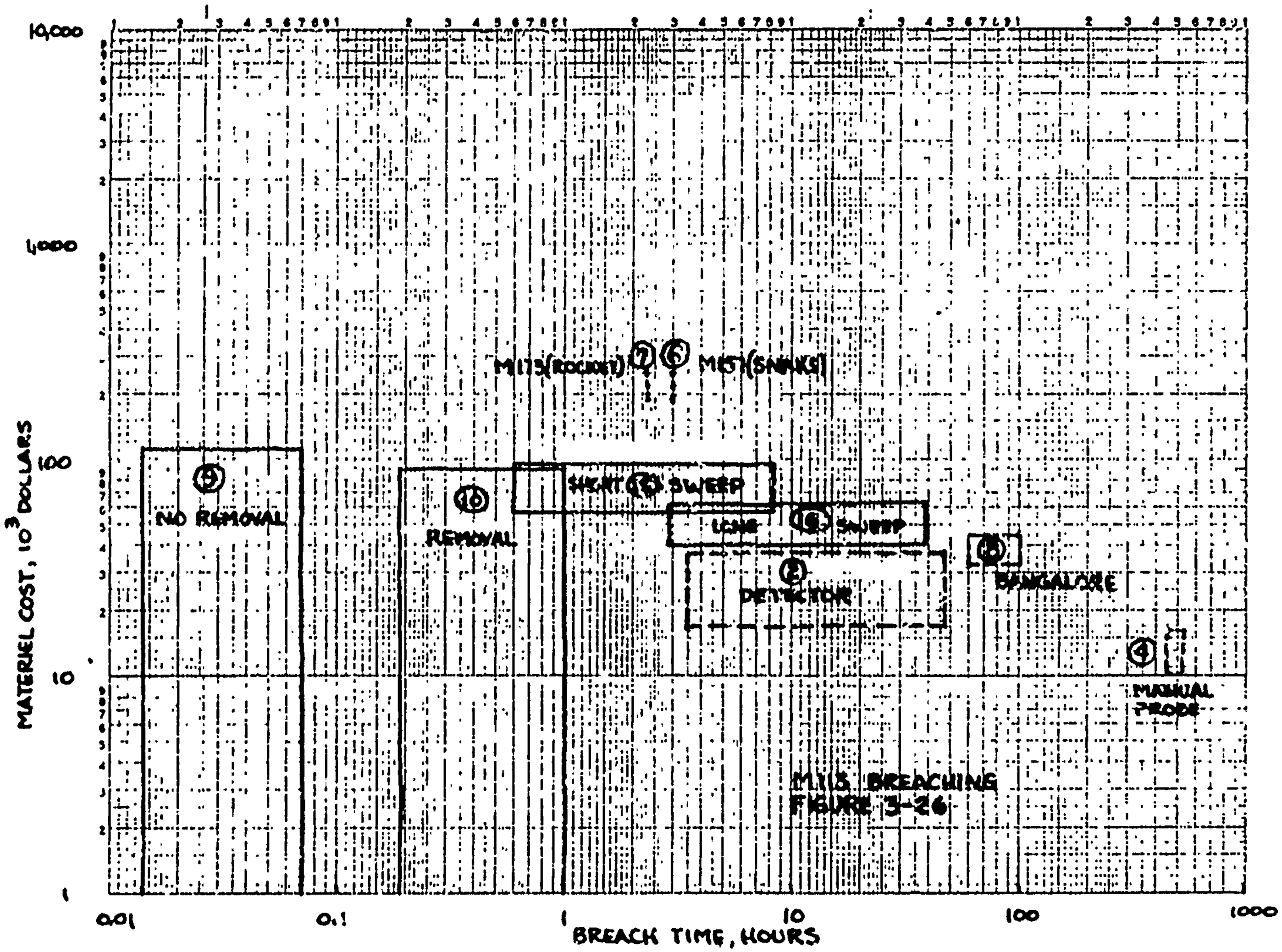

Fig. 34. M113 breaching: plot of materiel cost vs breach time.

