USE OF INDUSTRIAL DYNAMICS IN THE SIMULATION OF MILITARY COMBAT MODELS

A MASTER'S RESEARCH PAPER

Presented to

The Faculty of the School of Industrial Engineering

by

Louis Edward Abele

In Partial Fulfillment

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OF MILITARY COMBAT MODELS

Approved:

Chairman

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PREFACE

This project was originally initiated as a Special Problem, carrying 3-hours credit, in partial fulfillment of the non-thesis requirements for the degree of Master of Science in Industrial Engineering. As the work progressed, my advisor-Dr. Joseph Krol-felt that the results obtained were significant enough to warrant their publication. Since there was inadequate time to change from the non-thesis to the thesis program, it was decided to term this study a Master's Research Paper and to process it according to the regulations governing a Master's Thesis.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. Joseph Krol-a patient, skilled, and knowledgeable mentor-for his encouragement in my studies and his invaluable advice in the preparation of this research paper.

Special recognition is also given to Mr. Leon Kinard and the staff of the Rich Electronic Computer Center for their trying efforts in adapting the Burrough's Dynamo program to a disc system.

Finally, I am indebted to the patience of Mrs. Donna Linn in the typing of this study.

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GLOSSARY OF SYMBOLS USED

Symbol Term Represented

AARR . . . Actual Ammunition Resupply Rate
ACAS . . . Auxiliary Casualty Rate - Total
ACDF . . . Auxiliary Casualty Rate - Direct Fire
ACIF . . . Auxiliary Casualty Rate - Indirect Fire
ADES . . . Ammunition Desired
ADEL . . . Ammunition in Transit Delay
AMER . . . Ammunition Expenditure Rate
AMMO . . . Ammunition on Hand
AINF . . . Actual Indirect Fire Received Rate
AINT . . . Ammunition in Transit
ARNF . . . Ammunition Resupply Decision with No Firefight
ARRW . . . Ammunition Resupply Rate with Firefight
ARWF . . . Ammunition Resupply Decision with Firefight
AROF . . . Actual Platoon Rate of Fire
ARRN . . . Ammunition Resupply Rate with No Firefight
AREQ . . . Ammunition Requisitioned
ASAR . . . Auxiliary Straggler Ammunition Removal Rate
ASTG . . . Auxiliary Straggler Rate
BSTR . . . Battlefield Strength
CASR . . . Casualty Rate
CARR . . . Casualty Ammunition Removal Rate
CLIP . . . Special Function*
CLOK . . . Model Time
DINF . . . Desired Indirect Fire Rate
DROF . . . Desired Direct Fire Rate
DT . . . . Delta Time
DTVF . . . Desired Total Volume Fire
DVOL . . . Desired Volume of Indirect Fire
ECDF . . . Enemy Capability of Direct Fire
ECIF . . . Enemy Capability of Indirect Fire
EFFF . . . Effectiveness of Enemy Direct Fire
EINF . . . Intensity of Enemy Direct Fire
EINI . . . Intensity of Enemy Indirect Fire
EINT . . . Total Intensity of Enemy Fire
ESDF . . . Smoothed Direct Fire Capability of Enemy Fire
IROE . . . Incremental Rate of Desired Direct Fire
LDIF . . . Level of Desired Indirect Fire
LENGTH . . Time Length of Model Run*
MIN . . . Special Function*
NAMC . . . Negative Casualty Ammunition Removal Limit

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*See Dynamo User's Manual (13)

GLOSSARY OF SYMBOLS (Continued)

Symbol	Term Represented
NAMS . . .	Negative Straggler Ammunition Removal Limit
NEGC . . .	Negative Casualty Limit
NEGS . . .	Negative Straggler Limit
NORMRN . .	Special Function*
PLAT . . .	Pipeline Ammunition Test
PLOT . . .	Plot the Variables of Interest*
PLTPER . .	Plot at the Specified Time*
PREQ . . .	Positive Ammunition Requisition
PRFM . . .	Possible Rate of Fire Per Man
PRINT . .	Print-out Variables of Interest*
PRTPER . .	Print-out at the Specified Time*
PROF . . .	Possible Rate of Fire
PSTG . . .	Positive Straggler Rate
PULSE . .	Special Function*
RAWF . . .	Requested Ammunition with Firefight
RATO . . .	Ratio of Fire
RETR . . .	Straggler Return Rate
SAIR . . .	Straggler Ammunition Increase Rate
SAML . . .	Straggler Level of Ammunition
SARR . . .	Straggler Ammunition Removal Rate
SDEL . . .	Straggler Delay
SPEC . . .	Specification Card*
STGL . . .	Straggler Level
STEP . . .	Special Function*
STRG . . .	Straggler Rate
SWITCH . .	Special Function*
TABHL . .	Special Function*
TBL . . .	Table
TCAR . . .	Tried Casualty Ammunition Removal Rate
TOTA . . .	Total Ammunition on Hand and in Transit
TSAR . . .	Tried Straggler Ammunition Removal Rate

CHAPTER I

INTRODUCTION

1.1 The Nature of the Problem

Ninety-nine per cent of the time the battlefield is a place of emptiness, desolation, and solitude. It erupts the other one per cent of the time into a holocaust of numerous, small, isolated firefights, extremely sporadic in nature.

The basic ingredient of battle is fire; and as stated by the Honorable Robert B. Patterson, Secretary of War during World War II: "Finally, it is the volume of fire that counts. You win if you can kill more of the enemy than he can kill of you. If you cannot, you are defeated (1, p. 64)." Yet as simple as this principle is, its execution is one of the most complicated problems in the nature of warfare. General S. L. A. Marshall ably stated this problem in the following words: "The rarest thing in all battle is fire in good volume, accurately delivered, and steadily maintained (1, p. 66)."

Military historians describe battles in great detail. However, the victor has never been satisfactorily predicted because the variables of warfare are far too numerous and dynamic (i.e. varying over time).

1.2 Objectives

The purpose of this paper is to illustrate the construction of military combat models by the use of the industrial dynamics technique developed by Professor Jay W. Forrester and his associates at the Massachusetts Institute of Technology (11). The end objective is to develop a simulated model of an infantry rifle platoon and its fire upon the battlefield.

1.3 Scope and Limitations

The general model to be developed is to portray the time-varying behavior of an infantry rifle platoon over a 24-hour period. The initial model shows only the decline in firepower due to casualties sustained from enemy direct fire; however, more sophisticated models portray the effects of stragglers, ammunition supply, and indirect fire upon the platoon's rate of fire. The platoon undertakes a hasty defense of a position under the conditions of conventional warfare. A further assumption is made that upon losing two-thirds of its initial strength during the period considered, the platoon becomes ineffective as a combat unit and must be replaced immediately or the position lost.

1.4 Literature Search

1.4.1 Early Development

The earliest attempts to develop a science of military conflict culminated in a set of maxims named the principles of war. These principles are some nine or ten in number depending upon the interpretation followed. The United States Army in an official publication, American Military History 1607-1958, states: "The principles of war are interrelated. They are not absolute and have been successfully violated at times, but only for very special reasons that had been carefully considered beforehand (2, p. 3)."

Military historians, such as Jomini, Clausewitz, duPicq, Mahan, Foch, Douhet, and Fuller, have been notably lacking in quantitative thought. Clausewitz only goes so far as to state that the reserve should consist of from one-third to one-half the strength of the force (4, p. 56).

1.4.2 Lanchester Equations

The first mathematical model to achieve limited success was proposed around 1916 by F. W. Lanchester in connection with aerial combat (7). The two sets of differential equations he advanced have become known as Lanchester's linear law and Lanchester's square law of warfare. An excellent review and the present state of development of these equations is to be found in Major James Robinson's thesis (8). The development has not been notably successful due to the required use of differential equations to handle the dynamics of the problem, the mathematical difficulties encountered in manipulating more than several variables, and the general lack of quantitative data concerning military combat.

1.4.3 Use of Computers

With the advent of computers in the late 1950's, a new and promising field was opened. A sophisticated computer model has been developed by the United States Army Strategy and Tactics Analysis Group (STAG) at Bethesda, Maryland (10). Its war games include such variables as weather, terrain, movement, fire, supply and replacements put in at various levels. The computer can handle not only the numerous variables of battle, but can also provide the dynamics required.

While such programs are ideal for military "war-gaming", they are not necessarily best suited for the purposes of military research. In the latter case, the user must fully understand the parameters, the variables, and the dynamic relationships which have been programmed into the model. To do otherwise requires blind faith in the ability of the programmer and of the programs used. Understanding the program is difficult even to the experienced programmer due to the nature of the present computer languages and the method of constructing flow diagrams.

1.4.4 Industrial Dynamics

Professor Jay W. Forrester developed industrial dynamics in the early 1960's. Essentially, this technique involves the formulation of a model of the dynamic behavior of an industrial organization by means of an easily understandable computer language known as Dynamo. Several examples of industrial sophisticated models are detailed in

Dr. Forrester's book, Industrial Dynamics (11).

The industrial dynamics approach, readily handling as many as 2,000 variables and being dynamic in nature, is also applicable to military organizations. Delay functions, so necessarily a part of warfare, are easily handled by the Dynamo language.

1.5 The Rifle Platoon

1.5.1 Organization

The rifle platoon (infantry) consists of 44 men organized into three rifle squads, one weapons squad, and a platoon headquarters as shown in Figure 1.

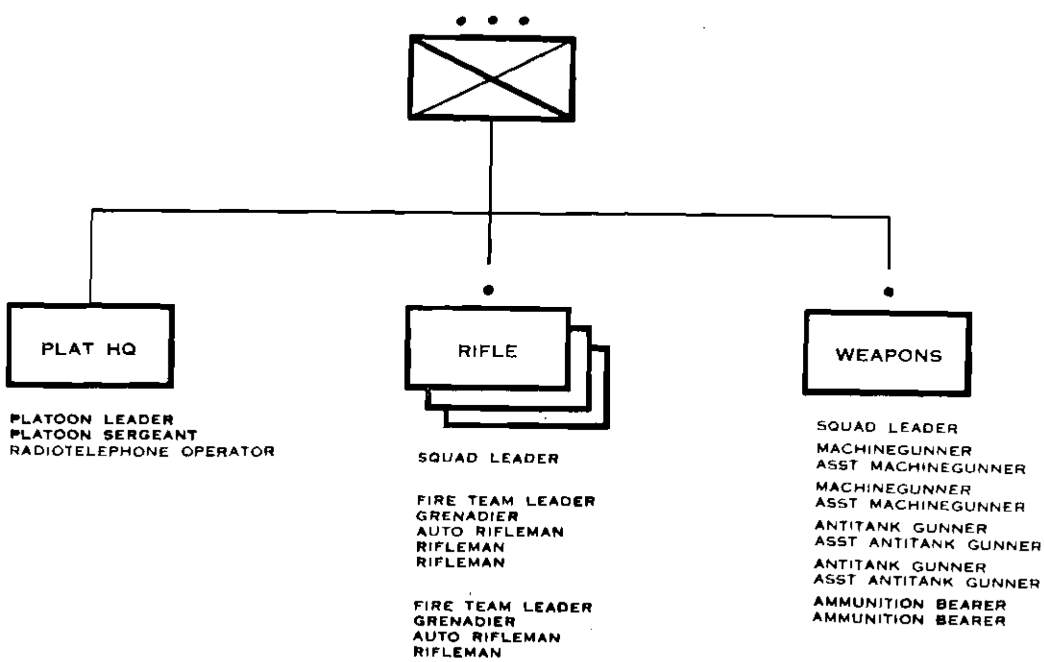

Figure 1. The Rifle Platoon.
(Adapted from FM7-15 (9, p. 5))

1.5.2 Mission

The United States Army Field Manual 7-15 states: "The basic mission of the rifle platoon is to close with the enemy by means of fire and maneuver in order to destroy or capture him, or to repel his assault by fire and close combat (9, p. 3)." A concept of a rifle platoon accomplishing the latter part of this mission is illustrated in Figure 2.

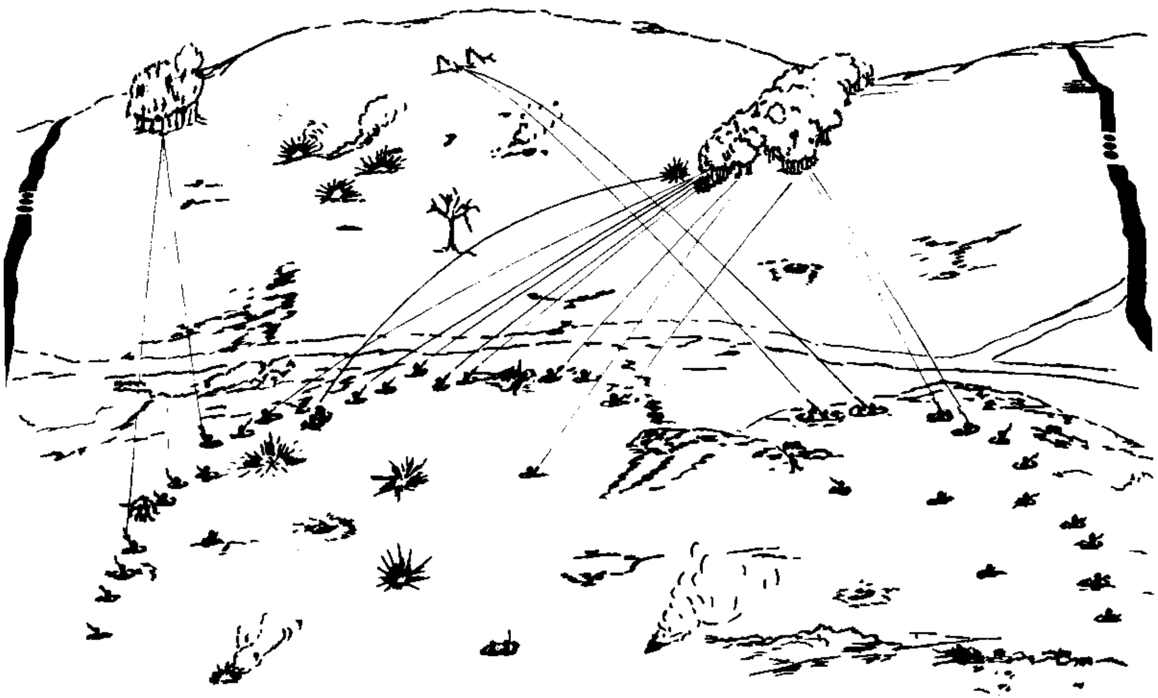

Figure 2. A Rifle Platoon Repelling an Assault.

1.5.3 Weapons and Communications

The weapons of the rifle platoon consist of thirty 7.62 mm rifles (light barrel), two 7.62 mm rifles (heavy barrel), six 40 mm grenade launchers, two 3.5 in rocket launchers, and fourteen caliber .45 automatic pistols (15, p. 133). Each rifleman carries 100 rounds of ammunition and there is an additional 100 rounds per rifleman on carrier in the company trains (15, p. 304).

The platoon has six AN/PRC-6[1] radios and six TA-1/PT[2] telephones for internal communication. The telephones are used primarily in defensive positions. An AN/PRC-25 radio is used for external communications to the company command post (15, p. 133).

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[1]Army Navy/Portable Radio Communication

[2]Telephone Apparatus-1/Power Telephone

CHAPTER II

PRELIMINARY MODEL FORMULATION

2.1 Model Description

In industrial dynamics, a large number of variables may be considered for inclusion in a model. These variables are divided into two parts: (1) a set of "endogenous" variables, each of which is directly influenced by the current or lagged value of other variables in the set (and/or by its own lagged values), and (2) a set of "exogenous" variables which have influence on the endogenous variables but are not influenced by them.

