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MILITARY APPLICATIONS OF DYNAMO

A THESIS

Presented to

The Faculty of the Graduate Division

by

Robert Bruce Vail

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

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CHAPTER I

INTRODUCTION

Nature of the Study

This study will examine the computer programming system, DYNAMO, and some of the problems to which this system has been applied. The studies which are cited were selected from both industrial and military applications. For the most part, however, industrial examples are limited to possible military analogies.

The principal point developed in this paper is the dichotomy of approach to a given problem; these may be termed, Industrial Dynamics and Dynamo Simulation. Before examining these terms and the underlying philosophy of each approach, the computing system used to implement them, DYNAMO, will be briefly discussed. A general understanding of this system is necessary for a more complete appreciation of the different approaches it serves.

The intent of this undertaking is to focus attention on the potential areas of applicability to military problem areas of Dynamo Simulation and Industrial Dynamics.

It is also anticipated that analyses of the examples cited will result in a basis for extrapolation of criteria fundamental to problem types applicable for study by either Industrial Dynamics or Dynamo Simulation.

Background Information

The author's interest in this subject area was first aroused during a course in Industrial Dynamics presented by Dr. B. C. Spradlin of The School of Industrial Engineering, Georgia Institute of Technology. The possibilities of this technique in a military environment appeared especially favorable. The high degree of aggregation used, the lack of a requirement for precise data and the managerial overview taken are all compatible with the nature of many military problems. Often in high echelon staff work it is necessary to attempt to reconcile beforehand the effect of a policy change on other sectors of the command or service. Traditionally this has been approached on a "best estimate" basis, often in situations too complex for even the collective best judgments provided by critical staff analysis. Industrial Dynamics was seen as a manner of approach which, though not a panacea, offered a much better, more sophisticated means of analysis. Behavior characteristics, rather than specific responses of a system are of usual interest in staff policy evaluations and this is the nature of the output of Industrial Dynamics, that is, to reveal the behavioral characteristics of the system and the control "loops" which govern them.

Subsequent study revealed that some scholars were in disagreement with some aspects of the Industrial Dynamics philosophy, and that others, ostensibly using Industrial

Dynamics, were actually only simulating a system and using the Dynamo computer programming process to accomplish the simulation. These factors, when taken together, indicated that there was a need for a realistic examination of the uses of Dynamo to place them into perspective, thus giving rise to this paper.

Scope and Limitations

The scope of this effort has been limited to the examination of essentially Army topics although the ideas espoused are paralleled in the other military services albeit in somewhat different terms and under differing circumstances. Similarly, the details of problems encountered will vary from service to service. However, these problems, in essence, are alike.

A limitation is imposed by the very nature of this undertaking which is primarily a search for and review of Dynamo applications; little is added to the existing body of knowledge on the subject. What is provided is rather an overview of the ideas of others coupled with an elementary problem analysis procedure and a reconciliation of the major philosophies involved. This study is not intended to be a theoretical dissertation but rather a practical examination of a useful scientific tool to be used on real-world problems.

CHAPTER II

LITERATURE SEARCH

General

Published studies involving the use of Dynamo are not numerous. Militarily oriented studies are practically non-existent except for some limited work done at a few universities, primarily by military students as part of thesis work. Due to this scarcity of background information the search for applied efforts involving use of Dynamo by military agencies was extended to include unpublished reports and working papers within the Department of Defense and in particular, within the Department of the Army. Limited contact was also made with a few consultant companies which have done extensive contract work for Department of Army agencies. Although some of this informal search for information was done by mail, most was accomplished by direct contact and visits to the staff agencies involved. The order in which the following descriptions appear is somewhat indicative of the formality of the documents' form and degree of sophistication, with those listed toward the end in the formative stage.

Dynamic Allocation Model

It was also found during the course of examining the literature that the term, DYNAMO, has also been used to describe a class of models based on an application of dynamic programming techniques. When used in this context DYNAMO is an acronym for Dynamic Allocation Model. A word of caution; the two methods, though having the same name, are entirely different and essentially unrelated. An example of the dynamic programming approach, "A General Dynamic Model For Air Defense," appeared in Operations Research Sept-Oct 1967 (1). The model presented is essentially probabilistic and concerned with optimization. As previously pointed out, each of these features is alien to the Industrial Dynamic or Dynamo Simulation approaches.

Search Limitations

The nature of this study is in many respects a literature search itself and due to the expressed intent of primarily exploring military subjects the direction of search was modified somewhat from the norm. The computerized facilities of Defense Documentation Center, (DDC), Alexandria, Virginia, were utilized to extend the limits of this exploration; it is to be realized, of course, that only unclassified material has been utilized in this paper and consequently the examples cited are by no means exhaustive. Unfortunately, the information retrieval system at DDC is not geared to methodologies or computer languages but rather to listings by subject matter. Several recent queries had been directed to DDC concerning Industrial Dynamics and Dynamo and this was itself of interest because of the paucity of completed studies on these subjects. The increasing interest in these techniques is manifested in this unusual rate of requests for information.

It will be seen in the following pages that with few exceptions the models and studies mentioned are academic in that they are not directed at specific real-world problems but rather at problem types which are encountered in substance in a military environment.

CHAPTER III

LANGUAGE AND PHILOSOPHIES

Dynamo Special Purpose Computer Language

The name, DYNAMO, is a contraction for DYNAmic MOdels. It was applied to a special purpose simulation language developed by Alexander M. Pugh III and others at the Alfred P. Sloan School of Management, Massachusetts Institute of Technology. This language was developed in 1959 for the purpose of simulating information feedback systems, primarily for the solution of problems in the Industrial Management field.

Dynamo fills a unique position in the field of simulation languages or systems in that it is geared to the solution of systems of simultaneous zero and first order difference equations representing a deterministic, closed loop, continuous system. Thus, its closest counterparts are the special purpose languages, MIDAS, MIMIC etc.which are used as digital simulation devices for simultaneous differential equations, normally associated with rather cumbersome analog computer techniques. Since difference equations are more practical to represent time sequences of system input and output than are differential equations, it is readily seen why such a language would have attraction for those interested in economic or managerial type studies, areas characterized by discrete time sequences. The niche occupied by Dynamo, in relation to other languages, is depicted in Figure 1. (2)

The essential variables of a dynamic systems study, state variables and output variables, are described in Dynamo by level equations and rate equations respectively. State variables (levels) describe the state or condition of the system at given time. Rate variables (rates) describe how the states change with the passage of time. Although the level and rate equations alone describe the system, it has been found that a component of the rate equation, which serves to completely describe the function of that rate equation, is generally required. In Dynamo these equations are termed auxiliary equations. The auxiliary equations form the basis for the control of the rates and are of great importance in a representation of feedback control. Detailed information on each of these equation types is found in Chapter 7 of Industrial Dynamics. (3)

Dynamo is a simple language to understand and use in comparison with other computer languages. The time notation used with it is particularly helpful in appreciating the sequence of computations; this is useful in preparing a Dynamo model. Another noteworthy feature of Dynamo is that, in addition to printed results, the user may obtain graphical plots of the value of selected variables at whatever scale the user may choose. For analysis of results of