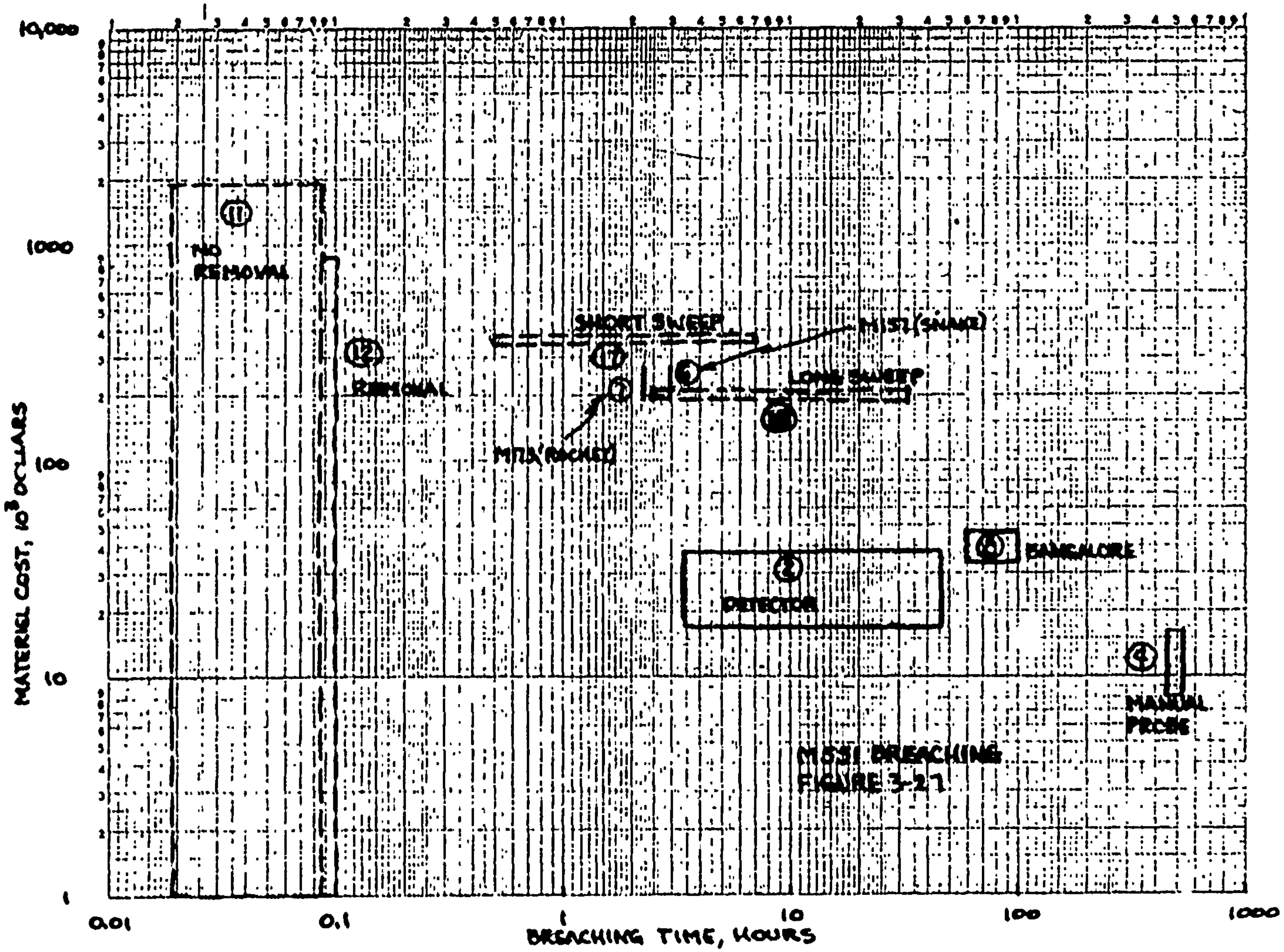

Fig. 35. M551 breaching: plot of materiel cost vs breach time.

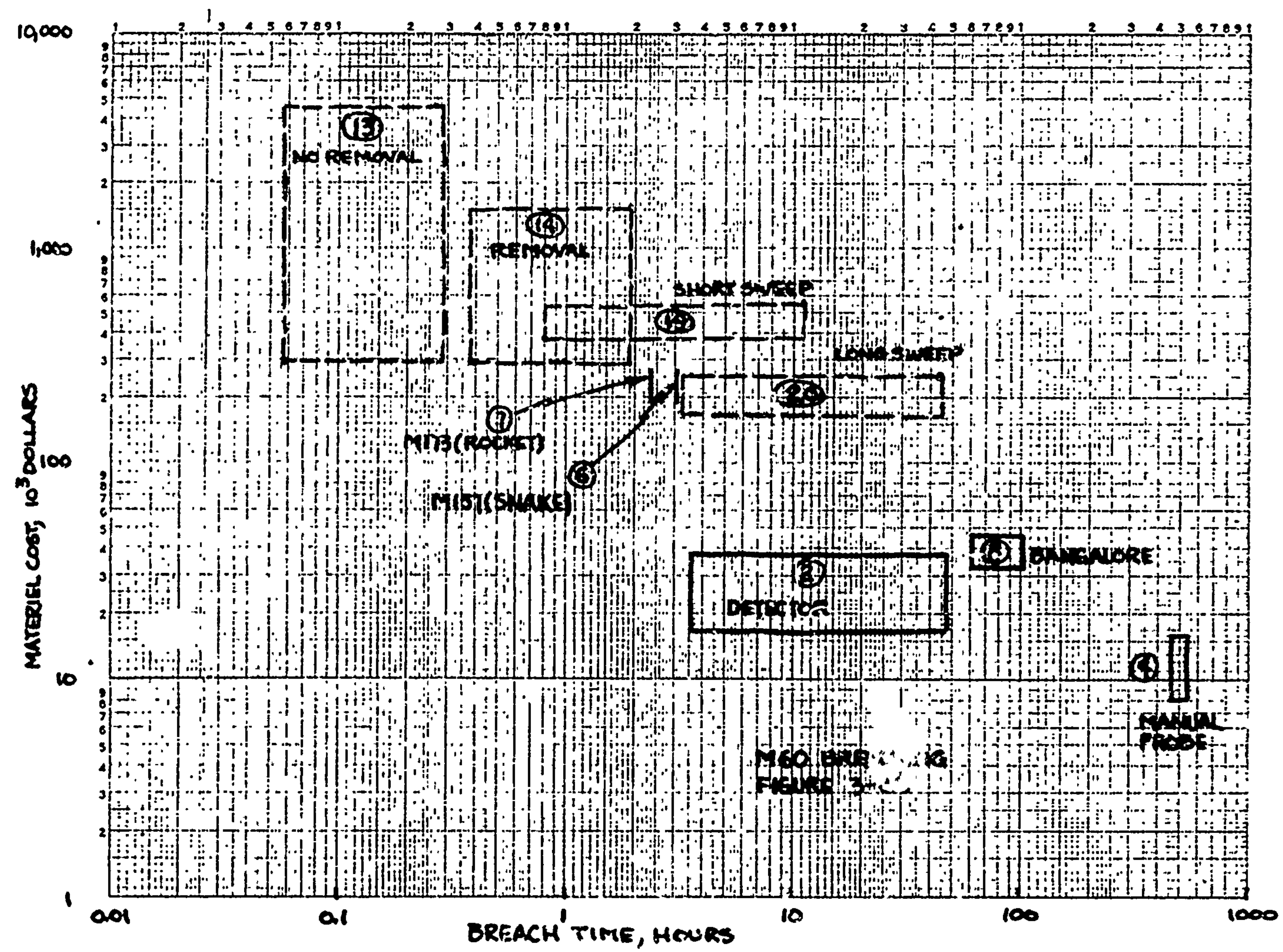

Fig. 36. M60 breaching: plot of materiel cost vs breach time.