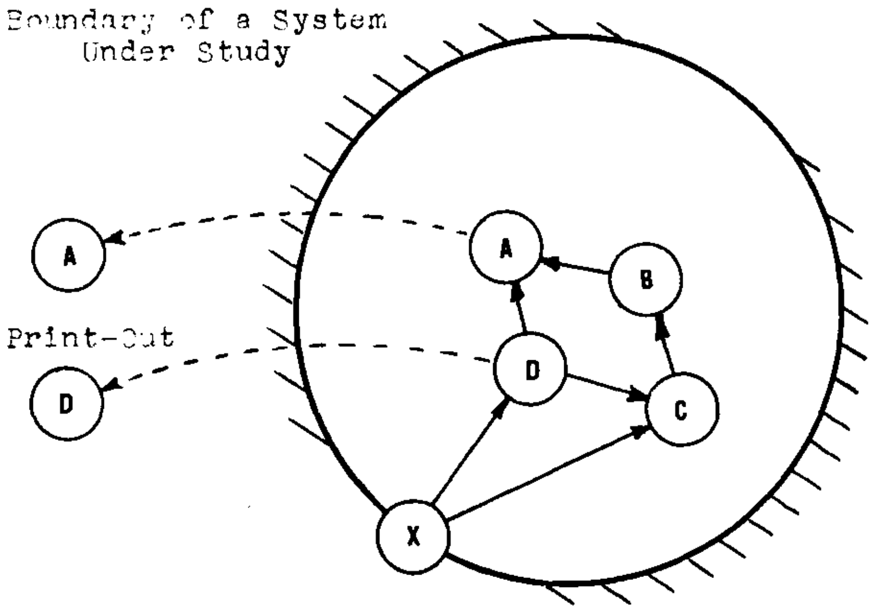
Any industrial dynamics model, however complex, consists of three parts:

(1) Input, which is represented by a set of exogenous variables,

(2) The structure of the simulated system, which is represented by a set of endogenous variables, and

(3) Output, which consists of a time-dependent printout and plot of the values of selected endogenous and/or exogenous variables.

Figure 3 shows graphically the relationships between the three parts of an industrial dynamics model. Input is represented by an exogenous variable "X"; the structure of the simulated system is represented by the endogenous variables "A", "B", "C", and "D"; and the output is represented by the selected variables "A" and "D".



A,B,C,D: Endogenous Variables

X : Exogenous Variable

Figure 3. Industrial Dynamics Model Concept.

The first consideration in construction of a model is the scope of the system to be simulated. This scope may later be enlarged or reduced, but an initial determination of the general outline of the boundaries of the system must be established. In this research the general boundaries of the system are the rifle platoon. A few, but by no means all, of the endogenous variables of this system are battlefield strength, casualty rate, rate of fire, and ammunition resupply. Other endogenous variables are added as the model is developed.

The second consideration is the establishment of one or more exogenous variables. In the case of the rifle platoon, that variable which exerts the most influence over the behavior of the platoon and over which the platoon exerts no influence is the capability of the enemy to deliver fire against it. The enemy has the capability of delivering two types of fire against the platoon: (1) direct fire primarily from small arms, and (2) indirect fire from mortars and artillery. The platoon, by its own means, can influence the enemy's effective use of his direct fire capability; the platoon cannot influence by its own means the enemy's effective use of his indirect fire means. Therefore, in the initial model only the enemy's direct fire capability is considered; however, later models developed in this study consider both means. In the initial model a constant input of 4000 rounds per hour is used for the enemy capability of direct fire. In later models several types of variable inputs are considered.

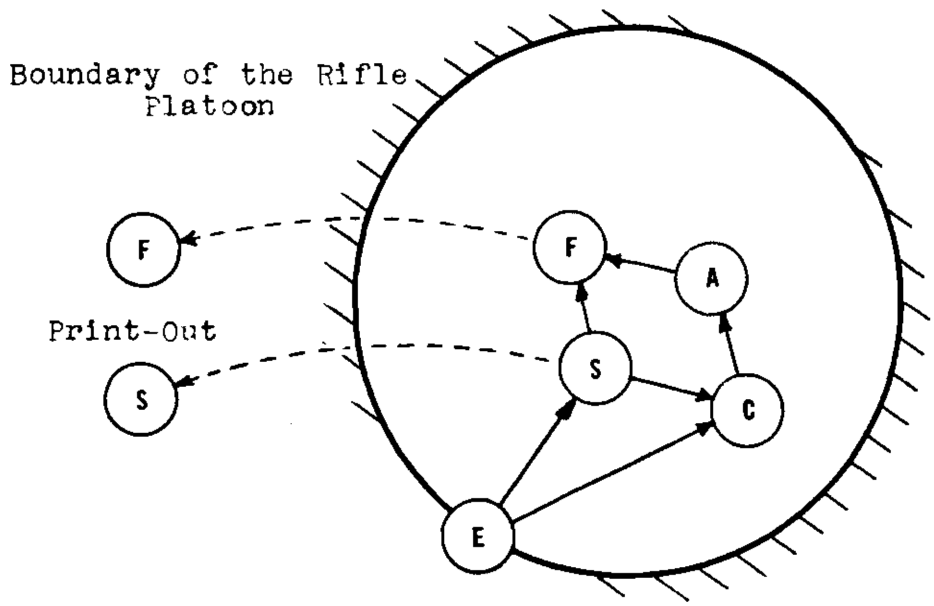
Figure 4 shows the preliminary model which has so far been suggested:

(1) An exogenous input of an enemy capability to deliver direct fire (E).

(2) Endogenous variables of battlefield strength (S),

casualty rate (C), ammunition level (A), and rate of fire (F), and

(3) Output showing the values of the platoon's rate of fire (F) and strength (S), both as a function of time.



A: Ammunition Supply
C: Casualty Rate
F: Rate of Fire
S: Platoon Strength
E: Enemy Capability of Fire

Figure 4. Preliminary Rifle Platoon Model.

2.2 Primary Parameters and Relationships

Although many parameters and relationships will be developed before completion of the initial model, a few principal ones require consideration before the details of the model are developed. Among these are the number of rounds per casualty, the ratio of fire between combatants, and the effectiveness of the enemy fire capability.

2.2.1 Casualties

Because numerous variables such as range, terrain, ratio of fire, and supply establish the parameter value for the number of rounds required to produce a casualty, no value or approximation is found in the textbooks. An estimate may be attained experimentally by firing at silhouette targets arranged as a platoon in a hasty defensive position from a nominal distance (say 300 meters). The number of rounds producing one casualty is attained by dividing the number of rounds fired by the number of targets hit.

Without experimentation, the problem is approached in another manner. To an attacker, the rifle platoon offers targets which are irregularly arrayed, behind cover, and difficult to detect (14, p. 4). The enemy therefore fires into the general area of the platoon and not at a specific target. Since a defender usually entrenches on high ground, the assumption is made that the slope of the defended ground will be 30°, as shown in Figure 5. The primary defensive positions of the platoon on the forward slope of the hill cover an area some 400 meters wide and 100 meters deep as shown in Figure 6. With enemy fire directed at this area from a 30° angle, the area to be targeted by the enemy is:

$$\text{Area} = 400 \text{ m} \times 100 \text{ m} \times \sin 30^\circ = 20{,}000 \text{ m}^2$$

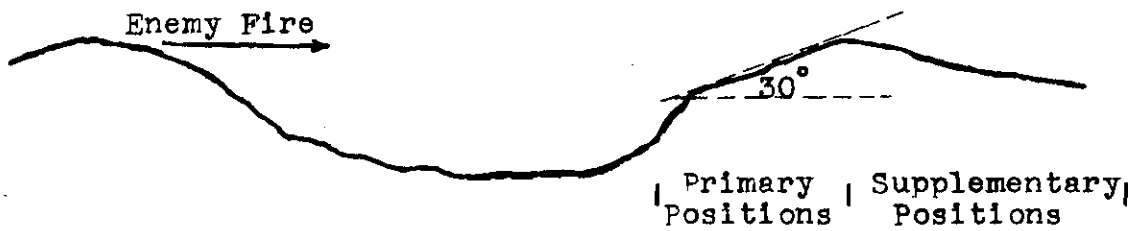


Figure 5. Typical Platoon Defensive Position.
(Not to Scale)

Since the platoon will make the most of cover, the target usually offered to the enemy is that of a rifleman

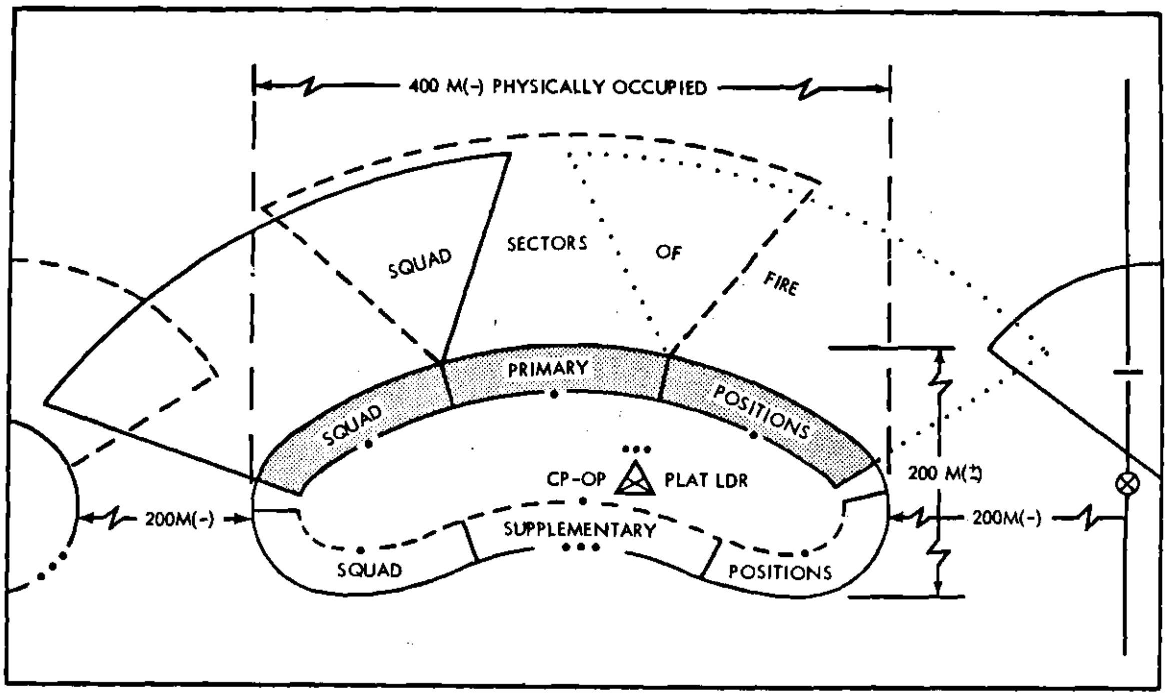


Figure 6. Platoon Defensive Position (Schematic).
(Adapted from FM7-15 (9, p. 106))

from the shoulders up as seen in Figure 7. Converting to the metric scale, the area of a target is:

$$\text{Area} = \frac{24 \text{ in}}{39.4 \text{ in/m}} \times \frac{18 \text{ in}}{39.4 \text{ in/m}} = 0.278 \text{ m}^2$$

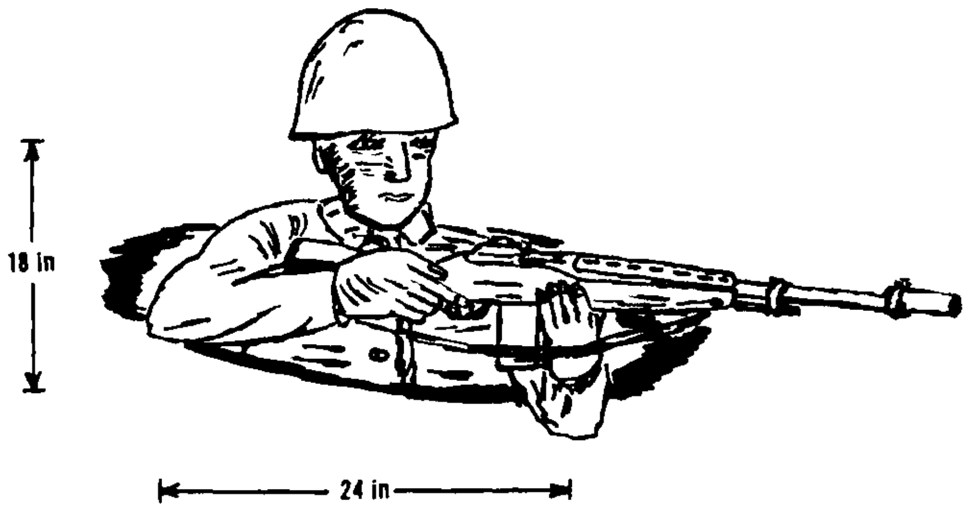


Figure 7. Typical Battlefield Target.

To cover the area occupied by the platoon and place one round in each 0.278 m^2 area, the following number of rounds is required:

$$\text{Number of Rounds} = \frac{20{,}000 \text{ m}^2}{0.278 \text{ m}^2} = 72{,}000$$

Assuming that all 44 men become casualties by the blanketing of the area with 72,000 rounds, 1650 rounds are required to produce a casualty.

It may be argued that the enemy will not systematically place a round in each 0.278 m^2 area of the platoon target, instead some areas will be overshot and some not hit at all, and that some of the platoon in a given instant will be totally behind cover. One may also theorize that rougher terrain requires additional rounds per casualty and that at night the number increases astronomically. But, a beginning must be made; for the purposes of this study, 1650 rounds produce one casualty.

2.2.2 Ratio of Fire

One of the more important endogenous variables is that of the ratio of friendly fire to the enemy capability to deliver direct fire. This ratio (hereafter called the ratio of fire) is important because the ability of a combatant to maneuver depends upon it. Most military men consider that a favorable two-to-one ratio permits relative freedom of maneuver and consequently a better placement and delivery of fire. Unfortunately for computer usage this ratio cannot remain as stated; for as the enemy capability to deliver fire approaches zero, the ratio of fire becomes infinite. To preclude such a possibility, the ratio of fire is therefore approximated by the following equation:

$$\text{Ratio of Fire} = \frac{1 + \text{Platoon Rate of Fire}}{1 + \text{Enemy Capability of Direct Fire}}$$

This approximation is adequate for use in any industrial dynamics model.

2.2.3 Effectiveness of Fire Concept

Upon being engaged by the enemy, the rifle platoon returns the fire, attempting to gain and maintain fire superiority (14, p. 16). If the platoon can maintain a two-to-one ratio of fire, then the effectiveness of the enemy firing capability is extremely low--say, near 15 per cent. In other words, the enemy soldier is pinned to the ground, is unable to maneuver and will in fact not "raise his head"; consequently his firing capability remains largely unused. On the other hand, if the platoon cannot maintain superiority and the ratio of fire falls to one-half, then the enemy has gained freedom of maneuver and may be expected to use his capability to deliver fire to the utmost. The effectiveness of the enemy capability is now near 100 per cent. If the

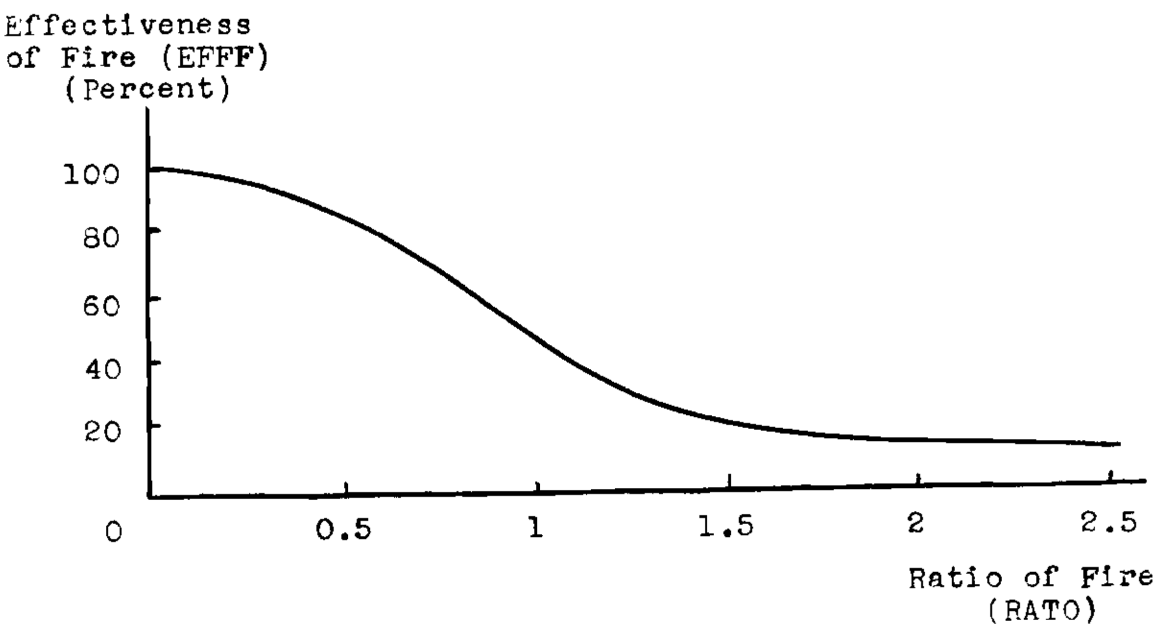


Figure 8. Effectiveness of Enemy Fire Concept.

ratio is near one, with neither side possessing superiority of fire, then the enemy should be expected to be able to utilize 50 per cent of his capability. This concept is embodied in Figure 8.