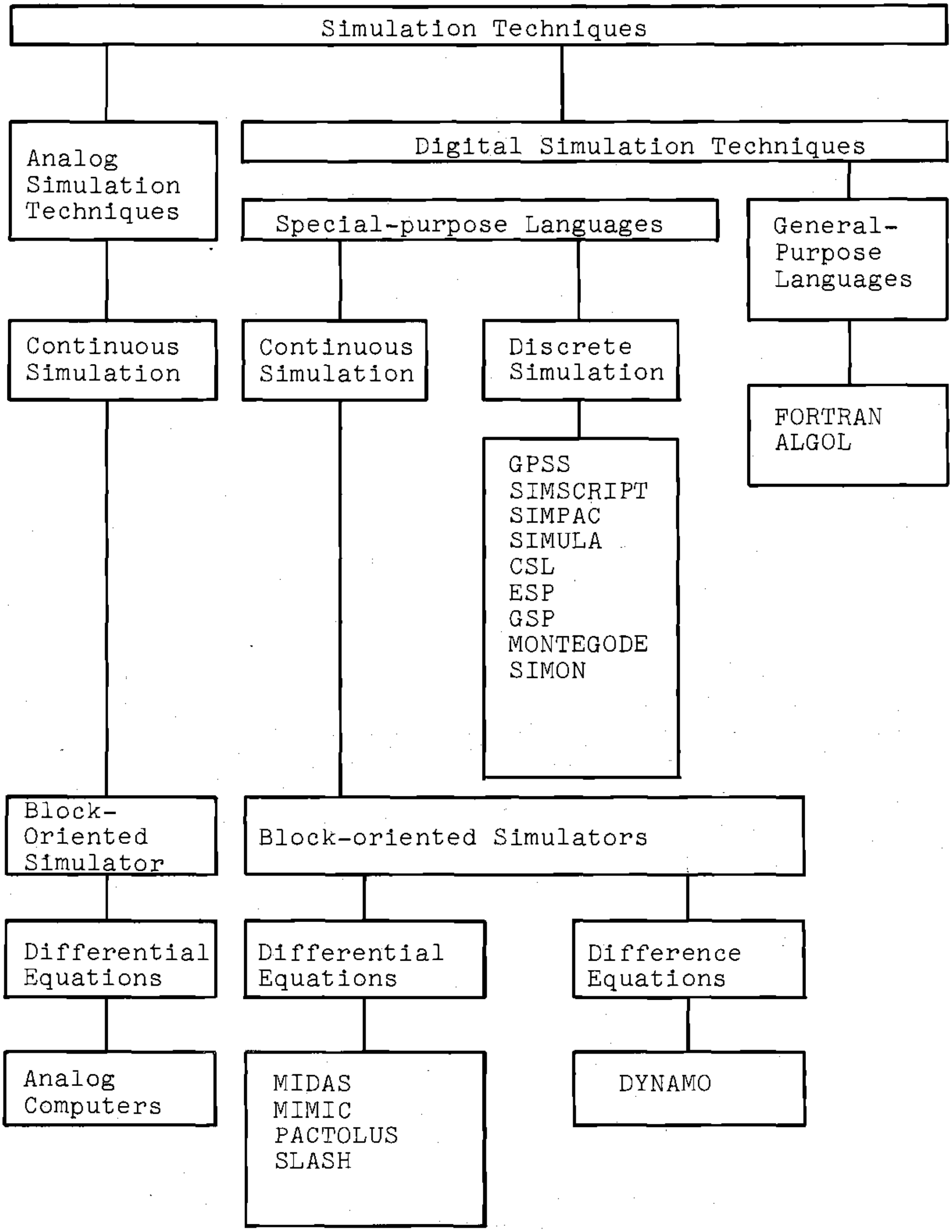


Figure 1. Classification of Continuous Simulation Devices

individual "runs" this feature is particularly valuable. In addition, this feature together with the nontechnical notation of the language itself, makes it especially adaptive for presentation of officers or managers unfamiliar with such methodology.

For those who are interested in the details of the Dynamo language and its implementing instructions, the Dynamo User's Manual (4) provides a concise reference. The following generalizations, however, provide the substance of the language itself and will facilitate understanding of the example problems to be discussed in later chapters. In brief, Dynamo utilizes two types of punched cards, equation cards and direction cards. The direction cards merely serve to specify the time interval, run length and the variables whose values are to be printed and/or plotted. Equation cards consist of seven quantity types, each identified by letter. These are:

L	Level
R	Rate
A	Auxiliary
C	Constants
N	Initial value (or computed constant)
B	Boxcar train
S	Supplementary

Levels, rates and auxiliary equations provide the nucleus of the equation types and were discussed earlier.

Constants are explicit numerical values held constant for a particular run. Initial values are imputed into the system at the beginning of the run via the initial value equations and provide a starting point for the computer program. Boxcar train equations are special sets of equations used to shift quantities from one time period to the next, such as in updating seasonal data or constructing "pipeline delays."

Using the Dynamo language for simulation is facilitated by a number of special functions which can be used in a variety of ways as required by the problem at hand. Random numbers for example can be generated in two ways; the first as "noise" in the system, uniformly distributed within limits specified by the user; second, as a set of normally distributed random numbers about a specified mean and with standard deviation established by the user. Similarly, delays of several types can be generated and these are particularly important to the Industrial Dynamics approach. Pulses, samplers, ramp and step functions, minimum and maximum functions, limiting, switching, summing and table functions round out and give flexibility to the language. Common functions such as the exponential, sine, cosine, square root and natural logarithm are available and may be adapted for particular requirements such as a specific amplitude and period for a trigonometric function.

The time notation used in Dynamo parallels the procedure used by the computer in calculating values in that both move through time in discrete steps and the values of each of the variables are calculated at each step. Present time is denoted by the suffix K, previous time by J, and future time by L. Figure 2 depicts this relationship. It should be noted that the intervals JK and KL are called DT; this is the time interval which must be specified by the user. This time notation enables the user to specify the time at which a quantity is to be calculated and to establish the time at which the quantities used in this calculation were previously computed. When all the variables have been calculated for Time K and the interval KL, the computer moves to the next time step and the values associated with Time K become the new Time J values etc. The order of computation, by a computer, is first levels then auxiliaries and finally the rates for the next time period of interest, KL.

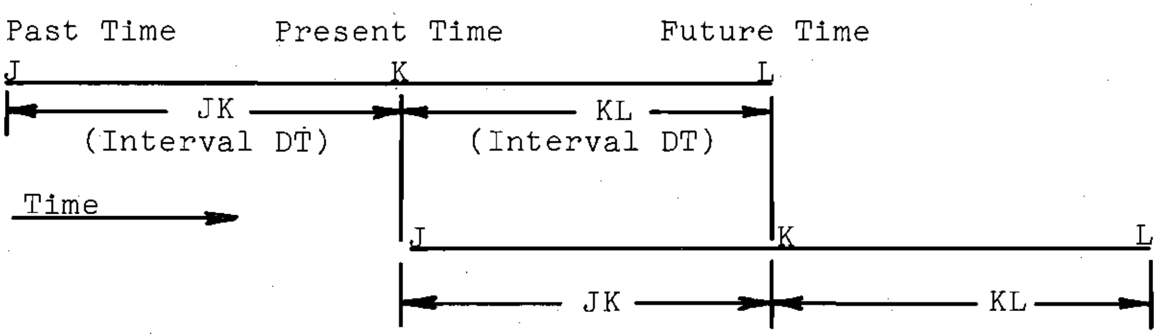


Figure 2. Dynamo Time Notation

Industrial Dynamics

"Industrial Dynamics is the investigation of the information-feedback character of industrial systems and the use of models for the design of improved organizational form and guiding policy." (5)

Professor Jay W. Forrester, the original developer of Industrial Dynamics, presents the above definition in the referenced work although it is but one of several definitions which he offers. Another descriptive phrase used to describe Industrial Dynamics is that it is a "way of studying behavior of industrial systems to show how policies, decisions, structure and delays are interrelated to influence growth and stability." (6)

These descriptions, while not unique definitions, form the basis of Industrial Dynamics. The salient ideas in these phrases are: information-feedback; an approach for relating interrelationships; and improved form and guiding policy. Implied in these ideas is some form of control to bridge the gap between the information feedback mechanism and the desired improvements. Thus, we have An approach or philosophy which relates the interrelationships within a system to that system's information-feedback control mechanism for the purpose of studying the system and effecting improved policies and system stability via the feedback control mechanism.

The emphasis in the foregoing discussion has been on information-feedback, consequently it will be discussed briefly as it is the foundation of the Industrial Dynamics approach. Professor Forrester states, "An information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions." (7) This cycle is of course continuous and regenerative; current results lead to new decisions which lead to future results. (The suitability of Dynamo as a study vehicle is readily seen here when related to the previous discussion of time notation). In an information-feedback system it is apparent that available information about the past state of the system is used as a basis for controlling future action. Information-feedback systems have three significant characteristics which are; their structure, delays and amplification. The component relationships which exist within the system provide the structure. Delays are those inherent in obtaining information, making decisions and implementing these decisions. Amplification is concerned with the sensitivity of the system to changes in policy. For example, an apparently small policy change may result in a greatly exaggerated response at some other point in the system.