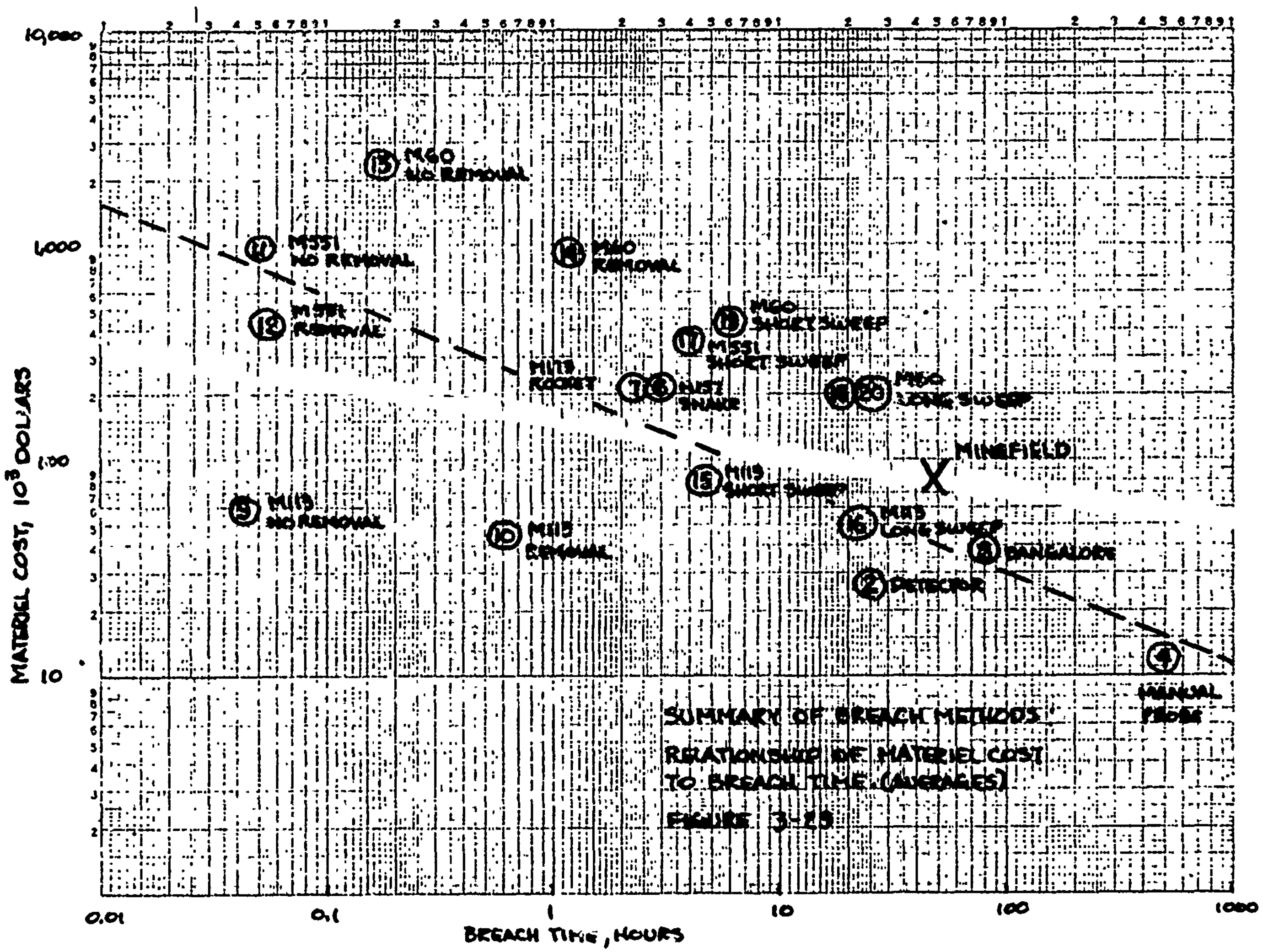

Fig. 37. Summary of breach methods: relationship of materiel cost to breach time.