2.3 Programming in Dynamo

2.3.1 Delta Time

Inherent in any dynamic problem is the concept of incremental time, that is the span from one time period to the next. In industrial dynamics this incremental time is known as "Delta Time" (DT). Time lagging one period in the past is represented by the letter, "J"; present time is known as "K", and time one increment into the future is time "L" as shown in Figure 9.

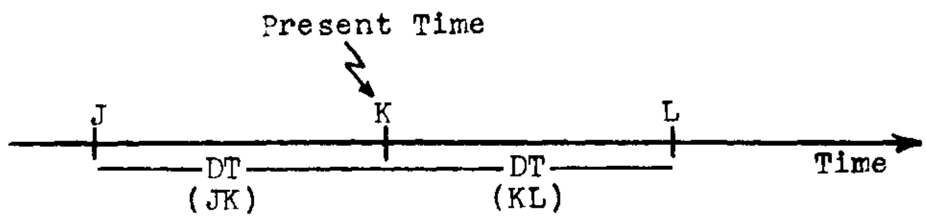


Figure 9. Dynamo Time Concept.

Delta Time may be established as large or as small as desired; but it is to be remembered that any decision made at the start of a period must apply without change throughout the period (11, p. 74). If the decision does not apply throughout the period, then DT should be decreased until it does. In this study, DT is taken as 1/16th of an hour (approximately 3.75 minutes). Delta Time may be readily changed even after completion of the model; however, it may not be changed during an actual run of the program.

2.3.2 Level Equations

Resources such as men, weapons, and ammunition are placed into the model by "level" equations. Levels may be considered as tanks or boxes which hold an amount of the resource, and they are represented on the flow diagram by a rectangle such as shown in Figure 10.

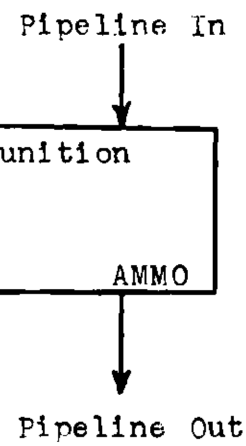


Figure 10. Dynamo Level Symbol.

The present level (K) is always equal to the level one time period ago (J) plus or minus the rate of the particular resource flowing into or out the level during the intervening time (JK). This statement forms the basis for all level equations.

Each type of resource has its own distinct symbol showing its flow into and out of a particular level. For example, Professor Forrester distinguishes five types of flows other than information flow, namely: materials, orders, money, personnel, and capital equipment.

2.3.3 Rate Equations

The flow of a resource into or out of a level is known as a "rate". The rate equation may be considered as a valve on a pipeline which permits resources to flow from one tank into another tank. This rate decision is represented by the symbol of a butterfly valve as shown in Figure 11.

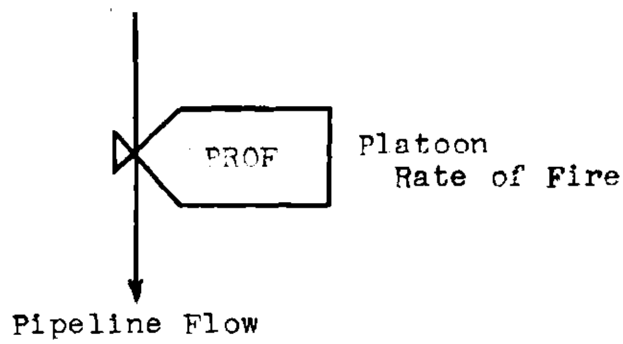


Figure 11. Dynamo Rate Symbol.

The rate for the future time interval (KL) is always dependent upon the state of the levels at the present time (K) and the rate of flows during the incremental time just past (JK).

2.3.4 Auxiliary Equations

In the real world, decisions are seldom based upon the state of just one flow or one level; rather the states of several flows and rates are usually combined along with certain parameters. For example, the platoon's rate of fire may depend upon the considerations of the intensity of enemy fire, the desire to maintain a two-to-one ratio of fire, and the level of ammunition on hand. The auxiliary equations "tie" the levels, pipelines, and rates together; they represent auxiliary decisions in the flow of information within the model. Auxiliary equations are represented by circles; the flow of information (from levels, rates, and other auxiliary variables) is represented by broken arrows as shown in Figure 12. Auxiliary variables are always computed at the present time (K) from the latest information available, i.e., time K from levels, time JK from rates, and time K from other auxiliaries. An auxiliary symbol must always have information flow in and information flow out (except in the case of the exogenous variable when information may only flow out).

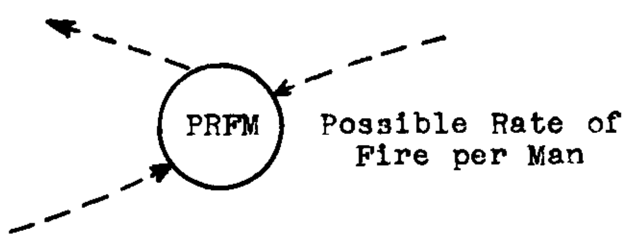


Figure 12. Dynamo Auxiliary Symbol.

2.3.5 Initial Conditions

As in the case of differential and difference equations, initial conditions for the system under study must be established. Each level and rate equation requires an initial condition. As auxiliary values are computed from information received from level, rate, and other auxiliary equations, they require no initial conditions; the auxiliary equations are simply centers of information exchange.

2.3.6 Constants

A constant may be specified in the body of a level, rate, or auxiliary equation; or it may be expressed as separate parameter of the system. For example, Delta Time is a parameter of the system and is expressed as:

$$DT = 0.0625$$

2.3.7 Equation Format

Dynamo requires each equation to follow a specified format. The formats available for use are listed in the Dynamo User's Manual (13, p. 52). Adequate formats exist to express most algebraical equations with a little rearrangement; certain special function formats also exist. Each format is numbered and this number must be punched into the first space available on the IBM card. Each number is followed by the letter representing the type of equation, e.g.: L for level, R for rate, A for auxiliary, N for initial condition, and C for constant.

CHAPTER III

THE INITIAL MODEL

3.1 Battlefield Strength

Construction of a model best begins with the development of the level equation of foremost interest. In the case of the rifle platoon, the battlefield strength (BSTR) is such a level; it is the only level to be found in the flow diagram of the initial model as shown in Figure 13. As replacements are not received on the battlefield, the battlefield strength (BSTR) is dependent only upon the casualty rate (CASR). The level equation for the battlefield strength (BSTR) is written:

1L[1] BSTR.K=BSTR.J+(DT)(0-CASR.JK)[2]

This equation states that the battlefield strength at the present time (BSTR.K) equals the strength at a time one incremental period in the past (BSTR.J) minus the casualty rate (CASR.JK) during the incremental period (DT). The initial strength of the platoon is 44 men:

6N BSTR=44

[1]Equation format number (13, p. 52).

[2]The zero is used to follow the specified Dynamo equation format.

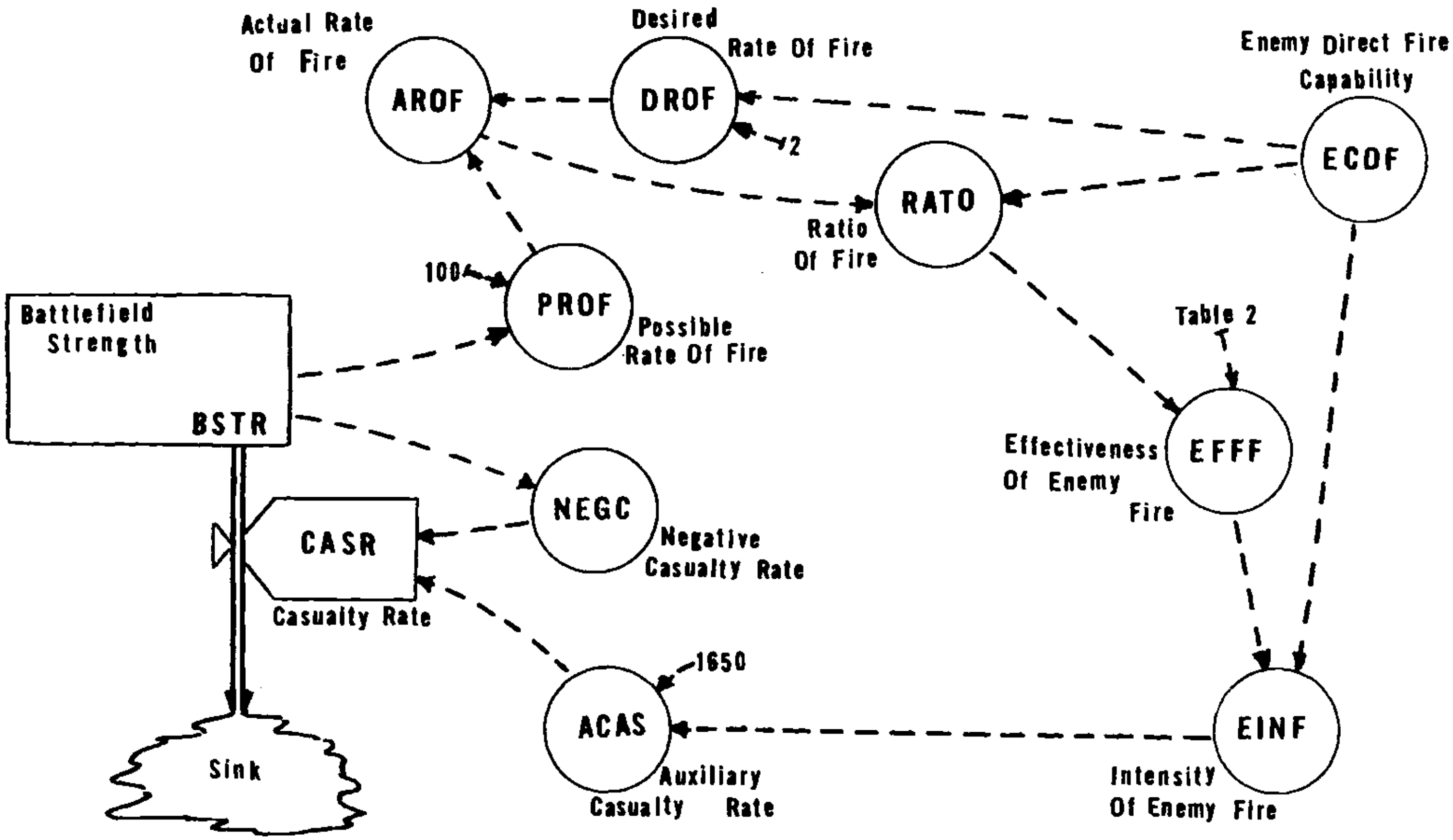


Figure 13. Flow Diagram of the Initial Model (I).

3.2 Casualty Rate

If the casualty rate (CASR) should exceed the strength of the platoon (BSTR) within a given incremental time, a negative platoon strength would result. This occurrence is prevented by establishing a negative casualty limit which the casualty rate cannot exceed:

```
20A    NEGC.K=BSTR.K/DT
```

Use is now made of an "auxiliary" casualty rate (ACAS) which is defined as the casualty rate with no limitations. This variable is dependent upon the intensity of enemy fire (EINF) and the casualty parameter (1650 rounds per casualty) previously established.

```
20A    ACAS.K=EINF.K/1650
```

The actual casualty rate (CASR) becomes the lesser of the auxiliary casualty rate (ACAS) or the negative casualty limit (NEGC):

```
54R    CASR.KL=MIN(ACAS.K,NEGC.K)
6N     CASR=0
```

3.3 Enemy Fire

The intensity of enemy fire (EINF) is dependent upon the capability of enemy to deliver direct fire (ECDF) and the effectiveness of this fire (EFFF):

```
12A    EINF.K=(EFFF.K)(ECDF.K)
```

The enemy capability to deliver direct fire (ECDF) is the exogenous variable and has been discussed previously. For the first model, designated Model 1-4000(I), a constant rate of 4000 rounds per hour is arbitrarily established after an initial period of one hour, during which time the enemy capability will be zero. This initial value of zero is purposely programmed to insure that stability exists in the model at the start of the time under consideration.

```
45A    ECDF.K=STEP(4000,1)
```

The effectiveness of enemy fire (EFFF) is dependent upon the ratio (RATO) of friendly fire to the enemy capability of fire as shown in Figure 8. This graph is translated into the Dynamo language (13, p. 38):

```
58A    EFFF.K=TABHL(TBL2,RATO.K,0,2.5,0.5)
C      TBL2*=1/0.9/0.5/0.3/0.2/0.15
```

The ratio (RATO) of actual friendly fire (AROF) to the enemy capability of fire (ECDF) has been previously discussed and is written:

```
26A    RATO.K=(1+AROF.K+0)/(1+ECDF.K+0)
```
[1]

3.4 Fire of the Platoon

There exists for the platoon a possible rate of fire (PROF) which is established by the ammunition resupply rate.

[1]The zeroes are used to follow the specified Dynamo equation format.

If the assumption is made that ammunition can be resupplied each hour, then the hourly rate of fire per rifleman is his basic load of 100 rounds:

12A PROF.K=(100)(BSTR.K)

It is obvious, however, that if the enemy fires at a rate of one round per hour, the platoon does not desire to fire at a rate of 4400 rounds per hour. Once the two-to-one ratio of fire is established, the platoon has little to gain by firing at a greater rate. In reality, as the platoon is never assured of an ammunition resupply, it will tend to conserve ammunition. The platoon, therefore, has a desired rate of fire (DROF) which is two times the enemy capability:

12A DROF=(2)(ECDF.K)

The actual rate of fire (AROF) becomes the lesser of either the desired rate of fire (DROF) or the possible rate of fire (PROF):

54A AROF.K=MIN(PROF.K,DROF.K)

The equations relating to the flow diagram shown in Figure 8 have been completed.

3.5 Run Equations

To obtain print-out and plot of the variables of interest, the following two cards are required:

```
PRINT 1)BSTR/2)AROF/3)RATO/4)EINF
PLOT  BSTR=S(0,60)/AROF=F,EINF=E(0,12000)/RATO=R(0,4)
                                          AMMO=A(0,10000)
```

The figures in parentheses indicate the scale desired in the plot.