With this background concerning Industrial Dynamics and its cornerstone, information-feedback control, there are a series of steps to be followed in developing a legitimate industrial dynamics study. These steps must be followed to insure retention of the basic philosophy of Industrial Dynamics; failure to follow these procedures increases the likelihood of developing a Dynamo Simulation model instead. This will be discussed as a separate technique in the next section. The procedural steps to follow for an industrial dynamics study, as outlined by Professor Forrester, are: (8)

1. Identify a problem.
2. Isolate the factors that appear to interact to create the observed symptoms.
3. Trace the cause-and-effect information-feedback loops that link decisions to action to resulting information changes and to new decisions.
4. Formulate acceptable formal decision policies that describe how decisions result from the available information streams.
5. Construct a mathematical model of the decision policies, information sources, and interactions of the system components.
6. Generate the behavior through time of the system as described by the model (usually with a digital computer to execute the lengthy calculations).
7. Compare results against all pertinent available knowledge about the actual system.
8. Revise the model until it is acceptable as a representation of the actual system.
9. Redesign, within the model, the organizational relationships and policies which can be altered in the actual system to find the changes which improve system behavior.
10. Alter the real system in the directions that model experimentation has shown will lead to improved performance.

These steps are predicated on a series of assumptions. These are: (9)

1. Decisions in management and economics take place in a framework that belongs to the general class known as information-feedback systems.

2. Our intuitive judgment is unreliable about how these systems will change with time, even when we have good knowledge of the individual parts of the system.

3. Model experimentation is now possible to fill the gap where our judgment and knowledge are weakest--by showing the way in which the known separate system parts can interact to produce unexpected and troublesome over-all system results.

4. Enough information is available for this experimental model-building approach without great expense and delay in further data gathering.

5. The "mechanistic" view of decision making implied by such model experiments is true enough so that the main structure of controlling policies and decision streams of an organization can be represented.

6. Our industrial systems are constructed internally in such a way that they create for themselves many of the troubles that are often attributed to outside and independent causes.

7. Policy and structure changes are feasible that will produce substantial improvement in industrial and economic behavior; and system performance is often so far from what it can be that initial system design changes can improve all factors of interest without a compromise that causes losses in one area in exchange for gains in another.

It is important to realize that the Industrial Dynamics approach is oriented toward top management decision making and a managerial overview of a system. It is not intended as an optimizing technique but rather an analytic examination of a number of complex interrelationships which include the effect of intangible factors as well as empirical quantitative data. The recognition of the intangible influences on decisions by Industrial Dynamics has been the source of some criticism by scholars. Industrial Dynamics may be defended however on the basis that it examines the behavior characteristics of a system rather than measuring a specific response. Professor Forrester states:

> There seems to be a general misunderstanding to the effect that a mathematical model cannot be undertaken until every constant and functional relationship is known to high accuracy. This often leads to the omission of admittedly highly significant factors (most of the "intangible" influences on decisions) because these are unmeasured or unmeasurable. To omit such variables is equivalent to saying they have zero effect - probably the only value that is known to be wrong.(10)

Dynamo Simulation

The second grouping of studies which use the Dynamo language may broadly be termed Dynamo Simulation for lack of a specific identifying phrase in the literature. To isolate what is meant by Dynamo Simulation in the discussion which follows, it will include all simulation using the Dynamo language which neither center upon the recognition of feedback characteristics of the system being simulated nor include intangible factors where these factors have major influences on the system. This general definition covers a wide range of studies but obviously orients Dynamo Simulation to detailed, quantitative examination of a system.

Simulation itself is basically concerned with imitating the operation of a system through a period of time. The uses to which the simulation may be applied are many and varied but the purpose of the actual computer simulation is merely to accurately imitate the system under study. A properly constructed simulation model then, of an inventory problem, given a set of historical data such as inventory levels, order rates and so one, should accurately reflect the changing inventory levels, back order rates etc., as shown in the historical records for the period. Thus, experimentation can be accomplished with the simulation model to determine the effect of changes, e.g. decreasing the reserve component of inventory to examine the effect of such a change on back order rates or other factors. This can all be examined without change in the real system until such time as a desirable policy, perhaps an optimal one, is obtained with the simulation model. A direct change can then be made in the real system, without recourse to trial and error experimentation with that system, and theoretically it also should operate at its optimum performance level e.g. least cost.

The use of Dynamo is well suited to a number of simulations, provided the system being imitated is of the continuous, deterministic, closed loop variety where system inputs and outputs can be assumed to be time sequences, such as in economic and managerial analysis.

Although much has been written on the general subject of simulation, there has been very little devoted to the philosophy underlying the use of Dynamo as a simulation vehicle, notwithstanding the number of models which have been constructed within the framework of what is called Dynamo Simulation. Dr. Joseph Krol of the Industrial Engineering Department, Georgia Institute of Technology, has proposed a set of principles for dynamic model building which, while they appear basically similar to those established by Professor Forrester for Industrial Dynamics studies, are, in fact, substantially different. The differences are primarly of perspective and of manner of approach, although there are several other differences to be noted. The six principles espoused by Dr. Krol are as follows:

1. The first principle is to state a clear purpose.
2. The second principle is to describe a closed system.
3. The third principle is to identify cause-and-effect relationships between all variables with judicious inclusion of feedback control processes.
4. The fourth principle is to give the following preferences to information used in model construction: (a) quantitative, (b) semiquantitative, and (c) verbal.
5. The fifth principle is to identify the major subsystems of the model.
6. The sixth principle is to recognize the information network of the system as the tissue which integrates the other components (11).

The difference in perspective between Dynamo Simulation and Industrial Dynamics is that whereas the latter technique aggregates variables which are felt to have little effect on the total system, Dynamo Simulation recognizes that significant interactions may exist among these variables and therefore must be included. Studies conducted with limited or no variable aggregation have been termed microdynamic by some writers. A great amount of aggregation, and the resultant "overview" provided, the Industrial Dynamics approach, consequently has been termed macrodynamic.

The manner of approach is basically one of synthesizing a system from known information about that system's components under the Dynamo Simulation concept. Contrasted with this is the analytical breakdown of a system into its primary cause-and-effect information feedback loops of Industrial Dynamics making extensive use of non-quantified verbal description. The two diametrically opposite approaches, synthesis on one hand, analysis on the other, are especially significant, as will be seen later, in ascertaining the preferred approach to a particular problem.

In substance, the Dynamo Simulation approach is the more conservative and traditional concept of engineers and economists. It focuses on the known, quantitative and tangible factors of a particular system and the overt relationships which govern the behavior of that system. Simulation lacks the mysterious "black box" stigma often associated with new concepts and is more readily accepted by prospective users, such as industry, than is a less readily understood and more controversial conecpt, in this case Industrial Dynamics. In the sections which follow, military applications of each of these ideas will be examined and the usefulness of each put into perspective. It is hoped that the present polarization of thought on the use of Dynamo can be somewhat alleviated through the development of criteria which guide an analyst to an approach to his particular problem which best suits the objectives of that problem.

CHAPTER IV

COMBAT MODELS

An Early Effort

The preponderance of effort to date in the use of Dynamo has been by industry, with some few studies of military subjects having been accomplished by students and faculty members of a few universities. These few specific applications, together with general analogies of military problems with industrial and institutional applications, form a broad spectrum of possible military uses. First to be considered are military combat models developed by officer students at Georgia Institute of Technology as Masters Research Papers or as complete thesis work.

In this regard, a great deal of effort has been expended in using the Dynamo computer language to study a variety of combat situations. In the terms of reference used in this paper, the use of the phrase, Industrial Dynamics, in the titles of some of those studies may be a source of some confusion as will be pointed out.

In 1966, Lt. Col. Louis E. Abele (12) developed a Dynamo model to study the behavior of an infantry rifle platoon exposed to enemy fire. Basically, this model examined the effect of various rates of enemy fire on the strength of the platoon as a function of time. This model was constructed in stages, with refinements and additions made at each successive stage. Figure 3 reflects the final stage of this model (13).

The appearance of the flow diagram is at first glance rather complex and meaningless to a layman. In a later discussion it will be seen that it is not very difficult to comprehend with a minimum of explanation. A significant point to note, however, is that the amount of detail used in this model of an infantry platoon may be expressed by the number of levels, seven in this case, and by the number of required equations, which is approximately 80. It will be seen later that an Industrial Dynamics model of an insurgent activity has also been described by a seventh order (seven levels) system and about 175 equations. This suggests the desirability of using the Industrial Dynamics concept on systems of greater import and significance, where the return on approximately the same study effort is considerably greater.