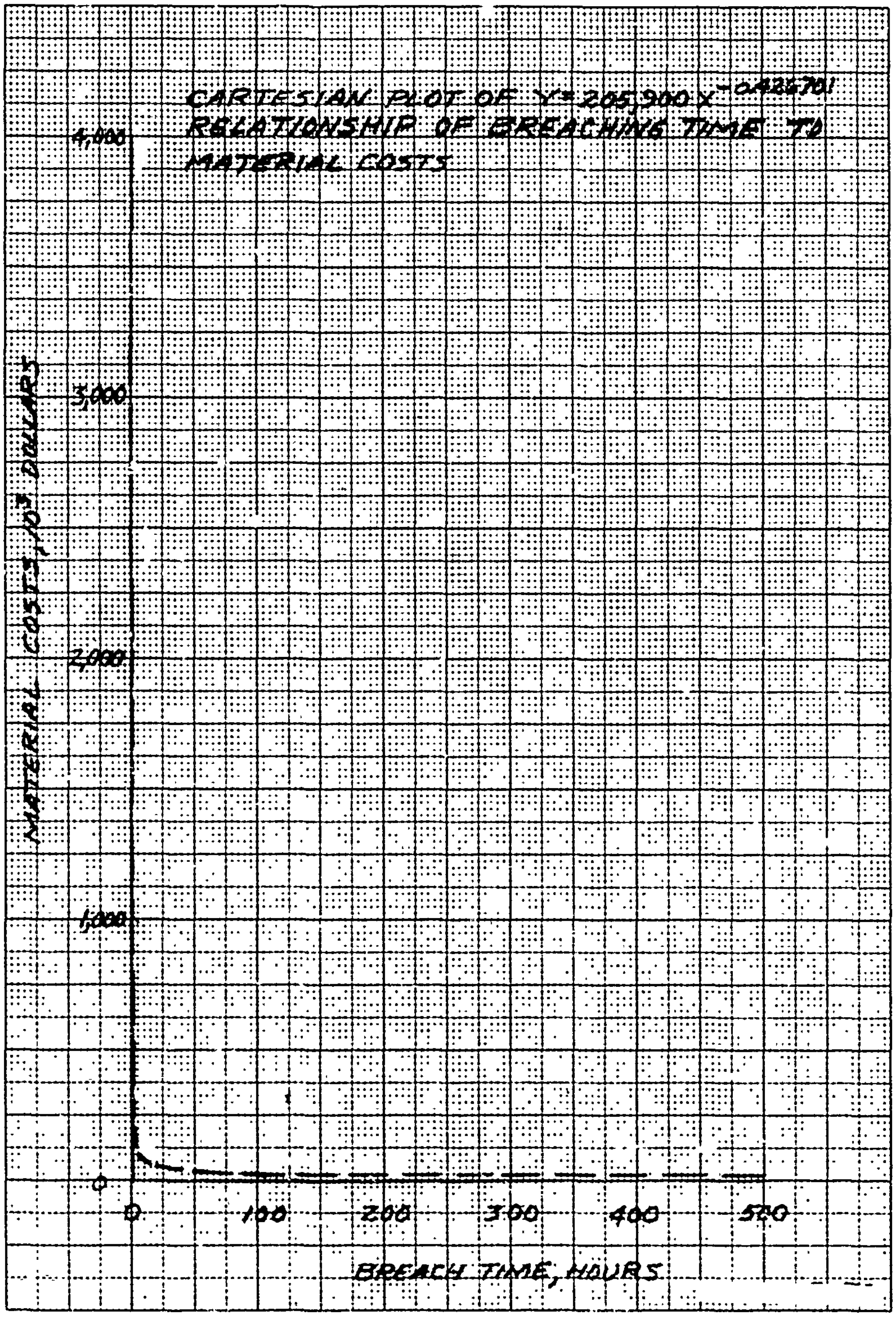

Fig 38. Summary of breach methods: relationship of materiel cost to breach time (Cartesian plot).

IV. CONCLUSIONS

8. **Conclusions.** It is concluded that:

a. **Dilemma.** One conclusion that may be drawn from the breaching models developed by this study is that present day countermine systems present the field commander with a dilemma. He must eventually choose between either a slow, costly breach system or a rapid, costly breach system. "Cost" in this sense has reference to one, many, or all of his resources such as time, labor, dollars, logistical burden, fuel, armored vehicles, casualties, morale, surprise, stealth, shock, and momentum, to name but a few.

To pursue this rationale a bit further, it also appears that future countermine systems must break the dilemma by drastically expanding the options of countermine warfare. In matrix form, the options are:

	low breach time	high breach time
low resource penalty	need	have
high resource penalty	have	have

b. **Nonlinear Approach.** It may also be concluded that conceptual systems and their supporting component development work must be directed to achieving a capability to breach rapidly with resource penalties significantly lower than the penalties of today. There are strong grounds to support the contention that logical although linear extensions of the state-of-the-art will not fill the bill. The slope of the curve $y = 205{,}900\ x^{0.426701}$ and other resource penalties must be reduced. If nonlinear results are required, then the studies must first begin to adopt a nonlinear, nontraditional approach to system synthesis and component development.

c. **Mine, Countermine, Barrier Studies.** It is further concluded that this study of countermine systems should be expanded to permit the parallel analysis of mine systems and barrier systems. The incremental cost of this expansion should be roughly 100% and yet will permit the development of a total military systems perspective by simultaneous consideration of system and counter system. Models and simulations will also be improved.

d. **Statistical Analysis.** When sufficient data are available, the techniques of statistical inference should be employed to gain new insight into countermine systems. It is anticipated that the required data will be available in the next phase of this study. Parametric analyses of minefield breaching is planned.

Analysis of variance, multivariate correlation, and other analytical methods will be used where applicable. Confidence limits will be established. An investigation of distributions will be undertaken.

These analysis should lead to a better understanding of all aspects of the system interface problems and a firmer basis for trade-off analyses.

APPENDIX A

ESTIMATIONS OF PENALTIES INCURRED DURING BREACHING OPERATIONS DUE TO COVERING FIRES

The time, labor, and materiel costs calculated in this report are based upon the assumption that no losses due to covering fire were incurred. Casualty effects were omitted from this report to provide a basis for comparison of alternative countermine systems exclusive of the highly scenario dependent effects of casualties. Reference was made in Paragraph 6 to the expected relationship between exposure time at the barrier and casualties incurred. It has been pointed out that the number of casualties incurred by a force delayed in a minefield which is covered by enemy fire doubles in the first 5 minutes of exposure and increases by a factor of 12 during the first hour of exposure.[44] In order to estimate the effect of covering fire upon breaching penalties, a very simple scenario was used in conjunction with the above mentioned casualty rate.

In order to study casualty effects upon breaching operations, it was assumed that the covering fire for a barrier was such that each 37-man platoon exposed in the barrier will incur one casualty in the first 5 minutes of exposure, thus, one casualty will be incurred during each additional 5 minutes of exposure. It is further assumed that this level of fire will continue during the entire breaching operation. With the addition of covering fire and casualties to the barrier breaching calculations, medical evacuation teams must be added to the breaching party. It is assumed that 3 men would require about 20 minutes to evacuate one casualty from the barrier minefield; thus, a minimum of four evacuation teams must accompany each 37-man platoon. The evacuation teams will also be subject to casualties at the same rate as the mine-clearing team. If all of these factors are taken into consideration, the casualty rate for this scenario is .4308 casualties/exposed manhour.

The estimates of casualties and costs were only calculated for breaching operations involving dismounted personnel since vehicle losses to covering fires were not calculated. The results of these calculations are shown in Table A-I. The relationship of casualties to breach time for the standard breaching methods is shown in Fig. A-1.