The duration of Delta Time, the total length of time being considered, and the intervals of time at which to print and plot the variables of interest are placed on a specification card. DT is already established as one sixteenth of an hour (0.0625). The values of the variables of interest are printed each half-hour in time and plotted each quarter of an hour:

```
SPEC  DT=0.0625/LENGTH=24/PRTPER=0.5/PLTPER=0.25
```

A run card to initiate action by the Dynamo program is also required:

```
RUN
```

3.6 Analysis

3.6.1 Model 1-4000(I)

These equations are now punched, along with the format numbers and letters on IBM cards, a deck is assembled and a pass made through the computer. The resulting output is shown in Figure 14 (a card listing), Figure 15 (print-out of the variables of interest), and Figure 16 (plot of the variables of interest).

```
RUN
NOTE SIMULATED RIFLE PLATOON,IE704, LOUIS E ABELE, DR JOSEPH KROL
45A    ECDF.K=STEP(4000,1)                        ENEMY CAPABILITY OF DIRECT FIRE
1L     BSTR.K=BSTR.J+(DT)(0-CASR.JK)              BATTLEFIELD STRENGTH
6N     BSTR=44                                    INITIAL CONDITION
54R    CASR.KL=MIN(ACAS.K,NEGC.K)                 CASUALTY RATE
6N     CASR=0                                     INITIAL CONDITION
20A    NEGC.K=BSTR.K/DT                           NEGATIVE CASUALTY LIMIT
20A    ACAS.K=EINF.K/1650                         AUXILIARY CASUALTY RATE
12A    EINF.K=(EFFF.K)(ECDF.K)                    ENEMY INTENSITY OF FIRE
58A    EFFF.K=TABHL(TBL2,RATO.K,0,2.5,0.5)        EFFECTIVENESS OF ENEMY FIRE
C      TBL2*=1/0.9/0.5/0.3/0.2/0.15               TABLE 2
54A    AROF.K=MIN(PROF.K,DROF.K)                  ACTUAL RATE OF FIRE
12A    DROF.K=(2)(ECDF.K)                         DESIRED RATE OF FIRE
12A    PROF.K=(100)(BSTR.K)                       POSSIBLE RATE OF FIRE
26A    RATO.K=(1+AROF.K+0)/(1+ECDF.K+0)           RATIO OF FIRE FRIEND TO ENEMY
PRINT  1)BSTR/2)AROF/3)RATO/4)EINF
PLOT   BSTR=S(0,60)/AROF=F,EINF=E(0,12000)/RATO=R(0,4)
SPEC   DT=0.0625/LENGTH=24/PRTPER=0.5/PLTPER=0.25
```

Figure 14. Card Listing: Model 1-4000(I).

PAGE 2 %00000 STARTED PRINTING AT 00134.5653 11 FEBRUARY 1966

TIME	BSTR	AROF	RATD	EINF
E+00	E+00	E+00	E+00	E+00
0,000	44,000	0,0	1,0000	0,0
0,750	44,000	0,0	1,0000	0,0
1,500	43,439	4343,9	1,0860	1862,5
2,250	42,586	4258,6	1,0646	1896,6
3,000	41,716	4171,6	1,0429	1931,4
3,750	40,831	4083,1	1,0208	1966,8
4,500	39,930	3993,0	0,9982	2005,6
5,250	39,003	3900,3	0,9751	2079,8
6,000	38,042	3804,2	0,9511	2156,6
6,750	37,045	3704,5	0,9261	2236,4
7,500	36,011	3601,1	0,9003	2319,0
8,250	34,939	3493,9	0,8735	2404,8
9,000	33,828	3382,8	0,8457	2493,7
9,750	32,675	3267,5	0,8169	2585,8
10,500	31,480	3148,0	0,7871	2681,4
11,250	30,241	3024,1	0,7561	2780,5
12,000	28,956	2895,6	0,7240	2883,3
12,750	27,623	2762,3	0,6906	2989,9
13,500	26,241	2624,1	0,6561	3100,4
14,250	24,808	2480,8	0,6203	3215,1
15,000	23,322	2332,2	0,5832	3333,9
15,750	21,781	2178,1	0,5446	3457,2
16,500	20,183	2018,3	0,5047	3585,0
17,250	18,542	1854,2	0,4637	3629,0
18,000	16,886	1688,6	0,4223	3662,2
18,750	15,214	1521,4	0,3805	3695,6
19,500	13,527	1352,7	0,3383	3729,3
20,250	11,825	1182,5	0,2958	3763,4
21,000	10,107	1010,7	0,2529	3797,7
21,750	8,374	837,4	0,2095	3832,4
22,500	6,625	662,5	0,1658	3867,3
23,250	4,859	485,9	0,1217	3902,6
24,000	3,078	307,8	0,0772	3938,3

Figure 15. Print-out of the Variables of Interest: Model 1-4000(I).

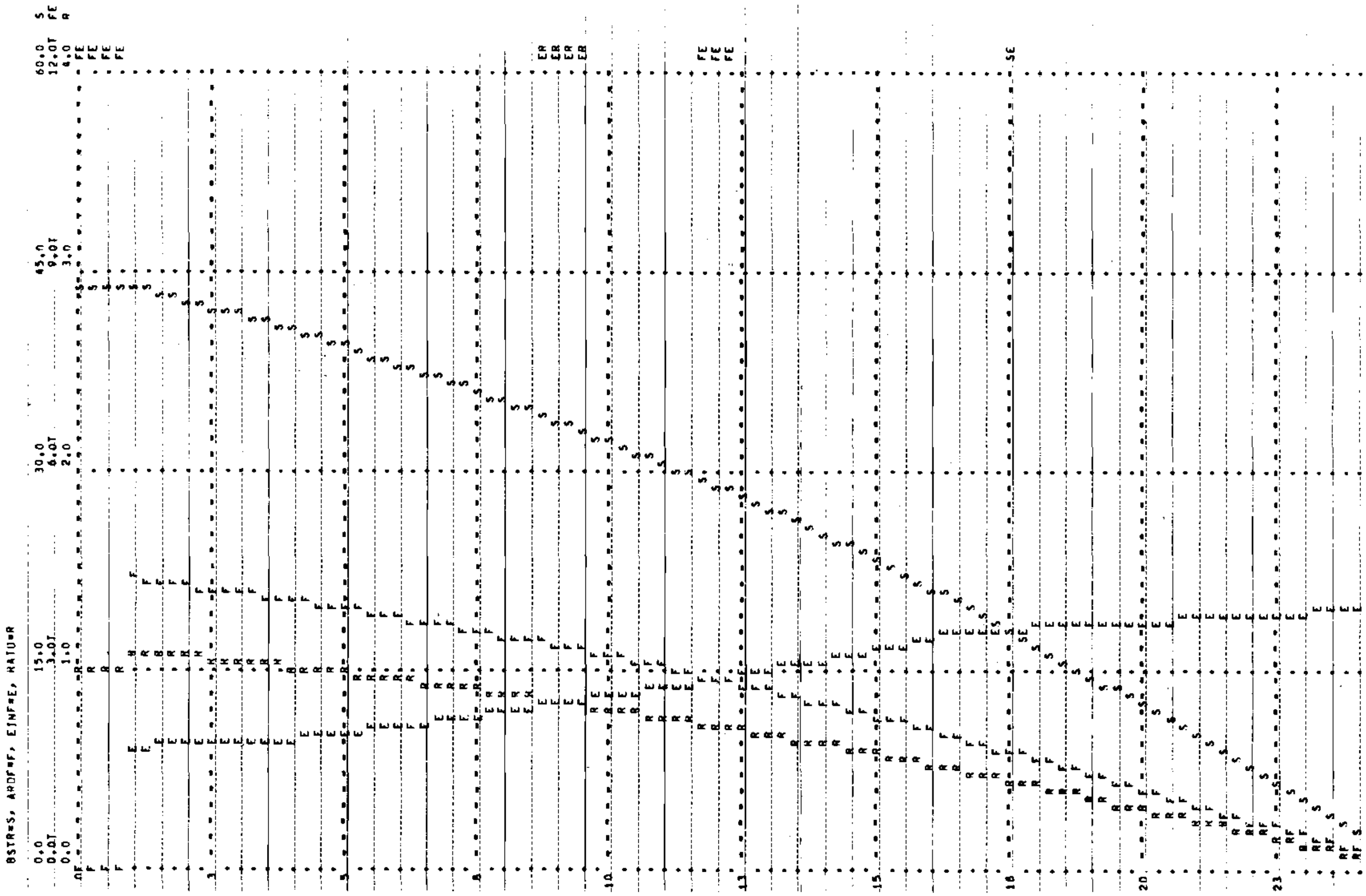


Figure 16. Plot of the Variables of Interest: Model 1-4000(I).

The most interesting of these three figures is the plot for it shows at a glance the dynamic behavior of the platoon. During the initial hour period of zero enemy capability the model demonstrates stability with no changes occurring from the initial conditions of platoon strength (S), ratio of fire (R), enemy intensity of fire (E), and the platoon rate of fire (F). Against the 4000 rounds of fire per hour, the platoon cannot obtain a two-to-one ratio of fire (R). Consequently, the platoon strength (S) drops off quite rapidly to three by the end of the 24 hour period. Under the criterion established in the scope and limitations of this study, the platoon ceases to become an effective fighting unit at the end of approximately 18 hours when it has lost two-thirds of its strength. As the platoon's strength (S) decreases, both the rate of fire (F) and the ratio of fire (R) decrease proportionally; however, the intensity of the enemy fire (E) increases as the enemy can more effectively use his fire capability. It should be noted that the platoon strength (S) is not a linear function; rather the weaker the platoon becomes, the greater is its casualty rate per time period.

3.6.2 Model 2-2000(I)

Model 2-2000(I) is essentially the same as Model 1-4000(I) except that the enemy capability to deliver direct fire after the first hour has been halved to 2000 rounds per hour from 4000 rounds per hour. The plot of the variables of interest of this model is shown in Figure 17. As might be expected, since the platoon can now maintain a two-to-one ratio of fire (R) for a period of about 19 hours, the battlefield strength (S) of the platoon remains quite high; at the end of 24 hours, there are still 38 men remaining in the platoon. As the platoon's rate of fire (F) decreases due to its losses, the intensity of the enemy fire (E) is seen to increase; and as this occurs the ratio of fire (R) also decreases. However, the ratio of fire (R) even at the end of the 24 hour period is almost at the desired two-to-one value. In other words, the platoon can adequately defend against an enemy capability of 2000 rounds of fire per hour for a period of 24 hours.

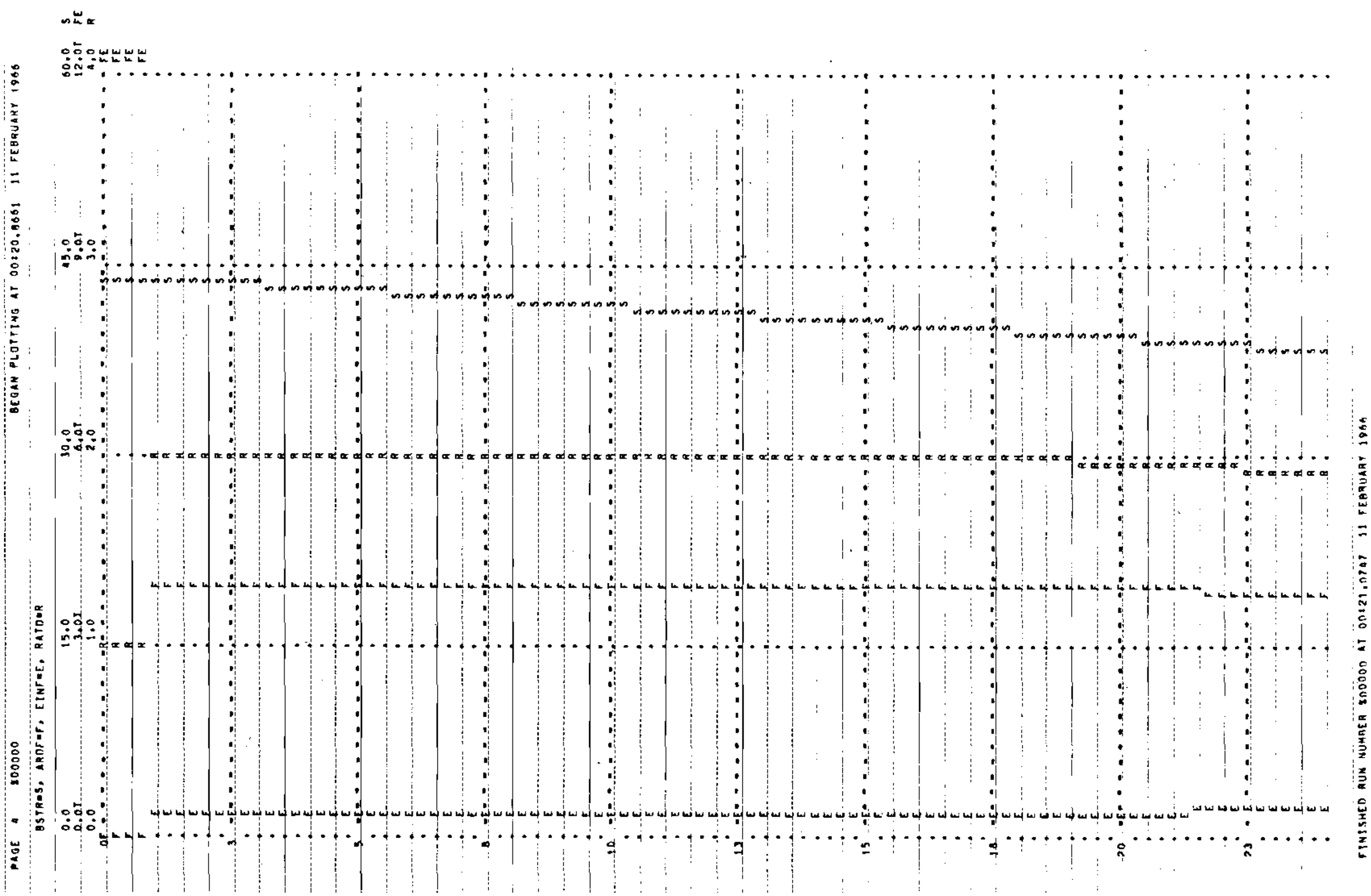


Figure 17. Plot of the Variables of Interest: Model 2-2000(I).

CHAPTER IV

A SOPHISTICATED MODEL

4.1 Stragglers: Model 3-4000(S)

There occurs in combat the problem of straggling, i.e. the wandering of men away from their unit, usually by accident but occasionally by design. Its effect is to decrease the strength of the unit and therefore the rate of fire of the unit for the period of time the straggler is absent. Consequently, the strength of the platoon (BSTR) must be changed by the subtraction of a straggler rate (STRG) and the addition of a return rate (RETR):

52L BSTR.K=BSTR.J+(DT)(RETR.JK-STRG.JK-CASR.JK+0)

The straggler rate is primarily dependent upon the intensity of enemy fire when men stray due to panic, upon becoming lost or disoriented, or in order to aid a stricken comrade. No study is available giving a quantitative estimate of this parameter which may be as great as the casualty rate. For the purposes of this paper, however, the rate will arbitrarily be established as one-half of the auxiliary casualty rate (ACAS). As with the casualty rate, a negative straggler limit (NEGS) is required. Due to the prior commitment of subtracting casualties (CASR) from the level of platoon strength (BSTR) the construction of the negative straggler limit (NEGS) is determined by subtracting the auxiliary casualty rate (ACAS) from the negative casualty limit (NEGC). If the quantity (NEGS) is negative, then the straggler rate (STRG) must be zero since there is no strength remaining in the platoon. If the quantity (NEGS) is positive then the straggler rate (STRG) is the minimum of the auxiliary casualty rate (ASTG) and the positive quantity, now called the positive straggler limit (PSTG):

```
54R    STRG.KL=MIN(ASTG.K,PSTG.K)
12A    ASTG.K=(0.5)(ACAS.K)
51A    PSTG.K=CLIP(0,NEGS.K,NEGC.K,ACAS.K)[1]
7A     NEGS.K=NEGC.K-ACAS.K
```

Before calculating the straggler return rate (RETR), the time the straggler is absent, or his delay in returning (SDEL) to his unit, must be established. With no enemy fire, the straggler returns quickly--say, in an hour. On the other hand, the more intense the enemy fire the more prolonged the delay, at least initially. There is probably some time, however, which is not exceeded regardless of the intensity of fire. This relationship is expressed in Figure 18, where the maximum limit of delay time has arbitrarily been established at five hours.