In Colonel Abele's study, the early stages of his model reflected only the linearities and monotonically increasing or decreasing nature of the variable values. As refinements were made on the model, information-feedback was introduced in meaningful amounts and consequently the characteristic oscillatory nature of variables controlled by information-feedback loops became apparent (Figure 4). (14)

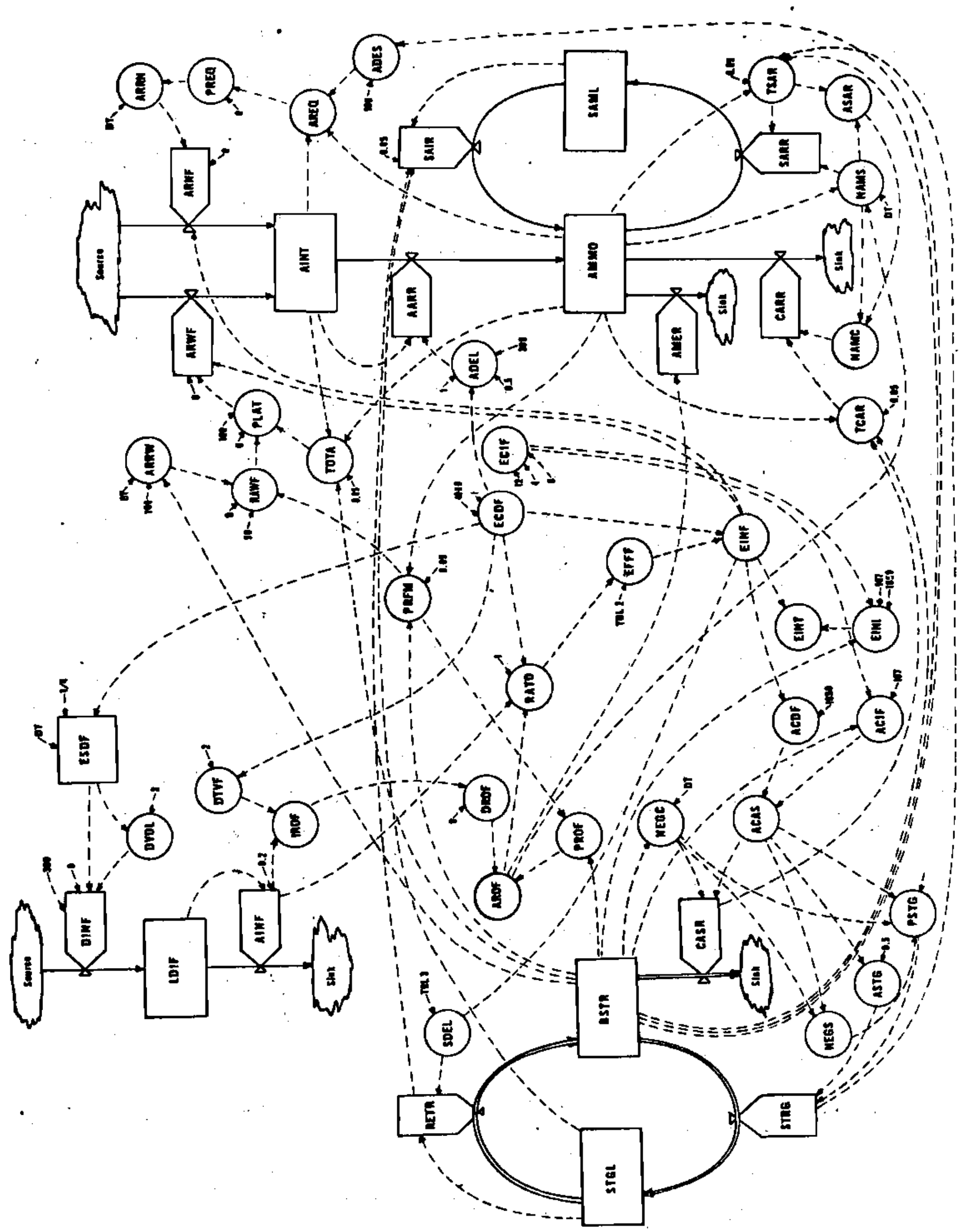


Figure 3. Flow Diagram of Abele Model

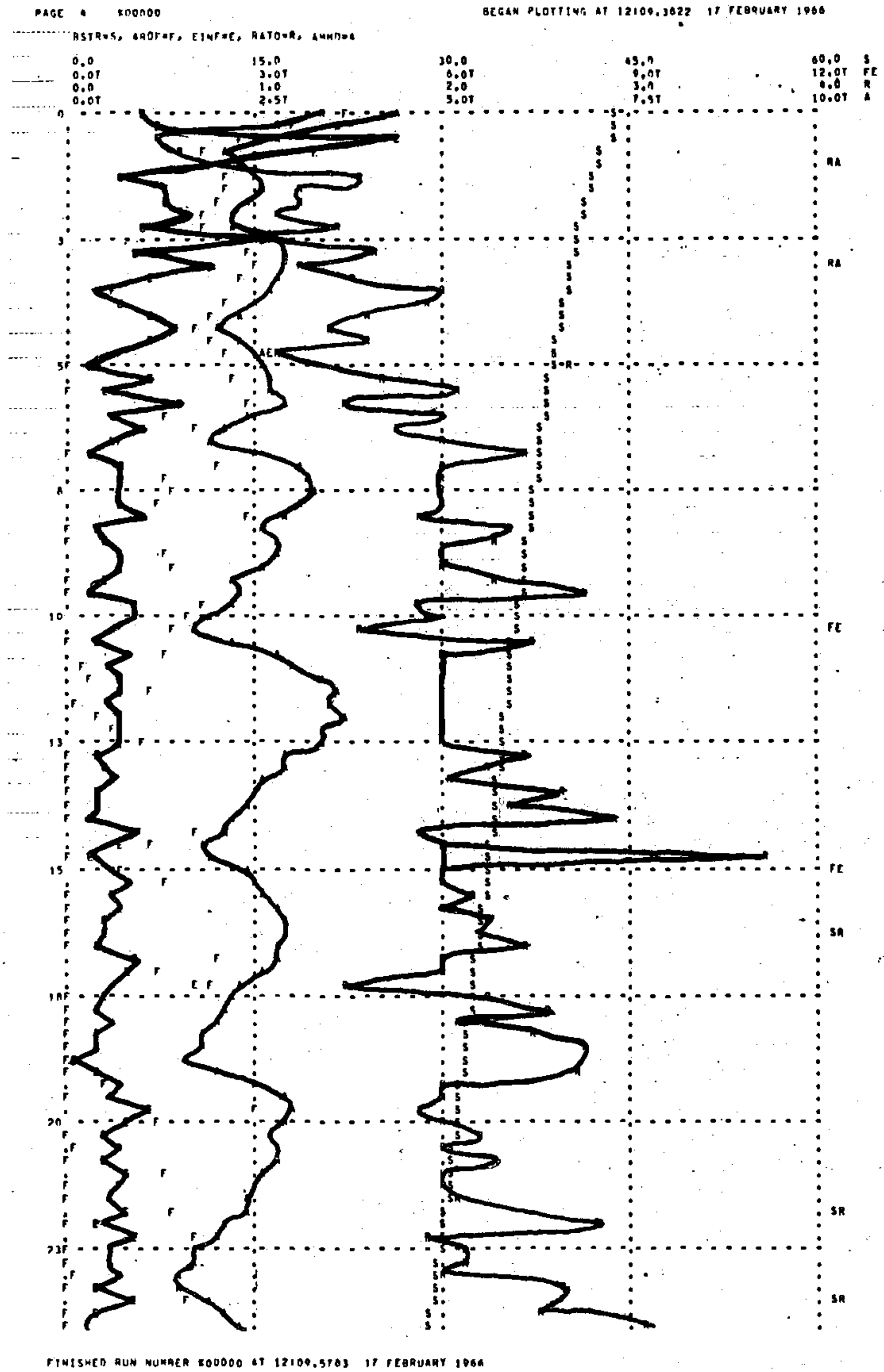


Figure 4. Plot of the variables of interest in Abele Model
(Point values connected for clarity)

It should be remembered, however, that the procedural steps set forth by Professor Forrester were not vigorously followed by this method of formulation. The procedure was, instead, a sythesizing approach; information feedback was included as the model was refined. This is the technique advocated by Dr. Krol in his statement of principles to follow (see page 19). Thus, this study must be termed a Dynamo Simulation pursuant to the demarcation which exists with regard to the degree of emphasis on information-feedback. The semantics of the situation aside temporarily, Colonel Abele summarizes his feelings concerning the military use of the Industrial Dynamics/Dynamo Simulation technique as follows:

> 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 methods designed to deal with the dynamic problems of management (15).