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[44] "Family of Scatterable Mines," Phase II Report, Vol 1, 70826, ACN 17852, CDC Engineering Agency, 1 Feb 72.

Table A-I. Summary of Costs Directly Associated with Several Standard Methods of Breaching a 6-8 Meter Vehicle Lane Through a 1-4-8 Barrier Minefield 400 Meters Deep with Covering Fire Inflicting .4308 Casualties/Exposed Manhour

Example Number	Breach Method	Time (Hr) Low	Time (Hr) High	Exposed Manhours(a) Low	Exposed Manhours(a) High	Casualties Low	Casualties High	Labor Manhours (b) Low	Labor Manhours (b) High	Material 10^3 $ (c) Low	Material 10^3 $ (c) High
	Dismounted										
4	Manual Probe	471	530	15700	17600	6764	7582	1662159	2087140	488	1503
2	Detector	3.5	47.3	118	1575	51	679	602	23035	25	270
8	Bangalore	61	108	1539	2290	663	987	29219	39101	291	241
6	M157 (Snake)	3		82		35		176		191	261
7	M173 (Rocket)	2.3		15		6		39		189	259
	Mounted & Dismounted										
15	M113 Short Sweep	.6	8.25	22.0	305	9	151	31.8	940	68	114
16	M113 Long Sweep	2.9	38.8	96.8	1292	42	557	272.6	13580	48	148
17	M551 Short Sweep	.5	7.1	18.5	262	8	113	26.5	745	357	394
18	M551 Long Sweep	2.5	33.4	83.3	1111	36	479	227.5	17134	201	289
19	M60 Short Sweep	.8	11.0	29.6	407	13	175	44.0	1507	167	567
20	M60 Long Sweep	3.3	44.5	110.9	1480	48	638	320.1	17444	172	354

(a) This is only for the mine-clearing party exclusive of reserves and evacuation teams.

(b) Includes hours spent by reserves waiting to be committed and does not include time of personnel after becoming a casualty.

(c) It is assumed that each reserve man carries a percentage of mine-clearing material equal to the percentage of the mine-clearing party which he represents.

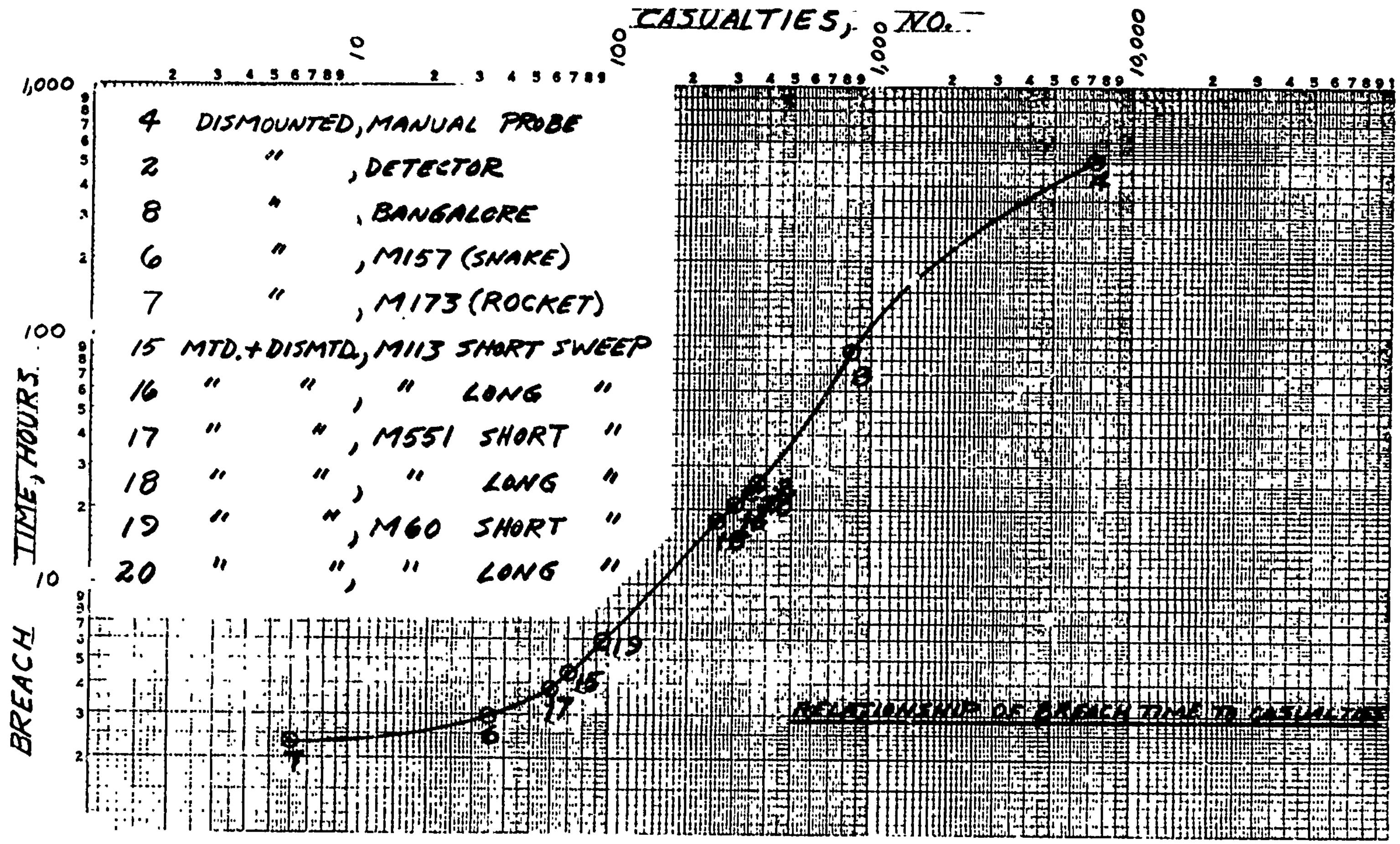

Fig. A-1. Relationship of breach time to casualties.