---

[1]PSTG = 0 if NEGC $\geq$ ACAS
PSTG = NEGS if NEGC $<$ ACAS

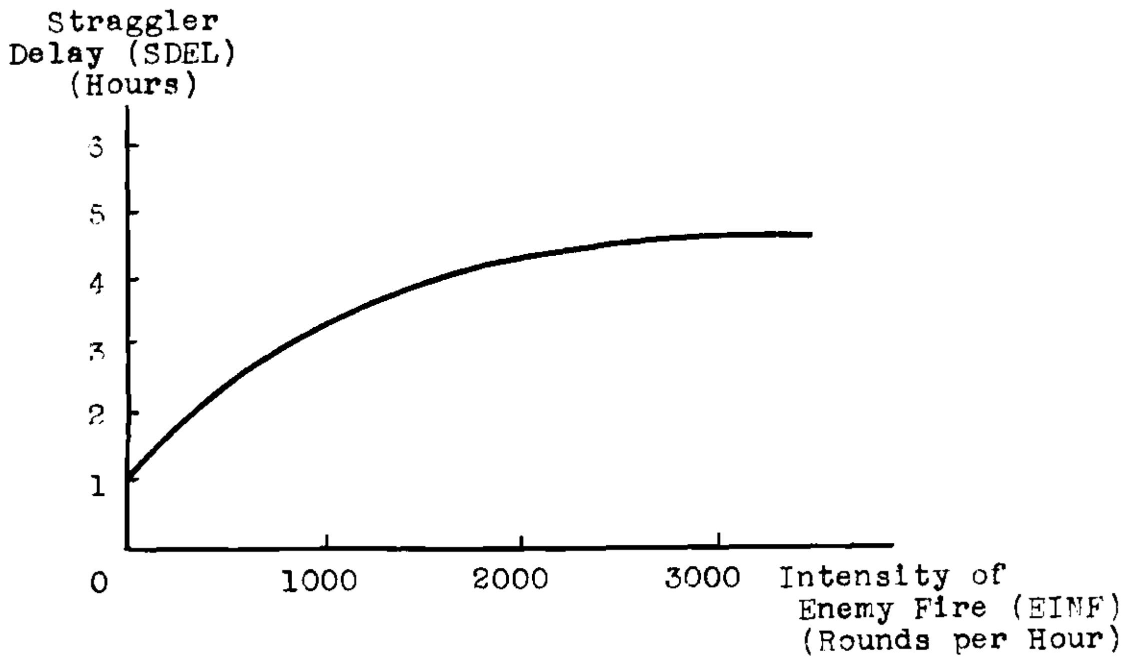


Figure 18. Variable Straggler Delay.

From this function, a table is made in the Dynamo language:

```
58A    SDEL.K=TABHL(TBL3,EINF.K,0,3000,1000)
C      TBL3*=1.0/3.5/4.5/5.0
```

The straggler return rate (RETR) may now be written as:

```
20R    RETR.KL=STGL.K/SDEL.K
```

From the variables which have been established, the number of stragglers absent from the platoon at any given instance (STGL) can be calculated as:

```
1L     STGL.K=STGL.J+(DT)(STRG.JK-RETR.JK)
6N     STGL=0
```

These equations, when added to those of Model 1-4000(I) form Model 3-4000(S). No separate flow diagram has been drawn for this model, but the straggler flow from and into the platoon becomes a part of the flow diagram of the more sophisticated model shown in Figure 24. This flow diagram, in addition to including the initial model shown in Figure 13, incorporates all the modifications discussed in this chapter.

The plot of Model 3-4000(S) is shown in Figure 19. It is to be noted that when the enemy capability of direct fire is fixed at 4000 rounds per hour (except for the first hour), stragglers have the effect of shortening the time span of the platoon's effectiveness as a fighting unit from the 19 hours of Model 1-4000(I) to 16 hours.

4.2 Ammunition Resupply: Model 4-4000(A)

The role played by ammunition and its resupply is important since the sustained firing rate of modern weapons is such that the limiting factor in the volume of fire is the resupply of ammunition rather than of the weapon. The U. S. Rifle, M14, for example, has the capability of a sustained rate of fire of 15 rounds per minute; or 40 rounds may be fired in each of the first two minutes of firing (16, p. 5). As the basic load of a rifleman is 100 rounds, ammunition resupply on the battlefield is of paramount importance.

The ammunition level of the platoon (AMMO) is

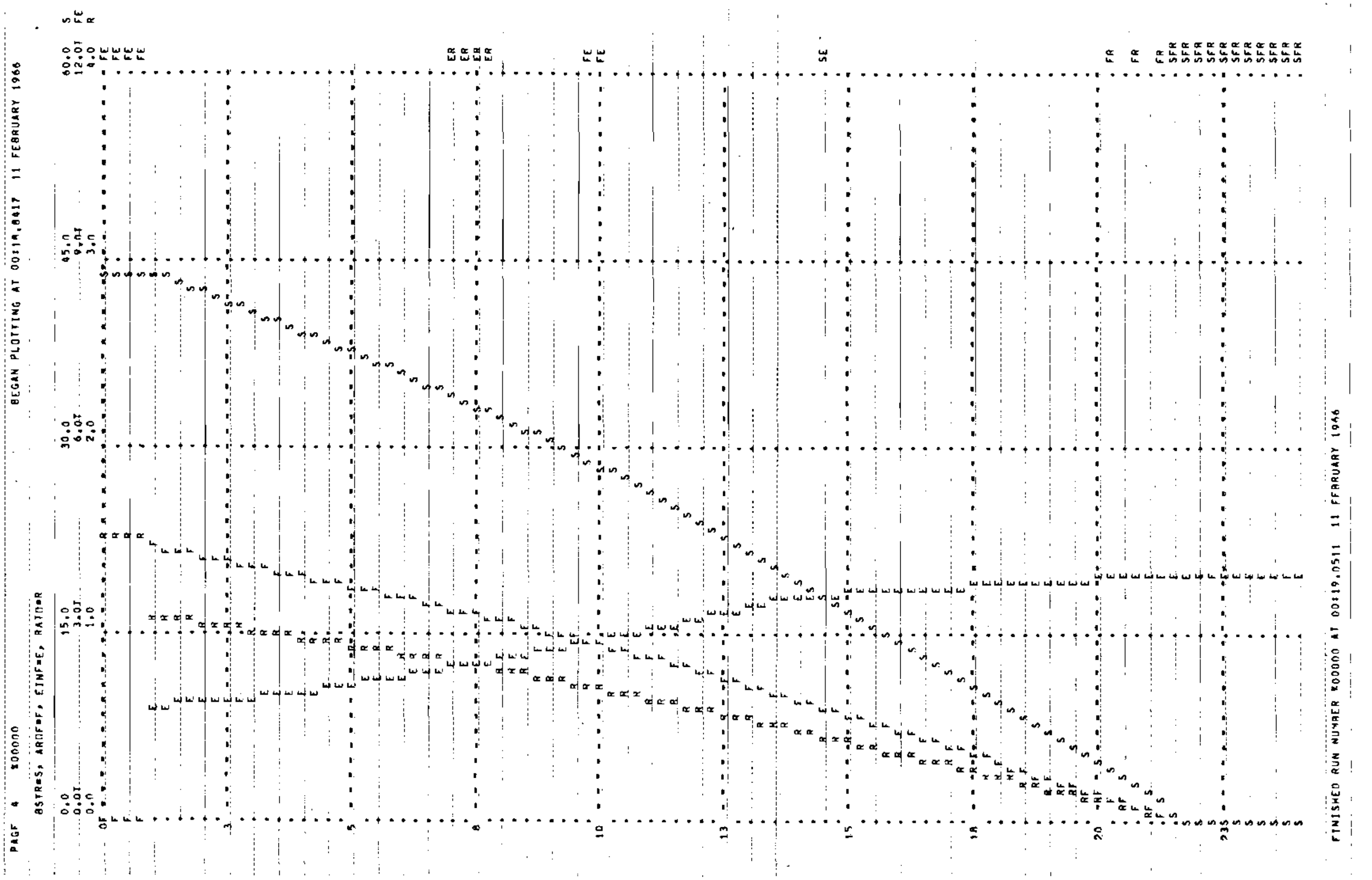


Figure 19. Plot of the Variables of Interest: Model 3-4000(S).

dependent upon the actual ammunition resupply rate (AARR) minus that ammunition expended against the enemy (AMER) and that ammunition removed by casualties (CARR) and stragglers (SARR). In addition, returning stragglers add ammunition to that available (SAIR); there also exists an amount of ammunition present on stragglers who have not yet returned (SAML):

```
2L    AMMO.K=AMMO.J+(DT)(AARR.JK+SAIR.JK-AMER.JK-CARR.JK
                                               -SARR.JK+O)
12N   AMMO=(BSTR)(100)
6R    AMER.KL=AROF.K
6N    AMER=0
50R   SAIR.KL=(SAML.K)(RETR.K)/(0.05+STGL.K)[1]
6N    SAIR=0
1L    SAML.K=(SAML.J)+(DT)(SARR.JK-SAIR.JK)
6N    SAML=0
```

As with any level which cannot fall below zero, negative limits must be established for those rates which are subtracted from the level equations. Since the actual rate of fire (AROF) must be less than the ammunition supply, the ammunition expended (AMER) already has its limit established. However, a negative straggler ammunition removal limit (NAMS) must be established along with a tried ammunition straggler removal rate (TSAR). Likewise a negative casualty removal limit (NAMC) and a tried casualty removal rate (TCAR) are established. An auxiliary straggler rate (ASAR) is also required in the formation of these equations:

---

[1] 0.05 is introduced to prevent this term becoming zero.

```
27A   NAMS.K=AMMO.K/DT-AROF.K
50A   TSAR.K=(AMMO.K)(STRG.JK)/(0.05+BSTR.K)¹
54R   SARR.KL=MIN(TSAR.K,NAMS.K)
6N    SARR=0
7A    NAMC.K=NAMS.K-ASAR.K
54A   ASAR.K=MIN(TSAR.K,NAMS.K)
50A   TCAR.K=(AMMO.K)(CASR.JK)/(0.05+BSTR.K)¹
54R   CARR.KL=MIN(TCAR.K,NAMC.K)
6N    CARR=0
```

The actual ammunition resupply rate (AARR) is supplied from ammunition in transit (AINT). In order to maintain simplicity the assumption is made that the ammunition is delivered to the platoon by a company bearer as is sometimes the case in combat. Should this assumption not be made, then the strength of the platoon would require reduction by the number of men in the ammunition resupply party for the length of their absence.

A time lag (ADEL) exists between the time that ammunition is requested and the time that it is delivered. This time lag is to a certain extent dependent upon the intensity of enemy fire. It is assumed here that the delay is half-an-hour if the intensity of enemy fire is less than 300 rounds per hour; otherwise the delay is an hour.

```
20R   AARR.KL=AINT.K/ADEL.K
6N    AARR=0
51A   ADEL.K=CLIP(1,0.5,EINF.K,300)
```

The time lag as constructed in this case is not desirable.

---

[1] 0.05 is introduced to prevent this term becoming zero.

An absolute delay be means of a programming device called a boxcar train (11, p. 418) is more appropriate and closer to reality. Unfortunately this feature was not incorporated into the Burrough's 5500 Dynamo program at the time this paper was written.

Ammunition resupply may take place under two conditions: (1) no enemy fire is being received (and the label used is ARNF), and (2) during a firefight (and the label used is ARWF).

Ammunition resupply in the first case (ARNF) is begun if the amount of ammunition on hand (AMMO) and in transit (AINT) is less than the desired ammunition (ADES) of 100 rounds per man (the basic load). The ammunition requested (AREQ) is the desired amount (ADES) minus that on hand (AMMO) and in transit (AINT). If this amount (AREQ) should be negative, then the amount desired (PREQ) would be zero since the platoon would not actually give up ammunition. The actual request rate (ARRN) must occur in one time period, i.e. instantaneously:

```
49R    ARNF.KL=SWITCH(ARRN.K,0,EINF.K)
6N     ARNF=0
20A    ARRN.K=PREQ.K/DT
44A    PREQ.K=CLIP(AREQ.K,0,AREQ.K,0)
8A     AREQ.K=ADES.K-AMMO.K-AINT.K
12A    ADES.K=(100)(BSTR.K)
```

Ammunition resupply in the second case (ARWF) is undertaken when half of the basic load is depleted.

Ammunition on hand is not accounted for; the platoon leader simply requests (ARRW) a full basic load of ammunition, i.e. (BSTR)(100) rounds. This request (ARRW) must meet two conditions: (1) the state (RAWF) that the ammunition on hand per man (PRFM) is less than half the basic load per man (50), and (2) the state (PLAT) that the total ammunition per man (TOTA) which is on hand (AMMO) and in transit (AINT) is less than the basic load (100):

```
49R   ARWF.KL=SWITCH(0,PLAT.K,EINF.K)
6N    ARWF=0
51A   PLAT.K=CLIP(0,RAWF.K,TOTA.K,4400)
26A   TOTA.K=(AMMO.K+AINT.K+0)/(0.05+BSTR.K+0)
51A   RAWF.K=CLIP(0,ARRW.K,PRFM.K,50)
44A   ARRW.K=(BSTR)(100)/DT
48A   PRFM.K=AMMO.K/(0.05+BSTR.K)
```

To complete the set of ammunition resupply equations the level of ammunition in transit requires definition:

```
52L   AINT.K=AINT.J+(DT)(ARNF.JK+ARWF.JK-AARR.JK+0)
6N    AINT=0
```

These equations are incorporated into the straggler Model 3-4000(S) by the platoon's possible rate of fire equation in the following form:

```
12A   PROF.K=(PRFM.K)(BSTR.K)
```

The addition of these equations for ammunition resupply to Model 3-4000(S) form Model 4-4000(A). A plot of the variables of interest in this model, using the step input of 4000 rounds per hour beginning at time one hour, is shown in Figure 20. It will be noted that limiting the ammunition supply has the effect of further decreasing the time the unit is considered an effective fighting force. In Model 4-4000(A) the platoon is no longer an effective unit at the end of 12 hours, as compared to the 16 hours of Model 3-4000(S).

It is also interesting to note that the platoon's rate of fire (F) and the ratio of fire (R) vary directly with the ammunition available to the platoon (A) while the intensity of enemy (E) varies inversely. A pipeline delay of the ammunition resupply would have caused the ammunition level (A) to be saw-toothed in nature; the delay function actually used causes it to be somewhat smoothed, but the results obtained give an adequate representation of reality.

4.3 Friendly Indirect Fire: Model 5-4000(FIF)

By the expeditious use of indirect fire from mortars and artillery, the platoon can conserve its ammunition and limit the effectiveness and intensity of the enemy fire.