An Assault River Crossing

Another and more complex combat model, of a different type, was developed by Lt. Col. Reed E. Davis (16) as a Master's Thesis while attending Georgia Institute of Technology. Entitled, "A Dynamo Simulation of an Assault River Crossing", this project examines from two aspects the problem of a mechanized infantry division conducting an assault river crossing. The first of these is a comparison of several alternative crossing plans to determine which plan best satisfies the requirements of the divisions stated tactical plan under a given set of crossing equipment conditions. The second aspect is concerned with determining a set of decision policies, relative to the forward movement of troop units and the density of troop concentration throughout the division zone, which best satisfies the requirements of full utilization of crossing capabilities while minimizing the presentation of worthwhile targets to enemy fire.

This comprehensive model was also built in successive stages, following the synthesis approach to model building, and ultimately included a number of refinements which dramatically indicate the degree of flexibility available to an imaginative user of Dynamo. The initial model considered five alternative crossing plans, under ideal conditions, from a strictly deterministic standpoint. As the model was improved, several probabilistic features were added to make the model more representative of a real-life environment. Theoretical distribution functions were included to describe delays, movement times and crossing capabilities. Construction of crossing means (rafts and bridges) was simulated by Monte Carlo technique rather than simply as phased input data. Movement of units from forward holding areas to crossing sites was examined by a set of decision rules which were based on an allowed level of troop concentration within the crossing area. This permitted a measure of defile control which is vital to the success of such an operation.

Defile control, and the associated acceptable levels of troop concentration, is of considerable significance from the standpoint of the tactical doctrine concerning assault river crossing operations, particularly with the advent of small yield tactical nuclear weapons. The effects of a variety of hypothetical weapons and their associated damage radii were used in the development of acceptable troop concentrations for this study.

In the final model, Colonel Davis included controls which permitted the effect of unpredicted outages of crossing means to be examined. Reliability factors for each of the crossing equipment types were used with equipment repair rate distribution functions in this simulation, thus allowing the effect of random outages and site downtimes to be introduced.

A significant facet of this simulation becomes apparent in view of the circumstances underlying the study. The basis for the model was a problem presented at the U.S. Army Command and General Staff College during 1964-65. Those familiar with the formulation of problems at military schools are aware that a great deal of study and a large amount of collective effort is involved not only in this problem formulation but also in the development of the "school solution." The Dynamo Simulation of this same problem, by a single analyst, supports the present doctrine concerning assault river crossings with one noteworthy exception. This exception, as stated by Colonel Davis is:

> In (a) tactical nuclear environment present defile control doctrine appears questionable, in terms of the hypothetical family of nuclear weapons. Levels of troop concentration simply cannot be reduced to the acceptable level established by the results of the research. What seems to be demanded is an assault river crossing doctrine that avoids defile negotiation, thereby eliminating the unacceptable concentration of forces. The crux of the problem is with the division's equipment. A marked increase in amphibious and heliborne capabilities for combat, logistical and administrative elements of the division should provide the impetus for revised doctrine (17).

Use of helicopters would avoid defile negotiation at ground level and consequently eliminate the problem of troop concentration.

If the foregoing conclusion is accepted as at least a reasonable assumption, then it follows that this single Dynamo Simulation model has, in a quantitative manner, cast doubt on the validity of an army doctrine formulated by a qualified military committee which used the long standing technique of pooled judgement and experience in its development. Of itself this may or may not be of consequence; however, the primary significance is in the implied application of Dynamo Simulation as a means of validating established doctrine or testing and evaluating proposed doctrinal concepts.

In his conclusions, Colonel Davis makes the following observation:

> The results of this research, when coupled with extensions that appear logical and possible, indicate that Dynamo could conceivably be developed into a special purpose simulator for tactical operations (18).

He adds that sub-routines for realistic terrain modeling are required and concludes:

> For the military operations analyst, a special purpose tactical simulator would be a welcome and powerful tool in the study of weapons systems, unit organizations, tactical doctrine and operational plans (19).

Insurgent Activity Simulation

The second combat model to be examined was prepared by Major Robert W. Faulkender and is entitled, "Use of Industrial Dynamics in Simulation of an Insurgent Activity" (20). The purpose of the research was to develop a computer simulated dynamic model of an insurgency effort. The approach used was that of Industrial Dynamics; the insurgency was considered as an operating dynamic system within a specific environment and the objective of the research was to investigate the behavioral aspects of this system. In Major Faulkenders' words:

> The specific objectives are to formulate a relevant system of dynamic relationships that describe an insurgent activity as a behavioral system, and to simulate this dynamic model by means of a digital computer program using the DYNAMO language (21).

The data used for the model was taken from a real-world situation, in particular from knowledge of an insurgent force operating in the Mekong River Delta of South Vietnam. The data was admittedly incomplete yet that which was available was derived from firsthand information. As mentioned in the section concerning Industrial Dynamics, data requirements need not be precise to utilize this approach, consequently the restrictions imposed by the lack of detailed information were not severe.

The model itself was composed of three major systems encompassing two operational phases (Figure 5). (22) One of the systems, that representing civil affairs is shown in flow diagram form in Figure 6, and the complete model in Figure 7. (23) These diagrams and the discussion of some of the development are shown here, along with one of the model runs, for illustrative purposes as it is considered that this model well illustrates some of the most salient features of both DYNAMO and Industrial Dynamics. The understandability of the flow diagram by one familiar with the project is facilitated by the abbreviated notation. Considering Figure 6 without prior knowledge of any of the terms, it is still possible to identify government operations (GYNOP), propaganda (PROPG), civic action (CVACT) and other terms on initial inspection. A brief orientation on the other terms and the significance of the symbol shapes clarifies and makes the diagram meaningful to even the most uninitiated individual. Rectangular symbols identify levels, the butterfly-valve shapes pertain to rates, the circles to equations which determine rates (auxiliary equations), and the irregular shapes to sinks or sources. Identifying the abbreviated notation once or twice, e.g. PMF stands for