APPENDIX B

MAJOR HARDWARE ELEMENTS OF THE COUNTERMINE SYSTEM

Major Hardware Elements of the System are as of 1 September 1971 via SB 700-20:

Hardware and Procedural Data for

- Detection
- Marking
- Detonation in Place
- Lane Marking
- General Mission Support

Table B-I. Hardware and Procedural Data: Detection

Lin	Generic Nomenclature	FSN	FSN Nomenclature	Unit Price	Data
G02204	Detecting Set Mine: PTBL Metallic and Non-Metallic	6665-179-5120	Litton System ANPRS-7	1,136.00	TM5-6665-293-13
		6665-537-4001	Detector ANPRS-4	350.00	TM5-9541
G02341	Detecting Set Mine: PTBL Metallic	6665-144-7655	Detect Set Mine VP200	455.00	
		6665-181-0369	Detect Set M4D5000	455.00	
		6665-181-0432	Detect Set Mine P190	487.00	
		6665-966-9071	Detect Set P153/P158	455.00	
		6665-966-9072	Detector M	455.00	
G02478	Detect Set Mine: Truck-Mounted	6665-879-4087	Detect Set Mine TM P170	30,329.00	
		6665-821-9020	Detect Set Mine WURL 232	28,114.00	
		6665-912-1846	Detect Set Mine WURL 324	28,114.00	

Table B-II. Hardware and Procedural Data: Detonation in Place

Lin	Generic Nomenclature	FSN	FSN Nomenclature	Unit Price	Data
D92017	Charge Demolition: Block Comp C-4 1-1/4 lb M112	1375-724-7040	Charge Demolition M112	1.01	TM9-1375-200
D93730	Charge Demolition: Block TNT 1 lb.	1375-028-5142	Charge Demolition Block TNT	.77	TM9-1375-200
F91490	Demolition Set Explosive: Electric and Semi-electric	1375-047-3750	Demolition Set Elec and semi	197.00	FM 5-25
F91627	Demolition Set Explosive: Initiating Non-electric	1375-047-3751	Demolition Set Expl Non-Elec	57.34	FM 5-25
F90668	Demolition Kit Bangalore Torpedo: M1 Series	1375-028-5247	Demolition Kit, M1A1	106.00	
F90685	Demolition Kit Bangalore Torpedo: M1 Comp B loaded	1375-926-1948	Demolition Kit M1A2	106.00	
F91216	Demolition Kit Projected Charge: M157F Mine clearing	1375-729-4632	Demolition Kit M157	10,786.00	TM9-1375-204-10
F91353	Demolition Kit Projected Charge: M173	1375-812-3972	Demolition Kit M173	8,137.00	TM9-1375-202-10
W38210	Tool Kit Explosive Disposal Squad:	4925-754-0644	Tool Kit Disp FM	591.00	
T23769	Shop Set Ammunition and Explosive Ordnance Disposal	1385-378-4354	Shop Set Ammo/EOD	7,373.00	
W48074	Tool Kit Pioneer Engineer Combat Platoon	5180-596-1539	Tool Kt Pioneer CBPT	269.00	

Table B-III. Hardware and Procedural Data: General Support

Lin	General Nomenclature	FSN	FSN Nomenclature	Unit Price	Data
M49096	Minefield Marking Set Engineers w/Components	9905-375-9180	Minefield Marking Set	465.00	9955 93-CL-E01
E63317	Compass Magnetic: Lensatic	6605-846-7618	Compass Mag Len	8.31	
H68063	Flamethrower Portable	1040-772-5245	Flamethrwr ABC M9-7	327.00	TM 3-366
		1040-08905034	" PTBL M9A1-7	1,347.00	
		1040-586-4560	" " M2A1-7	432.00	
		1040-368-6068	" " M2A1	432.00	
A92008	Body Armor Fragmentation Protective: For the Groin	8470-753-6110	Armor Body Frg Grn 28	19.10	
A92145	Armor Body Fragmentation Protective: For Neck & torso	8470-823-7370	Armr Bdy F/Nk-Trso SM	31.30	
A92282	Armor Body Fragmentation Protective: Neck Torso Nylon T1	8470-965-4772	Armr Bdy Nk-Trso NYS	174.00	
A92419	Body Armor Fragmentation Protective: For the Torso	8470-261-6637	Body Ar Frag Small	27.75	

Table B-IV. Armored Vehicles (Selected)

Lin	General Nomenclature	FSN	FSN Nomenclature	Unit Price	Data
V13100	Tank Combat Full-Tracked 105 MM Gun	2350-756-8497	Tank Cmbt 105MM M60A1	217,680.00	TM9235021535P
		2350-678-5773	" " " M60	147,475.00	"
D12086	Carrier Personnel Full-Tracked: Armored	2350-968-6321	Carrier Pers M113A1	30,566.00	TM9230022435P
		2350-629-1294	" " M113	27,158.00	"
A93124	Armored Recon Airborne Assault Vehicle: FT152MM	2350-873-5408	ARAAU M551 FT 152MM	214,670.00	TM9235023025P