The platoon leader requests this fire by means of radio or telephone. The volume of indirect fire desired (DVOL) is that amount which renders the enemy fire relatively ineffective, i.e. twice the volume of the enemy indirect fire averaged over the last 15 minutes (ESDF). This smoothing average is taken since the platoon leader normally

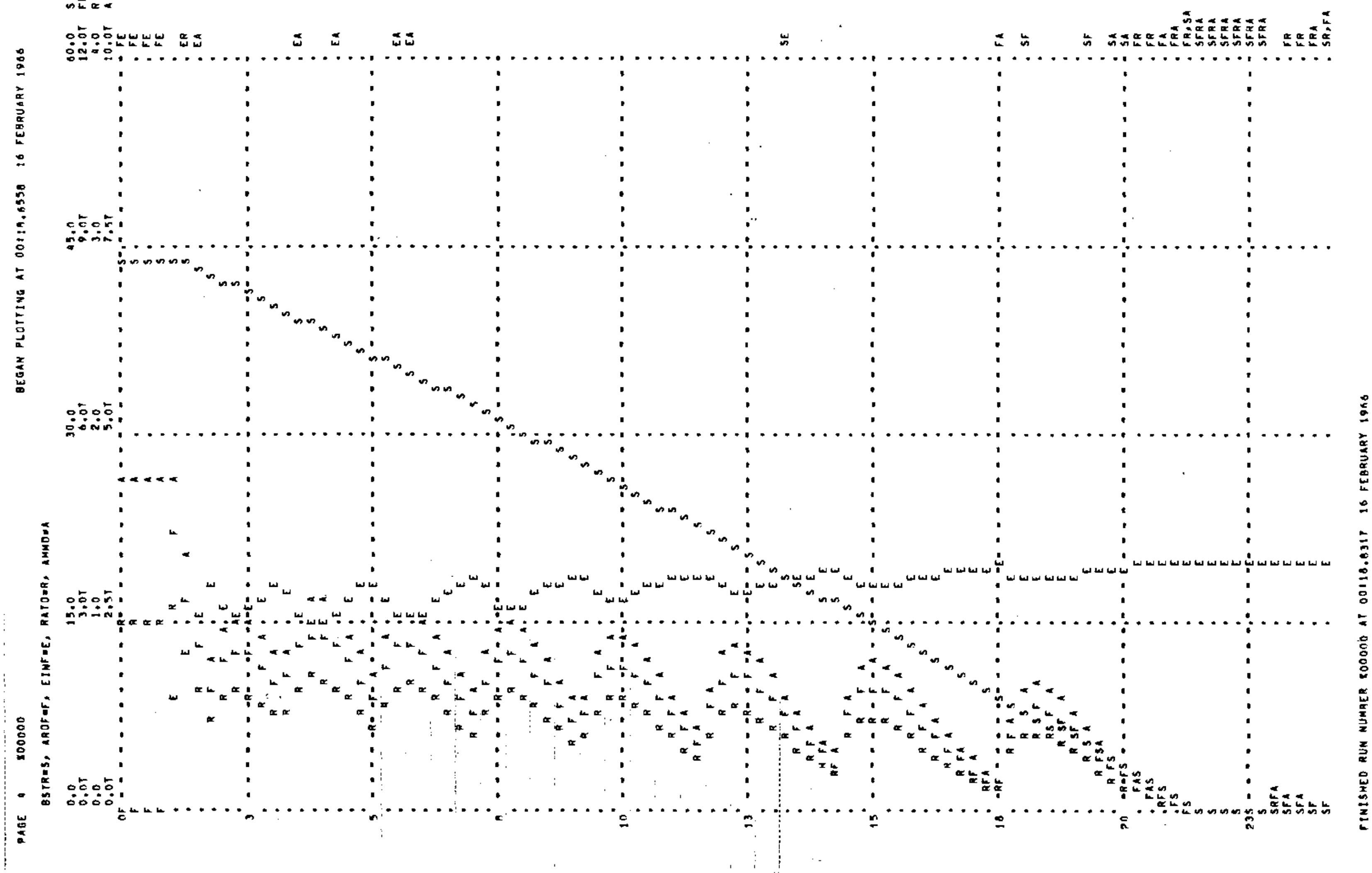


Figure 20. Plot of the Variables of Interest: Model 4-4000(A).

relies upon his own means of fire within the platoon to reply to a short burst of intense fire or to prolonged fire of very low intensity. The platoon leader, therefore, establishes a desired level (DINF) below which he will not call for indirect fire. This level is established in this study at 300 rounds per hour. The volume requested is in "equivalent" rounds of direct fire, and no attempt is made here to equate direct fire to indirect fire.

A stipulation is made that a delay of six minutes occurs between the indirect fire desired (DINF) and the actual delivery of the fire (AINF). It is further assumed that indirect fire requested is always received. (By enlarging the model with more variables this latter assumption need not be made.) The platoon's desired rate of fire (DROF), formulated earlier, makes up the difference (IROF) between the actual indirect fire support received at the moment (AINF) and the total volume of fire desired (DTVF). The indirect fire support must also be added to the ratio of fire (RATO):

```
3L    ESDF.K=ESDF.J+(DT)/(1/4)(ECDF.K-ESDF.J)
6N    ESDF=0
12A   DVOL.K=(2)(ESDF.K)
20R   AINF.KL=LDIF.K/0.2
1L    LDIF.K=LDIF.J+(DT)(DINF.JK-AINF.JK)
6N    LDIF=0
12A   DTVF.K=(2)(ECDF.K)
51R   DINF.KL=CLIP(DVOL.K,0,ESDF.K,300)
6N    DINF=0
7A    IROF.K=DTVF.K-AINF.JK
51A   DROF.K=CLIP(IROF.K,0,IROF.K,0)
26A   RATO.K=(1+AROF.K+AINF.JK)/(1+ECDF.K+0)
```

These equations are added to Model 4-4000(A) to produce Model 5-4000(FIF), whose plot of the variables of interest is shown in Figure 21. The addition of a friendly indirect fire capability has a noticeable effect upon the strength of the platoon (S). Whereas in previous models the platoon could not obtain the desired two-to-one ratio of fire (R), this ratio can now be obtained. Consequently, the platoon strength (S) drops rapidly during the first several hours until the desired ratio is obtained. Thereafter it decreases slowly; at the end of 24 hours some 30 men still remain in the platoon. As might be expected from a constant input, the model variables eventually reach a point of stability. By the end of the 24-hour period, indirect fire is meeting the entire enemy capability, no fire (F) is being put out by the platoon and no ammunition (A) is being expended. It takes the platoon five hours, however, to achieve this stability (and break away from the sinusoidal effect of Model 4-4000(A)). This period of time is considered excessive and the smoothing constant of fire averaged over 15 minutes probably requires modification. Such alteration is not undertaken in this paper as a better insight to the nature of the dynamic problem is obtained if stabilization is reached in five hours rather than in one hour.

4.4 Enemy Indirect Fire: Model 6-4000(SOPH)

So far only the exogenous variable of an enemy direct

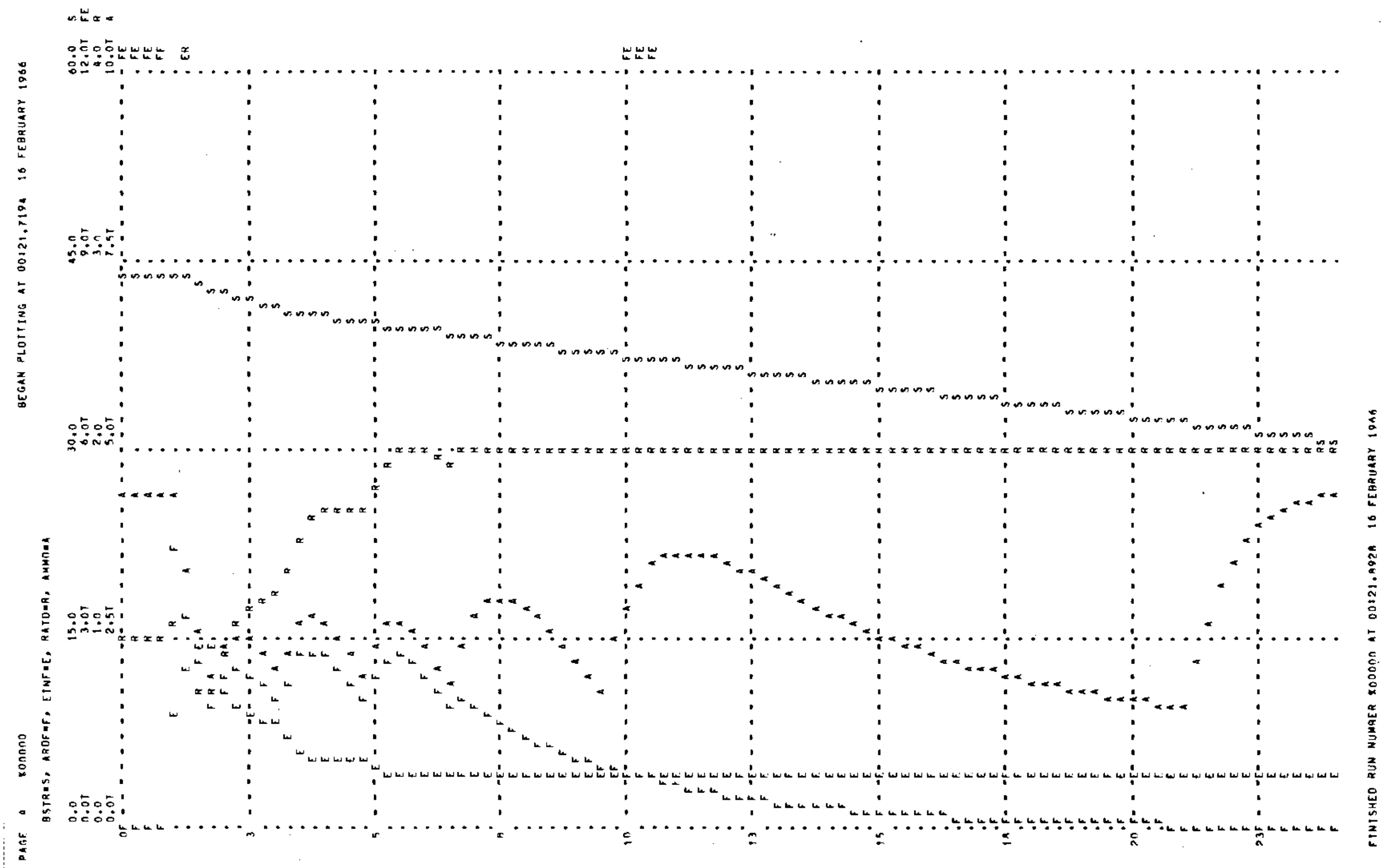


Figure 21. Plot of the Variables of Interest: Model 5-4000(FIF).

fire capability has been considered; now the important exogenous variable of the enemy indirect fire (ECIF) will be introduced. Any influence over the enemy capability of indirect fire lies with units other than the rifle platoon. Therefore, the input variable considers only the number of indirect fire rounds landing within the platoon area.

The assumption is made that the enemy indirect fire consists of 4.2 inch mortar rounds, which have an effective bursting area of 600 square meters (15, p. 323). Since this fire cannot be delivered with precise accuracy, i.e. targets of indirect fire are area targets, the entire platoon position including the rear slope of the hill must be covered. As this target is some 80,000 square meters in area (see Figure 6), 167 rounds are required to blanket the area. Since this same area must be covered regardless of the strength of the platoon, the number of rounds required to produce one casualty becomes 167 divided by the strength of the platoon at the moment.

A constant 1650 rounds of small arms fire, i.e. direct fire, produce one casualty; but with indirect fire, the number of rounds to produce one casualty varies inversely with the strength of the platoon. Therefore, any "equivalent" round parameter must be a variable; and one indirect fire round becomes the equivalent of (1650)(BSTR.K)/167[1] rounds

---

[1]BSTR.K is defined as the strength of the platoon at the moment of time under consideration.

of direct fire. Such dynamic formulation is generally not found in military texts which usually list equivalencies in deterministic quantities (18, p. 28).

As an input variable, an enemy indirect fire rate (ECIF) of 12 rounds on the platoon position every six hours, beginning four hours after the start of the time period, is arbitrarily established. The formulation of the appropriate equation is obtained with the aid of the PULSE function available in the Dynamo program.

Due to the limitations of equation format, auxiliary equations for direct fire casualties (ACDF) and for indirect fire casualties (ACIF) must first be formulated and then totaled to form the auxiliary casualty rate (ACAS). The total intensity of enemy fire (EINT) now becomes the sum of the intensity due to direct fire (EINF) and that due to indirect fire in equivalent rounds (EINI):

```
41A    ECIF.K=PULSE(12,4,6)
44A    ACIF.K=(BSTR.K)(ECIF.K)/167
20A    ACDF.K=EINF.K/1650
7A     ACAS.K=ACIF.K+ACDF.K
7A     EINT.K=EINF.K+EINI.K
46A    EINI.K=(ECIF.K)(BSTR.K)(1650)/(167)(1)(1)
```

These equations when added to Model 5-4000(FIF) form the "sophisticated" model (SOPH). The plot of the variables of interest of Model 6-4000(SOPH), where the constant step input of 4000 rounds per hour is used, is shown in Figure 22. As should be expected, when compared to Model 5-4000(FIF),