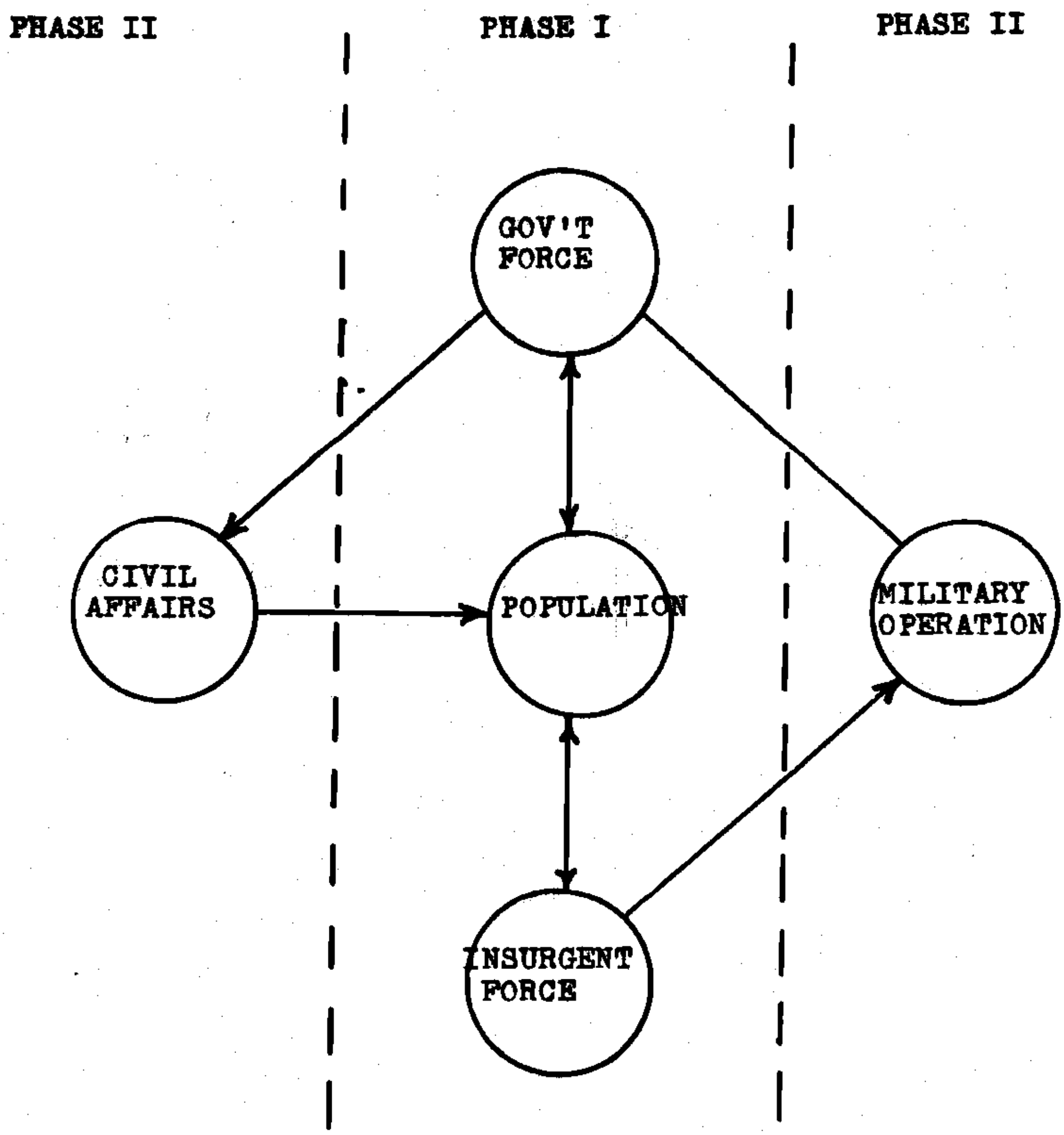


Figure 5. Systems and Phases in Faulkender Model

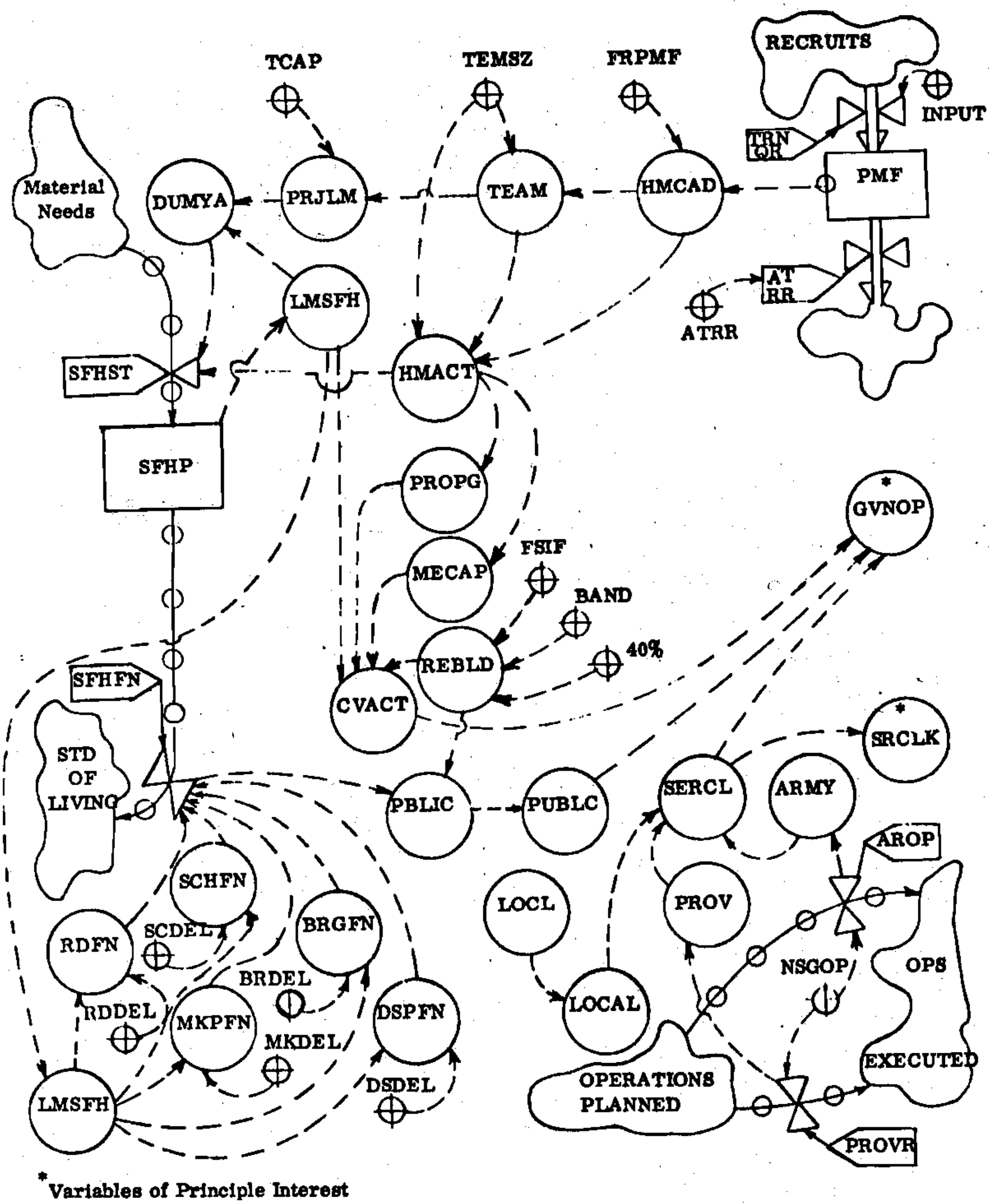


Figure 6. Flow Diagram of Civil Affairs Subsystem in Faulkender Model

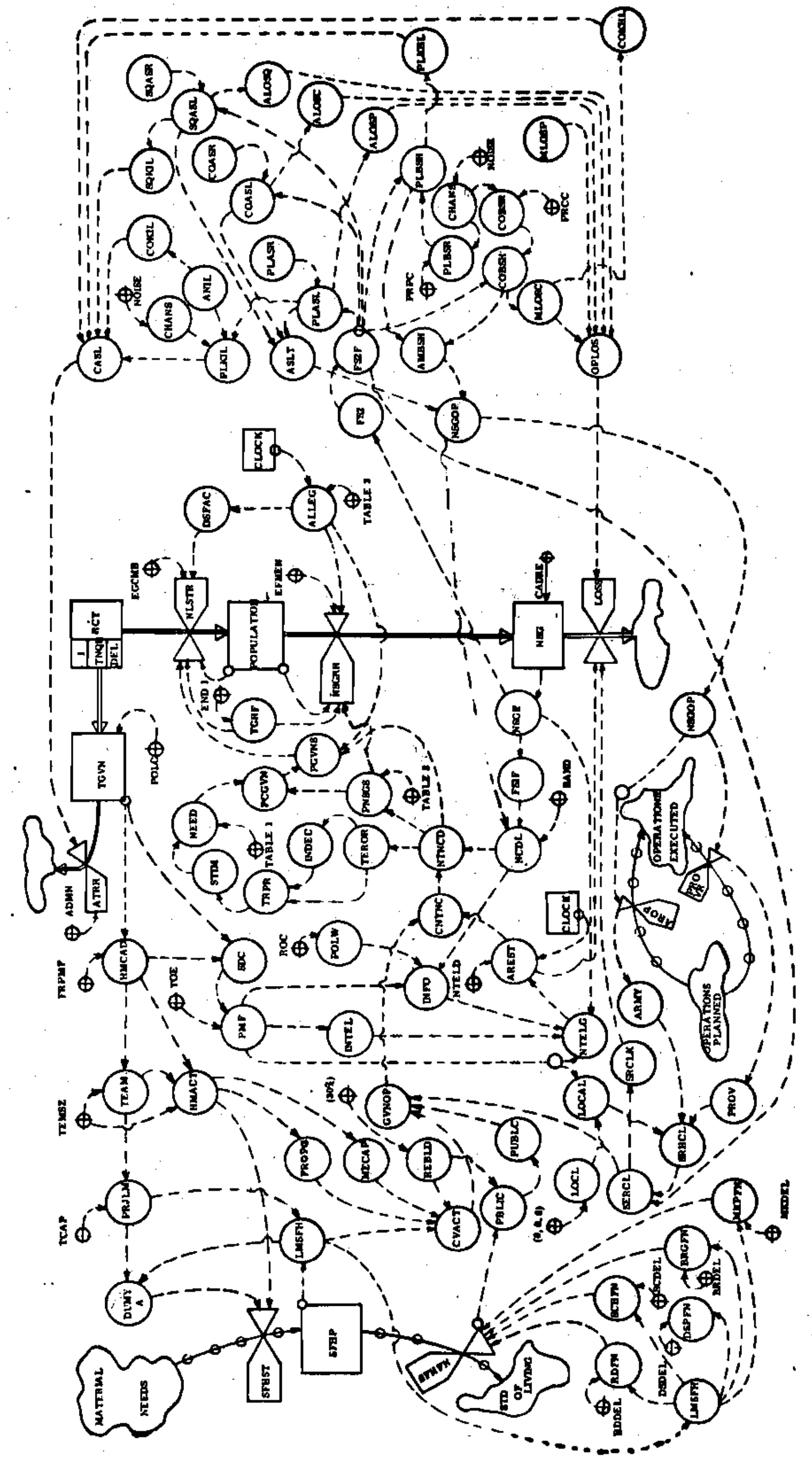


Figure 7. Flow Diagram of Insurgency in Faulkender Model

paramilitary forces, TRNQR for train and equip rate, PRJLM for project limit at any one time, etc., results in a high degree of model appreciation.