Table B-V. Countermine Equipment Dimensions and Weight

Lin	Generic Nomenclature --Brief--	FSN	Dimensions (Inches) Length	Width	Height	Weight (lb)	Cube (cu ft)	Code
G02204	Det Set Mine: PTBL Met & Non-Met	6665-179-5120	24.0	16.0	7.8	21	1.7	ICP
"	" " " " " "	" " "	25.5	16.8	8.0	27	2.0	B
G02341	Det Set Mine: PTBL Metallic	6665-966-9072	24.8	16.5	7.5	33	1.8	ICP
G02478	Det Set Mine Trk Mtd	6665-912-1846	274.0	68.5	71.0	3500	771.2	0
"	" " " " "	" " "	152.3	66.5	55.5	3250	325.3	RED-AR-220
	Antenna & Accessories		130.0	37.8	50.0	250	142.2	C
D92017	Charge Dem: Block Comp C-4 1¼ lb M112	1375-724-7040	(11)	(2)	(1)	(1.25)	(.01)	
D93730	Charge Dem: Block TNT 1 lb	1375-028-5142	(7)	(1.75)	(1.75)	(1)	(.01)	
F91490	Dem Set Exp: Elec & Semi Elec	1375-047-3750	34.3	19.5	13.3	42	5.1	ICP
F91627	Dem Set Exp: Non-Elec	1375-047-3751	11.1	9.0	5.5	6	0.3	ICP
F90668	Dem Kit Bangalore Torpedo: M1 Series	1375-028-5247	(64.1)	(13.4)	(7.1)	(176)	(3.5)	B
F90685	Dem Kit Bangalore Torpedo: M1 Comp B	1375-526-1948	(64.1)	(13.4)	(7.1)	(176)	(3.5)	B
F91216	Dem Kit Projected Charge: M157F M.C.	1375-725-4632	(4800)	(12)	(7)	(11000)	(233.3)	
F91353	Dem Kit Projected Charge: M173	1375-812-3972	(145)	(56.5)	(24)	(3100)	(133.8)	
W38210	Tool Kit Expl Disp Squad	4925-754-0644	N.D.	N.D.	N.D.	1067	N.D.	BI
T23769	Shopset Ammo & Expl Ord Disp	1385-378-4354	N.D.	N.D.	N.D.	N.D.	N.D.	BI
W48074	Tool Kit Pioneer Eng CBPT	5180-596-1539	66.5	18.5	16.8	368	12.0	ICP
"	" " " " "	" " "	69.6	19.9	21.3	428	17.1	B
M49096	Minefield Mark Set Eng w/Comp	9905-375-9180	.0	.0	.0	854	26.3	A
E63317	Compass Magnetic: Lensatic (*Act Wt 9 oz)	6605-846-7618	5.2	4.1	0.8	*1	0.0	ICP
H68063	Flamethrower Portable	1040-586-4560	3[illegible].8	23.8	19.0	87	8.8	ICP
A92008	Body Arm Frag Prot: For Groin	8470-753-6110	18.[illegible]	14.5	2.5	4	0.4	LF
"	" " " " " " " (10 ea)	" " "	21.3	15.5	15.5	45	3.0	D.P.
A92145	Arm Body Frag Prot: For neck & Torso	8470-823-7371	23.0	19.5	2.0	10	0.5	LF
A92282	Arm Body Frag Prot: Neck Torso Nylon	8470-965-4772						
A92419	Body Arm Frag Prot: For Torso	8470-261-6637	21.0	18.0	3.0	7	0.7	LF
"	" " " " " " " (4 ea)	" " "	18.0	16.0	12.5	33	2.1	D.P.

ICP = Item Cont Pkg 0 = Operational LF = Loose Folded A = Assembled B = Boxed D.P. = Depot Packed
RED-AR-220 = Veh Reduced to Min Ship Dims

Table B-VI. Armored Vehicle Dimensions and Weight

Lin	Generic Nomenclature –Brief–	FSN	Dimensions (Inches) Length	Width	Height	Weight (lb)	Cube (cu ft)	Code
V13100	Tank, Combat, Full Tracked M60A1	2350-756-8497	325.0	144.0	128.2	97000	3472.1	0
"	" " " " "	" " "	325.0	144.0	124.4	97000	3369.2	RED-AR-220
"	" " " " M60	2350-678-5773	320.0	144.0	126.3	93000	3368.0	0
"	" " " " "	" " "	320.0	144.0	124.9	93000	3330.7	RED-AR-220
D12086	Carrier Per Full Track Arm M113A1	2350-968-6321	191.5	105.8	98.3	20125	1152.6	0
"	" " " " " "	" " "	191.5	100.0	86.5	20125	958.6	RED-AR-220
"	" " " " " M113	2350-629-1294	191.5	105.8	98.3	19755	1152.6	0
"	" " " " " "	" " "	191.5	100.0	86.5	19755	958.6	RED-AR-220
"	" " " " " M113/PLT	" " "	254.0	108.0	91.0	22150	1444.6	20 Ft Mod Plat
A93124	Arm Recon AB Assault Veh M551	2350-873-5408	248.9	110.5	112.0	29960	1782.6	0
"	" " " " " "	" " "	248.9	110.5	97.2	29960	1547.1	RED-AR-220

0 = Operational

RED-AR-220 = Veh Reduced to Min Ship Dims

APPENDIX C

CALCULATIONS FOR ENERGY EXPENDED IN BREACHING

Example 9	Fuel Rate:	6.4 gallons per hour 6.4 x 6.45 x 18000 = 743,000 Btu/hour		
	Fuel Supply:	80 gallons 80 x 6.45 x 18000 = 9,288,000 Btu		
	0.071 hour x 743,000		=	52,753
	9,288,000 x 4		=	37,152,000
				37,204,753 Btu
Example 10	1.009 hours x 743,000		=	743,000 Btu
	9,288,000 x 3		=	27,864,000
				28,607,000 Btu
Example 11	Fuel Rate:	5.3 gallons per hour 5.3 x 6.45 x 18000 = 615,330 Btu/hour		
	Fuel Supply:	158 gallons 158 x 6.45 x 18000 = 18,343,800 Btu		
	0.085 hour x 615,330		=	52,303 Btu
	18,343,800 x 9		=	165,094,000
				165,146,503 Btu
Example 12	0.97 hour x 615,330		=	596,870 Btu
	18,343,800 x 4		=	73,375,200
				73,972,070 Btu