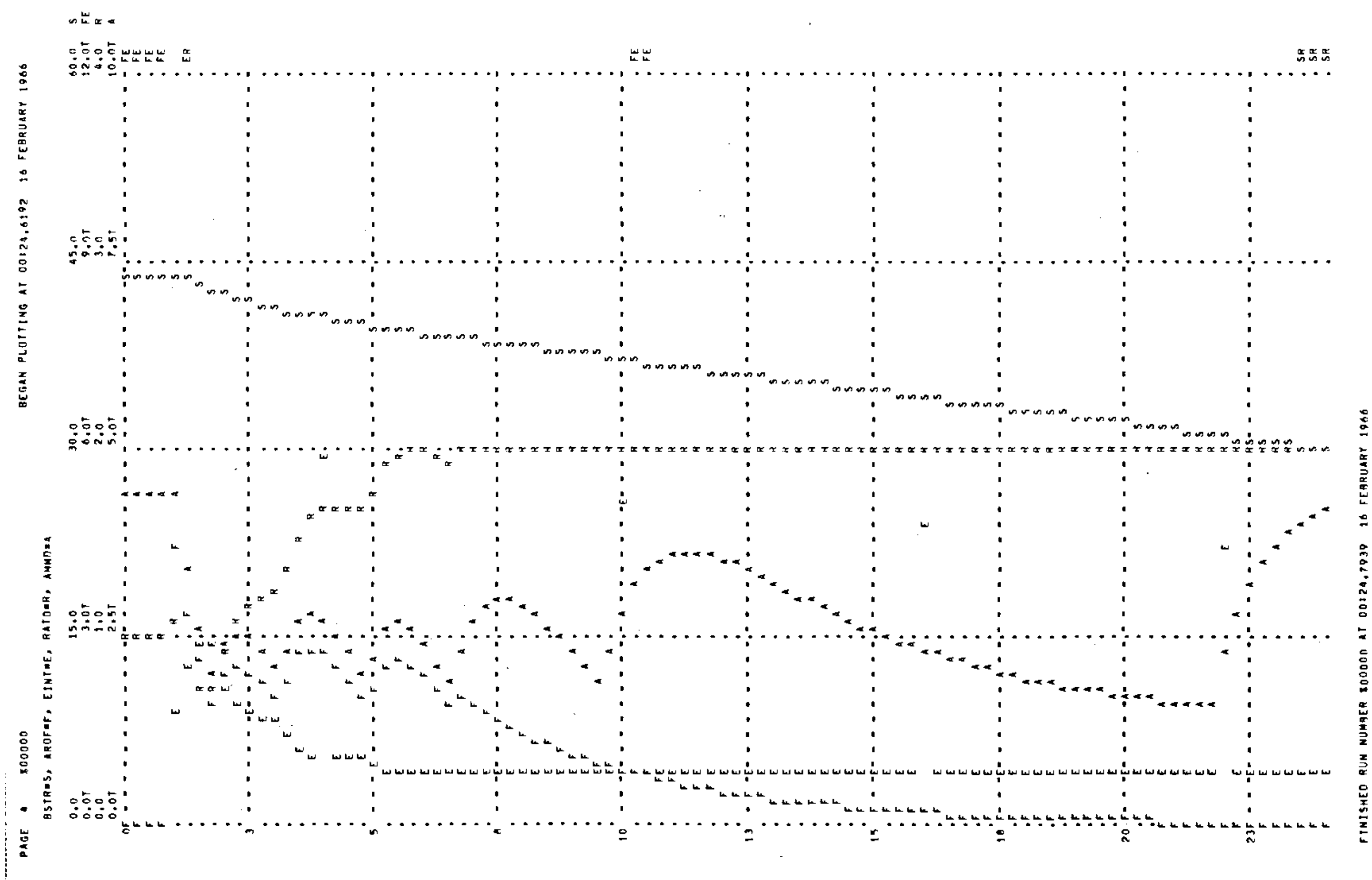


Figure 22. Plot of the Variables of Interest: Model 6-4000(SOPH).

```
RUN
NOTE SIMULATED RIFLE PLATOON,1E/04, LOUIS E ABELE, DR JOSEPH KRUL
45A   ECDF.K=STEP(4000,1)                          ENEMY CAPABILITY OF DIRECT FIRE
41A   ECIF.K=PULSE(12,4,6)                         ENEMY INDIRECT FIRE CAPABILITY
52L   BSTR.K=BSTR.J+(DT)(RETR.JK-STRG.JK-CASR.JK+0)  BATTLEFIELD STRENGTH
6N    BSTR=44                                      INITIAL CONDITION
54R   CASR.KL=MIN(ACAS.K,NEGC.K)                   CASUALTY RATE
6N    CASR=0                                       INITIAL CONDITION
20A   NEGC.K=BSTR.K/DT                             NEGATIVE CASUALTY LIMIT
12A   EINF.K=(EFFF.K)(ECDF.K)                      ENEMY INTENSITY OF FIRE
58A   EFFF.K=TABHL(TBL2,RATO.K,0,2.5,0.5)          EFFECTIVENESS OF ENEMY FIRE
C     TBL2*=1/0.9/0.5/0.3/0.2/0.15                 TABLE 2
7A    ACAS.K=ACIF.K+ACDF.K                         AUXILIARY CASUALTY RATE
20A   ACDF.K=EINF.K/1650                           AUXILIARY CASUALTY DIRECT
44A   ACIF.K=(BSTR,K)(ECIF.K)/167                  AUXILIARY CASUALTY RATE INDIREC
7A    EINT.K=EINF.K+EINI.K                         TOTAL INTENSITY OF FIRE
46A   EINI.K=(ECIF.K)(BSTR.K)(1650)/(167)(1)(1)    INTENSITY INDIRECT FIRE
26A   RATO.K=(1+ARDF.K+AINF.JK)/(1+ECDF.K+0)       RATIO OF FIRE FRIEND TO ENEMY
20R   AINF.KL=LDIF.K/0.2                           ACTUAL INDIRECT FIRE
6N    AINF=0                                       INITIAL CONDITION
1L    LDIF.K=LDIF.J+(DT)(DINF.JK-AINF.JK)          LEVEL OF DESIRED INDIRECT FIRE
6N    LDIF=0                                       INITIAL CONDITION
51R   DINF.KL=CLIP(DVOL.K,0,ESDF.K,300)            DESIRED INDIRECT FIRE
6N    DINF=0                                       INITIAL CONDITION
3L    ESDF.K=ESDF.J+(DT)(1/4)(ECDF.K-ESDF.J)       ENEMY SMOOTHED DIRECT FIRE CAP
6N    ESDF=0                                       INITIAL CONDITION
12A   DVOL.K=(2)(ESDF.K)                           DESIRED VOLUME OF FIRE
54A   AROF.K=MIN(PROF.K,DROF.K)                    ACTUAL RATE OF FIRE
48A   PRFM.K=AMMU.K/(0.05+BSTR.K)                  POSSIBLE RATE OF FIRE / MAN
12A   PROF.K=(PRFM.K)(BSTR.K)                      POSSIBLE RATE OF FIRE
52L   AMMU.K=AMMU.J+(DT)(AARR.JK+SAIR.JK-AMER.JK-CARR.JK-SARR.JK+0)  AMMU LEVEL
12N   AMMO=(BSTR)(100)                             INITIAL CONDITION
20R   AARR.KL=AINT.K/ADEL.K                        ACTUAL AMMO RESUPPLY RATE
6N    AARR=0                                       INITIAL CONDITION
51A   ADEL.K=CLIP(1,0.5,ECDF.K,300)                AMMU DELAY
2L    AINT.K=AINT.J+(DT)(ARNF.JK+ARWF.JK-AARR.JK+0+0+0)   AMMO IN TRANSIT
6N    AINT=0                                       INITIAL CONDITION
49R   ARNF.KL=SWITCH(ARRN.K,0,EINF.K)              AMMO RESUPPLY W/NO FIREFIGHT
6N    ARNF=0                                       INITIAL CONDITION
20A   ARRN.K=PREQ.K/DT                             AMMO RESUPPLY RATE W/O FIRE
51A   PREQ.K=CLIP(AREQ.K,0,AREQ.K,0)               POSITIVE AMMO REQUISITION
8A    AREQ.K=ADES.K-AMMO.K-AINT.K                  AMMO REQUISITIONED
12A   ADES.K=(100)(BSTR.K)                         AMMO DESIRED
49R   ARWF.KL=SWITCH(0,PLAT.K,EINF.K)              AMMO RESUPPLY W/FIREFIGHT
6N    ARWF=0                                       INITIAL CONDITION
51A   PLAT.K=CLIP(0,RAWF.K,TOTA.K,100)             PIPELINE AMMO TEST
26A   TOTA.K=(AINT.K+AMMU.K+0)/(0.05+BSTR.K+0)     TOTAL AMMO
44A   RAWF.K=CLIP(0,ARRW.K,PRFM.K,50)              REQUESTED AMMO W/FIREFIGHT
44A   ARRW.K=(100)(BSTR)/DT                        BASIC LOAD RESUPPLY RATE
50R   SAIR.KL=(SAML.K)(RETR.JK)/(0.05+STGL.K)      STRAGGLER AMMO INCREASE RATE
6N    SAIR=0                                       INITIAL CONDITION
1L    SAML.K=SAML.J+(DT)(SARR.JK-SAIR.JK)          STRAGGLER AMMO LEVEL
6N    SAML=0                                       INITIAL CONDITION
54R   SARR.KL=MIN(TSAR.K,NAMS.K)                   STRAGGLER AMMU REMOVAL RATE
6N    SARR=0                                       INITIAL CONDITION
50A   TSAR.K=(AMMU.K)(STRG.JK)/(0.05+BSTR.K)       TRIED STRAGGLER AMMU RATE
27A   NAMS.K=AMMU.K/DT-AROF.K                      NEG STRAGGLER AMMU LIMIT
6R    AMER.KL=AROF.K                               AMMO EXPENDITURE RATE
6N    AMER=0                                       INITIAL CONDITION
54R   CARR.KL=MIN(TCAR.K,NAMC.K)                   CASUALTY REMOVAL RATE
6N    CARR=0                                       INITIAL CONDITION
50A   TCAR.K=(AMMU.K)(CASR.JK)/(0.05+BSTR.K)       TRIED CASUALTY AMMU REMOVAL
7A    NAMC.K=NAMS.K-ASAR.K                         NEG CASUALTY AMMO REMOVAL
54A   ASAR.K=MIN(TSAR.K,NAMS.K)                    AUXILIARY STRAGGLER AMMO
51A   DROF.K=CLIP(IROF.K,0,IROF.K,0)               DESIRED RATE OF FIRE
7A    IROF.K=DTVF.K-AINF.JK                        INCREMENTAL RATE DESIRED FIRE
12A   DTVF.K=(2)(ECDF.K)                           DESIRED TOTAL VOLUME OF FIRE
54R   STRG.KL=MIN(ASTG.K,PSTG.K)                   STRAGGLER RATE
6N    STRG=0                                       INITIAL CONDITION
12A   ASTG.K=(0.5)(ACAS.K)                         AUXILIARY STRAGGLER RATE
51A   PSTG.K=CLIP(0,NEGS.K,NEGC.K,ACAS.K)          POSSIBLE STRAGGLER RATE
7A    NEGS.K=NEGC.K-ACAS.K                         NEGATIVE STRAGGLER LIMIT
20R   RETR.KL=STGL.K/SDEL.K                        STRAGGLER RETURN RATE
6N    RETR=0                                       INITIAL CONDITION
58A   SDEL.K=TABHL(TBL3,EINF.K,0,3000,1000)        STRAGGLER DELAY
C     TBL3*=1.0/3.5/4.5/5.0                        TABLE 3
1L    STGL.K=STGL.J+(DT)(STRG.JK-RETR.JK)          STRAGGLER LEVEL
6N    STGL=0                                       INITIAL CONDITION
PRINT 1)BSTR/2)AROF/3)RATO/4)EINF/5)AMMO
PLOT  BSTR=S(0,60)/AROF=F,EINF=E(0,12000)/RATO=R(0,4)/AMMO=A(0,10000)
SPEC  DT=0.0625/LENGTH=24/PRTPER=0.5/PLTPER=0.25
```

Figure 23. Card Listing: Model 6-4000(SOPH).

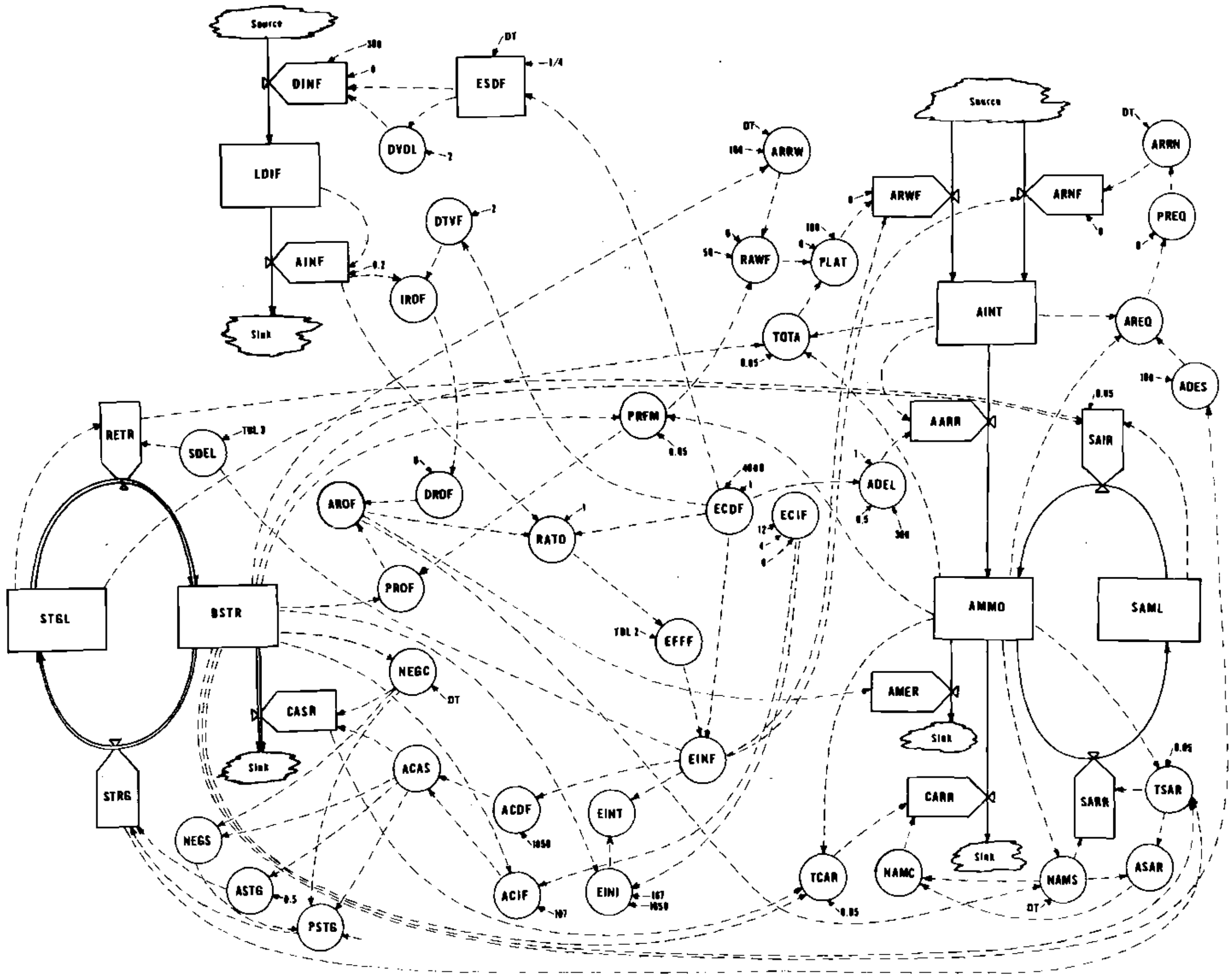


Figure 24. Flow Diagram: Model 6-4000(SOPH).

the enemy intensity of fire (E) jumps when indirect fire is placed upon the platoon (at hours 4, 10, 16 and 22); and the strength of the platoon (S) naturally decreases at a slightly greater rate.

The card listing and flow diagram of Model 6-4000(SOPH), which shows all the essential features of the "sophisticated" model, are shown in Figures 23 and 24, respectively.

4.5 Variable Direct Fire Input

4.5.1 Model 7-VFDF(SOPH)[1]

So far in the treatment of the direct fire capability of the enemy (ECDF) only a step function has been considered. It may be expected that the enemy, for reasons best suited to his purposes, will alter his capability to fire. For example, if the enemy decides to break off an attack for a certain period, then he purposely reduces his capability of firing on the platoon to zero for the period of decision. Alteration of the direct fire capability can be made to fit any desired function, such as the one shown in Figure 25. By changing the time scale of this diagram, any function can be approximated with any desired degree of accuracy. In Dynamo language this input becomes:

---

[1]Variable function for direct fire (sophisticated model).

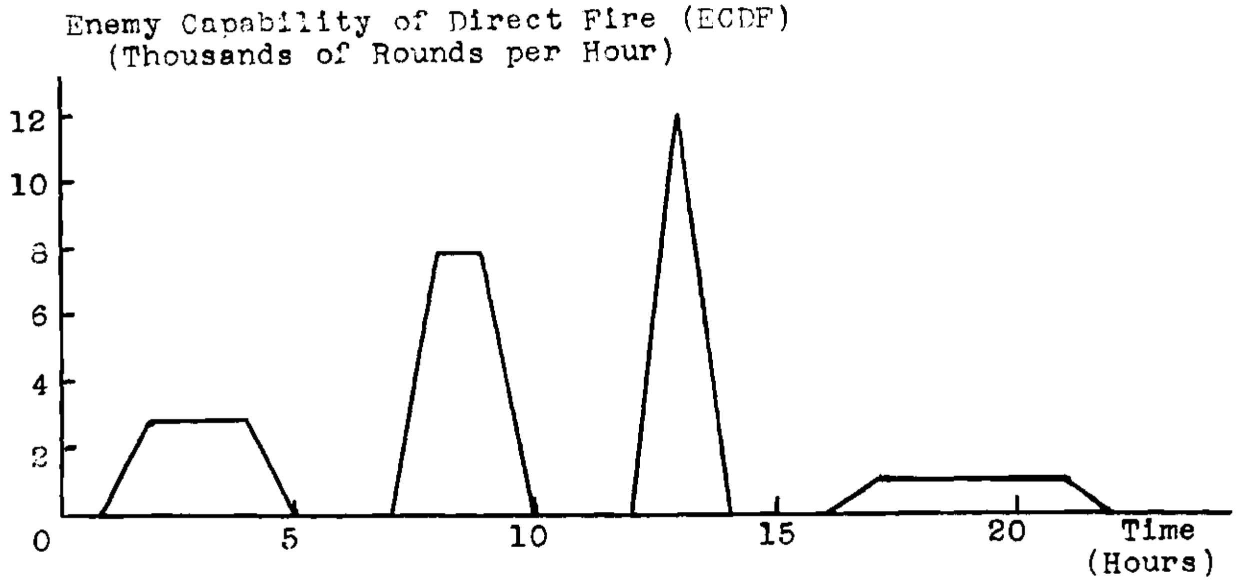


Figure 25. Variable Direct Fire Input for Model 7-VFDF(SOPH).

```
58A    ECDF.K=TABHL(TBL1, CLOK.K[1],0,24,1)
C      TBL1*=0/0/3000/3000/3000/0/0/0/8000/8000/0/0/0/0/[2]
                 12000/0/0/0/1000/1000/1000/1000/0/0/0
1L     CLOK.K=CLOK.J+(DT)(1+0)
6N     CLOK=0
```

The plot of the variables of interest of Model 7-VFDF(SOPH) is shown in Figure 26. The model performs as expected; when the enemy intensity of fire (EINT) is high due to either direct or indirect fire, the platoon decreases in strength (S). When it is zero, the platoon suffers no losses. Due to the platoon's use of indirect fire and the

[1]Present time in the model.

[2]Use of a continuation card is necessary as an IBM card holds only 72 spaces for programming purposes (13, p. 25).