The formulation of equations is similarly quite easily understood and may be readily explained. To illustrate:

PMF.K = PMF.J + (DT) (TRNQR.JK-O)

or in words, the size of the paramilitary force at time K is equal to the size at previous time J plus the number trained and equipped during the interval JK. Similarly, TRNQR.KL = INPUT (men/two weeks) and this equation involves no interpretation except to say that the input could be a constant, a table function or could be made to be a variable whose value was dependent on one or more auxiliary equations. Those who have had experience in "selling" an engineering or research proposal to critical, but nonscientifically oriented personnel will appreciate the advantages of these aspects of Dynamo. In this context, the actual results of a model, the computer run, is also a convenient device to show how the dynamic system behaves. This is an interpretive procedure in which both the graphical output of the run and the feedback loops of the system are used together to determine the dominant factors influencing the system. The extent to which analysis and interpretation of results can be applied is evidenced in the discussion concerning one of the experiments with the insurgent operation.

Consider one of the runs of the model under discussion (Figure 8). (24) Major Faulkender describes the analysis of this run in the following manner:

> The insurgent influence builds up steadily while antigovernment sentiment continues until the intelligence network can counter the terror factor. Incidents continue to occur, however, even as the paramilitary force grows. The terror factor starts to climb back until the paramilitary can control or reverse insurgent growth. When this occurs and the terror factor is reversed again the target group response then improves for the government. At first, intelligence affects principally the terror factor and the insurgent ability to recruit. In time, however, the information flow switches its principal effect to the arrest rate and subsequent insurgent degeneration. In spite of the impressive support gathered, without consolidating its control with a hard line policy, the insurgent force does not succeed (25).

These graphical results add considerably to the attractiveness of Dynamo, not only for purposes of explanation but also for analysis by the researcher. Sensitivity of the system to changes in various parameters is readily apparent by comparison of the results of the separate runs. Systems which are under, over, or critically damped, or even explosive, can be recognized with some practice by examination of the plotted results. Figure 9 portrays examples of a variety of system responses which serve to illustrate the general nature of some of these characteristics.

This model of an insurgent activity reflects another of the basic characteristics of the Industrial Dynamics concept, that is the recognition of the intangible, non-quantitative aspects of a problem; pressure, persuasion, fear and terror are terms not normally associated with