Example 13	Fuel Rate:	20 gallons per hour 20 x 6.45 x 18,000 = 2,322,000 Btu/hour		
	Fuel Supply:	375 gallons 375 x 6.45 x 18,000 = 43,537,500 Btu		
		0.057 hour x 2,322,000	=	132,354 Btu
		43,537,500 x 2	=	87,075,000
				87,207,354 Btu (low)
		0.29 hour x 2,322,000	=	673,380 Btu
		43,537,500 x 21	=	914,287,500
				914,960,880 Btu (high)
Example 14		0.38 x 2,322,000	=	882,360 Btu
		43,537,500 x 2	=	87,075,000
				87,957,360 Btu (low)
		1.92 x 2,322,000	=	4,458,240 Btu
		43,537,500 x 7	=	304,762,500
				309,220,740 Btu (high)

ENERGY COSTS, $/Btu

	Btu/ea	Cost/ea	Cost/Btu
M15 AT	45,100	$ 21.82	$0.00048
M16 AP Frag	2.100	14.97	0.0071
M14 AP Blast	108	2.80	0.026
Charge Demo	2,100	0.77	0.00037
Bangalore	18,450	106.00	0.0057
M157 (Snake)	6,560,000	10,786.00	0.00164
M173 (Rocket)	3,526,000	8,137.00	0.0023
Gasoline	1 gallon	0.15/gallon	0.000008

APPENDIX D

EMPIRICAL EQUATION FOR BREACH TIME AND MATERIEL COST

An empirical equation has been derived for the average values of Fig. 37. The technique used is that presented in Article 167, "Numerical Mathematical Analysis," by James B. Scarborough, Sixth Edition.

The equation is $y = 205{,}900\ x^{-0.426701}$, where y = materiel cost in dollars and x = breach time in hours. The equation should be reasonably accurate since it is noted that the residuals are of varying signs and the sum of the squares of the residuals is small.

The equation was derived as follows:

Example No.	Breach Time (Hours) x	Materiel Cost (Dollars) y
M113-9	.043	61,000
M551-11	.05	966,000
M60-13	.17	2,433,000
M551-12	.53	430,000
M113-10	.6	46,000
M60-14	1.15	910,000
Dism-7	2.3	224,000
Dism-6	3	226,000
M551-17	3.8	367,000
M113-15	4.43	80,500
M60-19	5.9	466,000
M551-18	18	206,000
M113-16	21	51,500
M60-20	23.7	211,000
Dism-2	25.3	27,500
1-4-8 MF	48	105,000
Dism-8	81.5	39,000
Dism-4	501	12,000

$y = ax^n$

therefore $\text{Log } y = \text{Log } a + n \text{ Log } x$

The residuals are really:

$v_1 = ax_1^n - y_1, \; v_2 = ax_2^n - y_2$, etc.

But, with little error:

$v_1' = \text{Log } a + n \text{ Log } x_1 - \text{Log } y_1$

$v_2' = \text{Log } a + n \text{ Log } x_2 - \text{Log } y_2$

etc.

$V_1' = \text{Log } a + \bar{2}.633468n - 4.785330$

$v_2' = \text{Log } a + \bar{2}.698970n - 5.9894977$

$v_3' = \text{Log } a + \bar{1}.230449n - 6.386142$

$v_4' = \text{Log } a + \bar{1}.724276n - 5.633468$

$v_5' = \text{Log } a + \bar{1}.778151n - 4.662758$

$v_6' = \text{Log } a + 0.060698n - 5.959041$

$v_7' = \text{Log } a + 0.361728n - 5.350248$

$v_8' = \text{Log } a + 0.477121n - 5.354108$

$v_9' = \text{Log } a + 0.579784n - 5.564666$

$v_{10}' = \text{Log } a + 0.646404n - 4.905796$

$v_{11}' = \text{Log } a + 0.770852n - 5.668386$

$v_{12}' = \text{Log } a + 1.255273n - 5.313867$

$v_{13}' = \text{Log } a + 1.322219n - 4.711807$

$v_{14}' = \text{Log } a + 1.374748n - 5.324282$

$v_{15}' = \text{Log } a + 1.403121n - 4.439333$

$v_{16}' = \text{Log } a + 1.681241n - 5.021189$

$v_{17}' = \text{Log } a + 1.911158n - 4.591065$

$v_{18}' = \text{Log } a + 2.699838n - 4.079181$

$18 \text{ Log } a + 4.478871 n = 93.735644$

$4.478871 \text{ Log } a + 44.5297978980 n = 4.79852765297$

or

$$\left.\begin{aligned} 44.529798n + 4.478871 \text{ Log } a &= 4.798528 \\ 4.478871n + 18 \text{ Log } a &= 93.735644 \end{aligned}\right\} \text{Normal Equations}$$

$$n = \frac{\begin{vmatrix} 4.798528 & 4.478871 \\ 93.735644 & 18 \end{vmatrix}}{\begin{vmatrix} 44.529798 & 4.478871 \\ 4.478871 & 18 \end{vmatrix}} = \frac{-333.456354}{781.476078} = 0.426701$$

$$\text{Log } a = \frac{\begin{vmatrix} 44.529798 & 4.798528 \\ 4.478871 & 93.735644 \end{vmatrix}}{781.476078} = \frac{4152.537305}{781.476078} = 5.313710$$

therefore: $a = 205{,}900$

$v'_1 = 1.652083$

$v'_2 = 0.480386$

$v'_3 = -0.546387$

$v'_4 = 0.415992$

$v'_5 = 1.409691$

$v'_6 = -0.671231$

$v'_7 = -0.190888$

$v'_8 = -0.243986$

$v'_9 = -0.498350$

$v'_{10} = 0.132093$

$v'_{11} = -0.683599$

$v'_{12} = -0.535783$

$v'_{13} = 0.037711$

$v'_{14} = -0.597178$

$v'_{15} = 0.275664$

$v'_{16} = -0.424866$

$v'_{17} = -0.092848$

$v'_{18} = 0.082505$

$\Sigma V_i^2 = 7.616736$