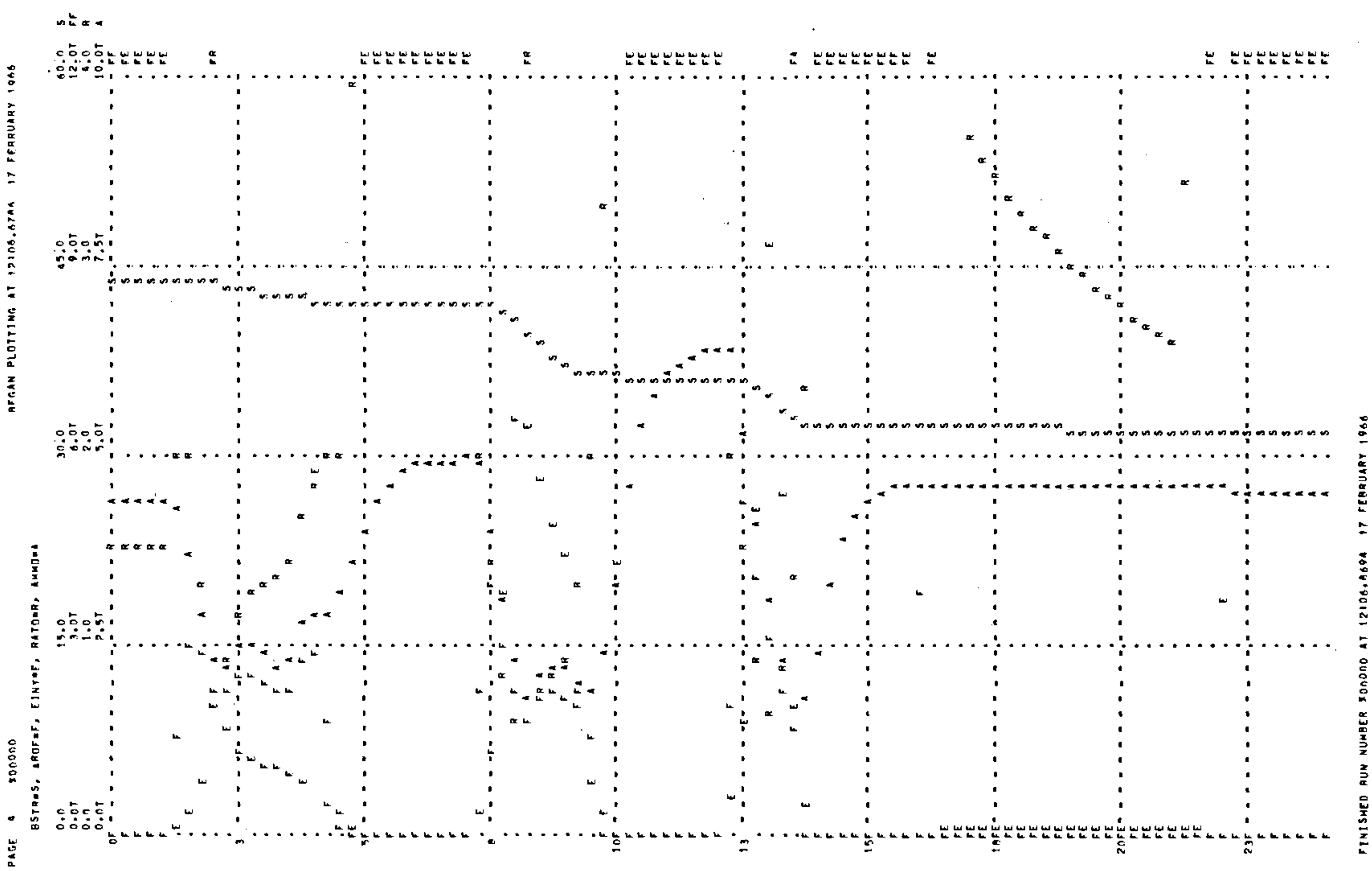


Figure 26. Plot of the Variables of Interest: Model 7-VFDF(SOPH).

slow responsiveness of this type of fire to the actual enemy capability, the ratio of fire (R) is often quite large, as is to be expected.

4.5.2 Model 8-RFDF(SOPH)[1]

The Dynamo language permits the selection of a random input. This may be done either through the use of a table in which values are randomly selected or through use of the normal distribution, should fire be so distributed. As an example, one might suppose that enemy fire averages[2] 4000 rounds per hour, but is normally distributed with a standard deviation of 1000 rounds.

```
34A    ECDF.K=(1)NORMRN(4000,1000)
```

The plot of the variables of interest of this model is shown in Figure 27. This plot is quite interesting; for it shows that despite the complete randomness of the enemy capability of fire, the platoon's strength (S) behaves as it did in Model 6-4000(SOPH) where the capability of enemy fire was maintained at a constant rate of 4000 rounds per hour.

4.6 Additional Experimentation

The sophisticated model is considered to be developed adequately to permit additional experimentation. The basic load, for example, may be established at 200 rounds per man

[1]Random function of direct fire (sophisticated model).

[2]i.e., has a mean of

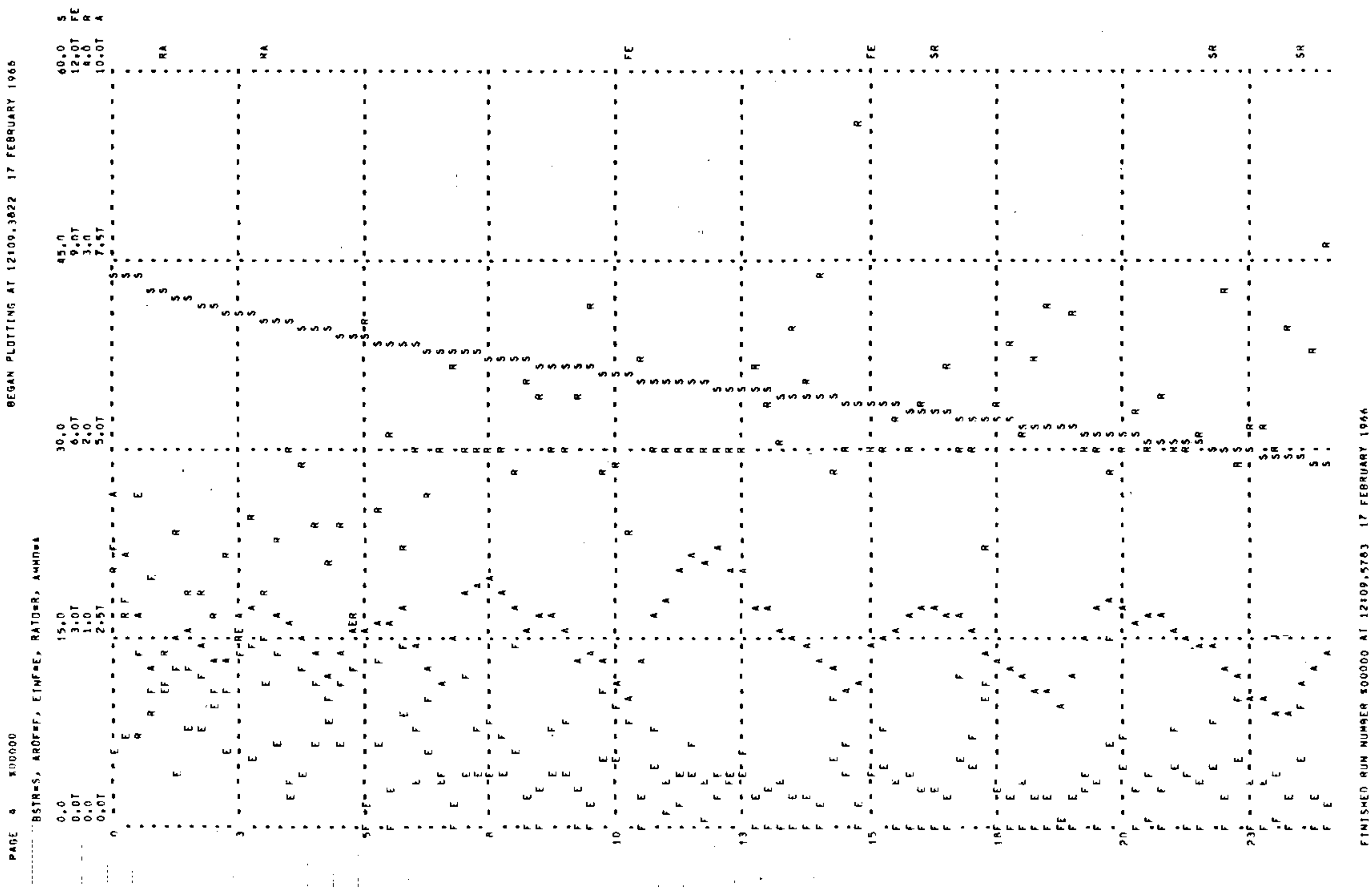


Figure 27. Plot of the Variables of Interest: Model 8-RFDF(SOPH).

instead of 100. Ammunition may be delayed five hours, or friendly indirect fire may not be delivered during certain time intervals due to other commitments. Each of these changes would have its effect, either large or small, on the other variables of the model. The number of changes and variations is infinite and depends only upon the ingenuity of the model builder. However, the objectives of this study as established in paragraph 1.2 have been accomplished and only a few additional comments relating to the model sensitivity will be made.

The parameter of the number of rounds of direct fire required to cause one casualty (1650) was rather artifically and arbitrarily derived. An assumption is now made that this parameter is erroneous by a 50 per cent margin, i.e. the number of rounds required to produce one casualty is 2475. Model 9-4000(SOPH-A) shows this effect in the plot of the variables of interest appearing in Figure 28. It will be noted that at the end of the 24-hour period the strength of the platoon (S) is 34 men as compared to the 30 men of Model 6-4000(SOPH). This is a noticeable, but not a particularly significant, change in the model. The variables of interest, it will be noted, other than for slight changes in value, behave in much the same manner regardless of which parameter value is used. In other words, due to the numerous variables involved in an industrial dynamics model, variables are not particularly sensitive to gross errors of determination.

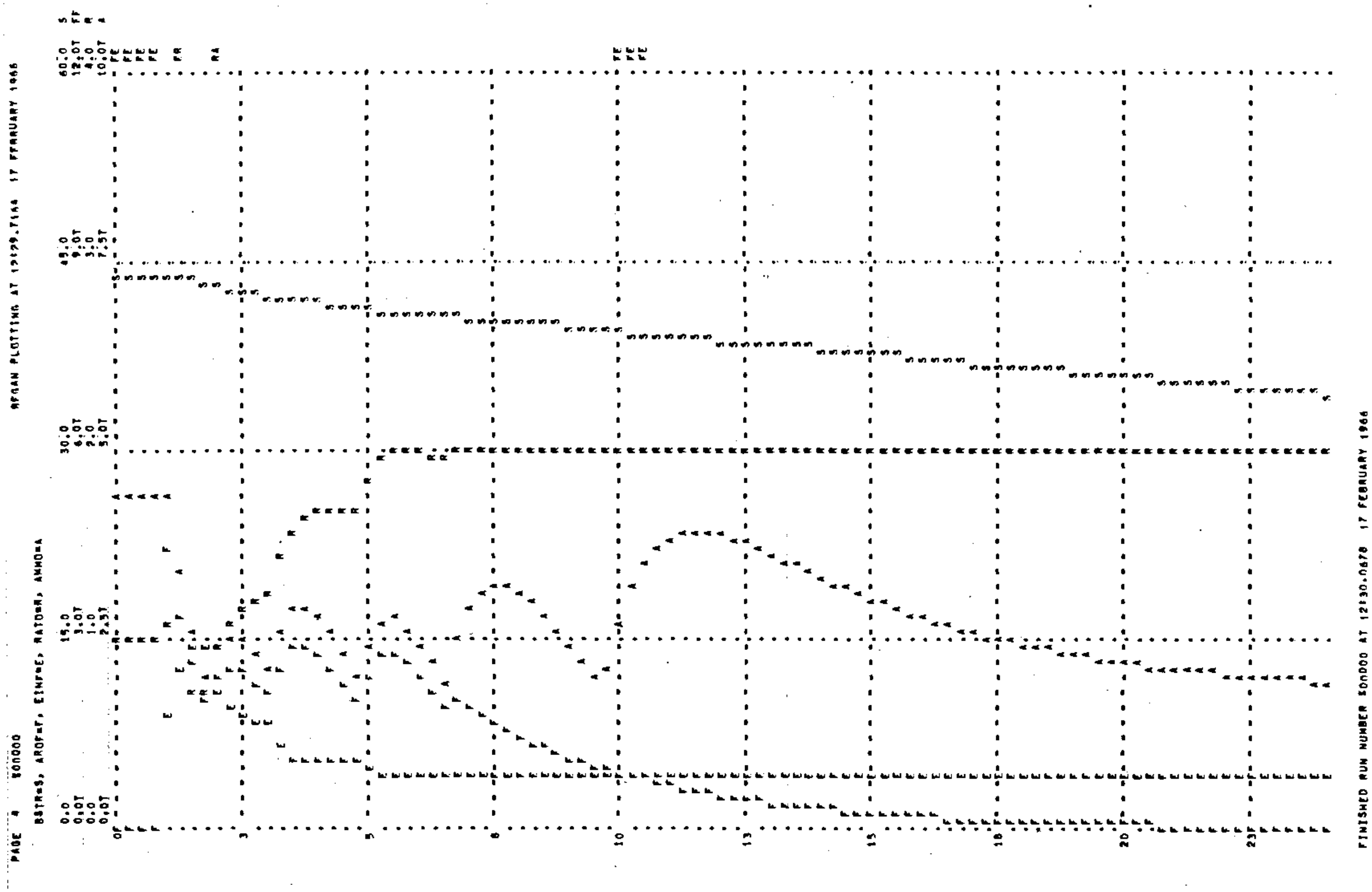


Figure 28. Plot of the Variables of Interest: Model 9-4000(SOPH-A).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The behavior of a military unit upon the delivery of fire on the battlefield has been probed in the nine models developed in this study. The probe is admittedly incomplete and the surface has been merely scratched. Difficulties were experienced in the lack of quantitative data, and in consequence the interrelationships of many of the variables are undoubtedly inaccurate. More detailed observation combined with statistical studies can provide a closer approach to reality. However, it should be pointed out, that with the possible exception of several dominant variables, the other variables render but a small contribution to the overall performance of the model. In other words, in the dynamics of the model, even a gross error in the relationship of a function, or in the estimation of a parameter, contributes but a slight change in the behavior of the significant output variables.

Only the most important parameters of a rifle platoon model have been examined. Certainly the fighting spirit, or aggressive will, is an important variable[1] requiring addition

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[1]See General S. L. A. Marshall's work, Men Against Fire (1), for the importance of this variable.

to the set of equations. Other variables such as range, terrain, and the conditions of visibility also play a role. Perhaps even the sophisticated model is too crude, and the variable of the platoon's strength should be divided into automatic and semi-automatic weapons' personnel. Furthermore, the effect of the platoon's high-explosive type weapons, such as the rocket launcher, may require separate treatment.

The addition of any or all such variables can be made to the military model using the technique of industrial dynamics. The "sophisticated" models of this paper require no more than 70 variables out of the 2000 variables which present Dynamo computer programs can handle. However imperfect these simulated models may be, they are far superior to the mathematical models which employ only a few variables in portraying the dynamics of complex military problems. The industrial dynamics flow diagram, with its matching set of equations, can be easily read and understood by any professional officer not possessing computer programming skill. This feature alone makes the industrial dynamics approach superior to the other presently developed computer languages designed to deal with the dynamic problems of management.

5.2 Recommendations

Further expansion of the Dynamo language would materially aid the development of operational methods. Absolute delays were not available for the author's use in the Dynamo program developed for the Burrough's 5500 computer; such delays are available, however, in the IBM 7094 program. Development of a greater variety of special functions, and in particular of a pulse function whose interval over time could be varied, would be especially useful.

A model of a rifle platoon in the assault, programmed over a period of perhaps one hour from its occupation of the assembly area through the enemy counterattack after its objective has been seized, should prove illuminating. In such a model the number of casualties should be dependent upon the range from the objective and should not necessarily be linear in nature.

The overall examination of the organization of a field army or of the Defense Establishment should throw new light and understanding on the interplay of such systems. The industrial dynamics model is not limited to examination of small organizations. It works equally well, in fact perhaps better, in models of large organizations for it strips away all unessential features.

Finally, the Defense Establishment must gather, evaluate, and publish the data so necessary to the development of any quantitative model. As evidenced by General S. L. A. Marshall's book, Men Against Fire (1), a beginning was made during World War II. From this experience, the

HUMRO[1] studies have led to new concepts in rifle marksmanship. Further research, using improved mathematical and statistical techniques, must illuminate the way in studies of organization, communications, weapons, tactics and doctrine and portray their interrelationships and interplay with one another. The method of industrial dynamics is ideally suited to these purposes.

---

[1]Human Research Organization

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