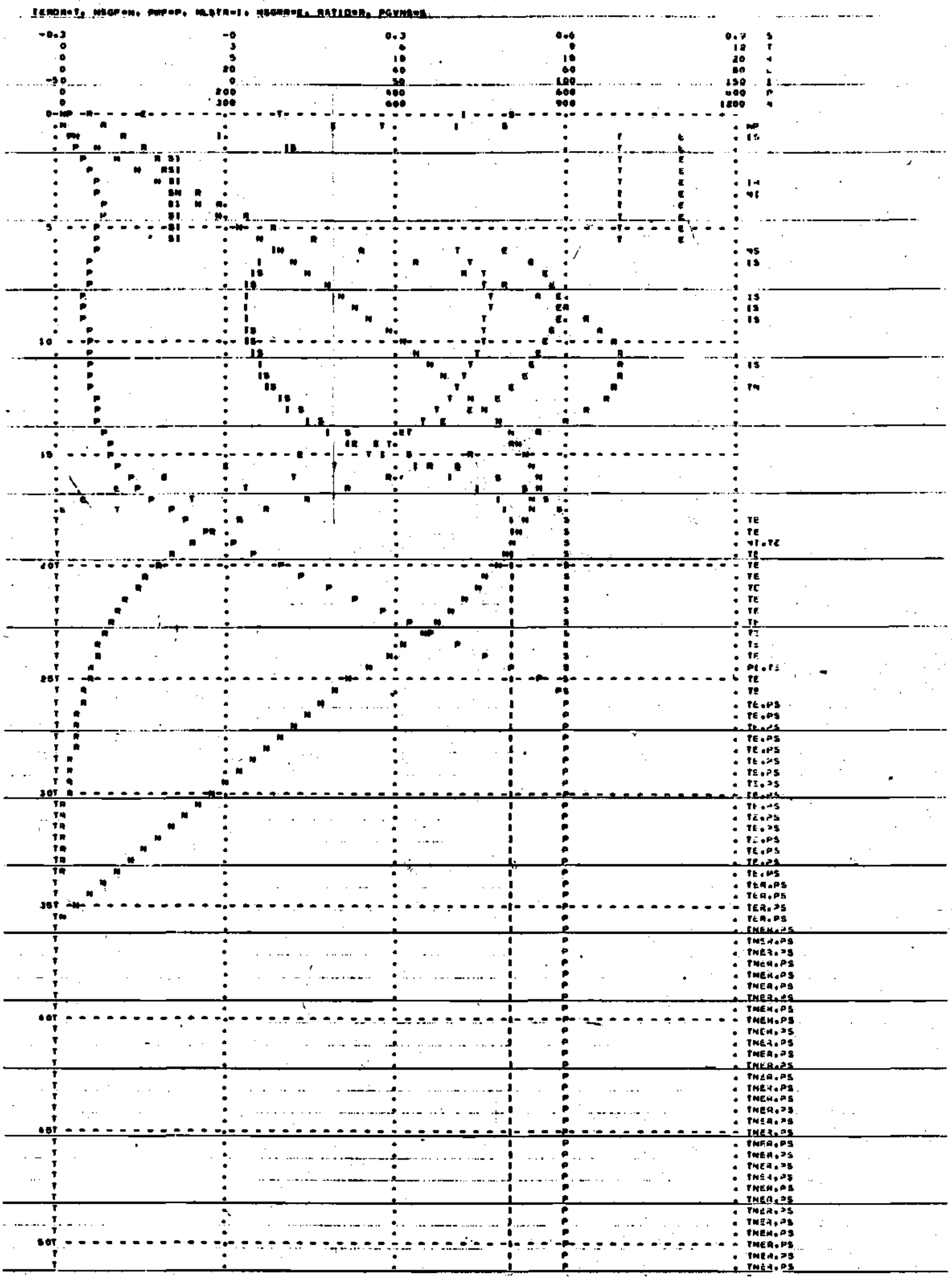


Figure 8. Plot of Dynamic Behavior of Faulkender Model

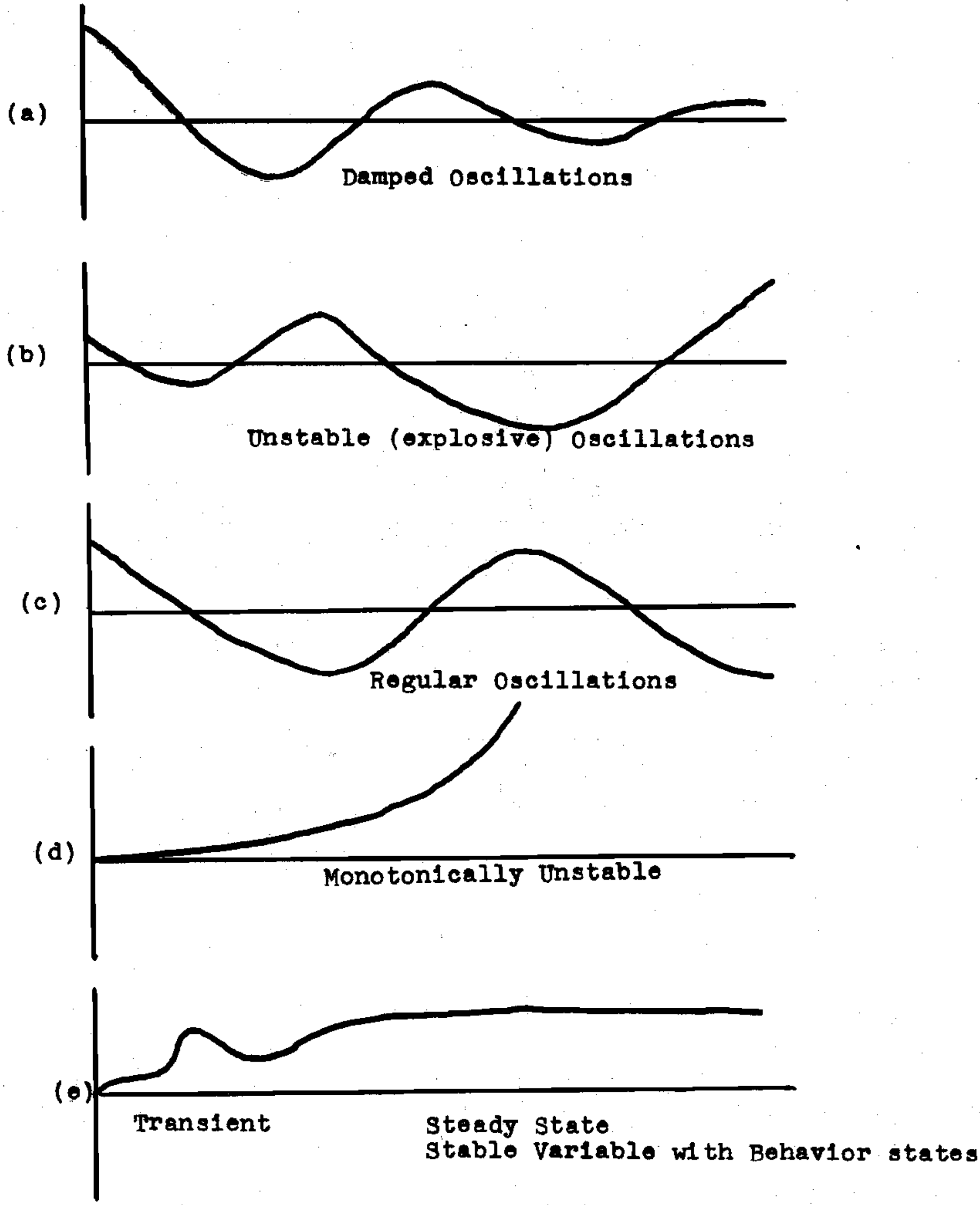


Figure 9. System Responses

system studies, yet they are included in the model. Terror is described as a function of the frequency of acts of terror, a measurable quantity, and the magnitude of violence, the latter quantified by a scalar procedure. Pressure on the population is expressed in terms of uncontrolled incidents, and allegiance to the government is reflected in a combination of measurable quantities. Other intangibles such as dissatisfaction, social stability and other factors are also recognized and included in the model.

Several conclusions were made by Major Faulkender from analysis of the model runs. The scope of the conclusions is broad, and reflective of the behavioral aspects of the model as is characteristic of Industrial Dynamics studies. The macro-nature of the approach results in generalized conclusions which are nonetheless meaningful. This is exemplified in the model of the insurgent activity when the conclusions were interpreted by Major Faulkender as follows:

> The above five conclusions suggest certain guidelines with reference to counterinsurgency efforts. The formulation of the simulation is such that the insurgency fails when it cannot create unpunished incidents. This fact suggests that the most successful counter to insurgency during early stages of a movement would be any program aimed at reducing the enemy input rate. If reforms and civic action programs are to have any major success, the simulation indicates that such success should occur in these early stages. Likewise, the obvious and perhaps most efficient counter to insurgency would be the commitment of outside forces at the first recognition of an active movement. In later stages, when enemy strength has carried the movement into Phase II, the success of the

insurgency is still dependent on its ability to generate unpunished incidents and military operations. The simulation suggests that during these latter stages, the most successful counter to insurgency is a program aimed at directly increasing the losses in enemy manpower.

The overall implication of the above points is that the most successful counterinsurgency programs are those which directly reduce the enemy force. Programs aimed directly at public welfare or public opinion have their greatest effect in the very early stages of anti-social activities and become less effective as the insurgency continues (26).

It is to be noted that each of the aforementioned combat models was developed with the guidance of Dr. Joseph Krol whose principles concerning model building have already been shown. Dr. Krol's own research using Dynamo has included the development of computer simulated models of Lanchester type combat. His work on this project was presented at the NATO Conference on Operational Research in July 1967 (28). The structure of the model constructed by Dr. Krol incorporates three types of fire between the opposing forces, these are:

1. Primary system 1 (i.e., attacker) versus primary system 2 (i.e., defender).
2. Supporting weapons systems versus the opposing primary systems.
3. Supporting weapon system 1 versus supporting weapon system 2.

This model which is an extension of the Abele model and which is also of the Dynamo Simulation group, according to its author resulted in the unification of the theory of differential games with the methodology of Dynamo. Figure 10

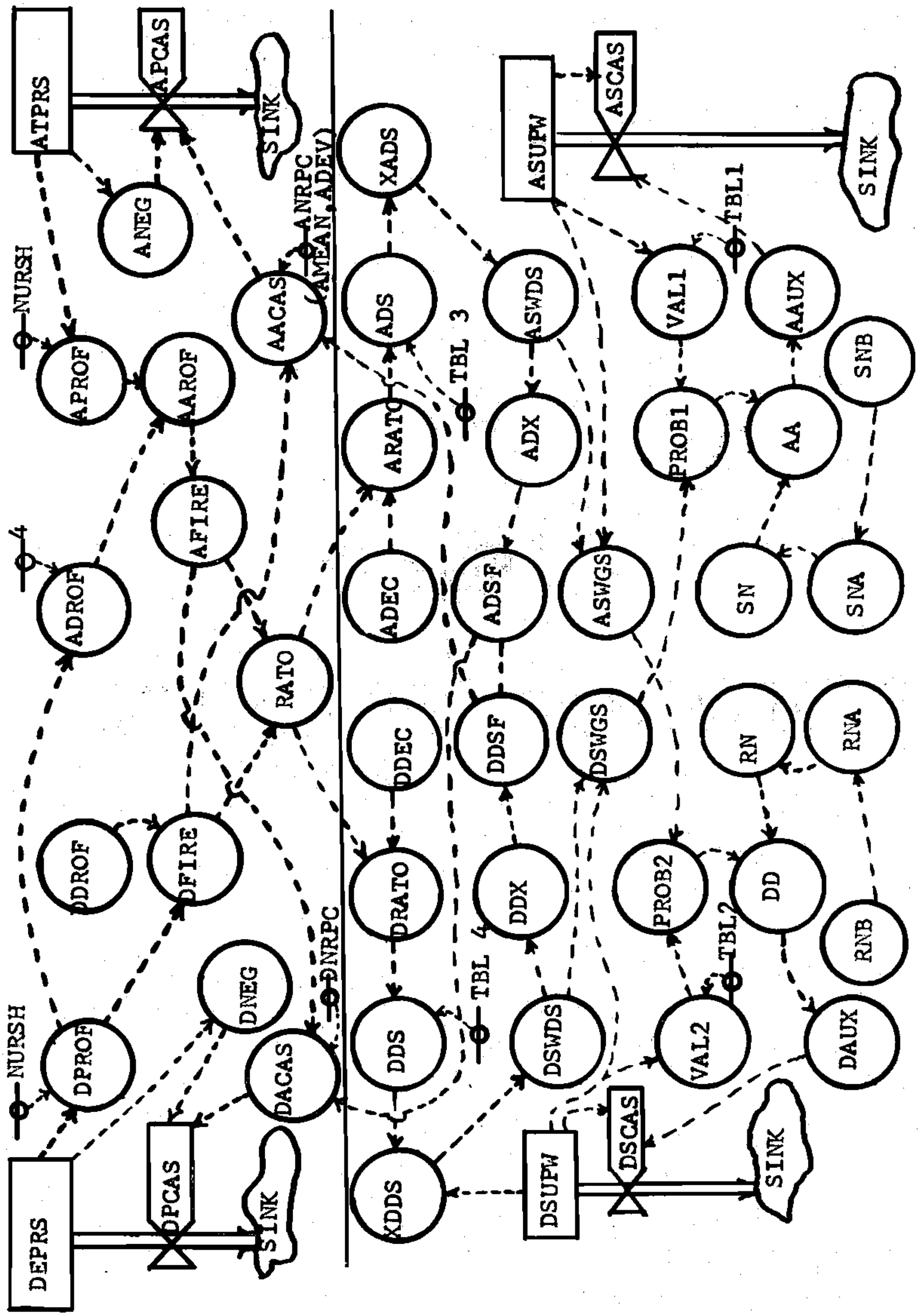


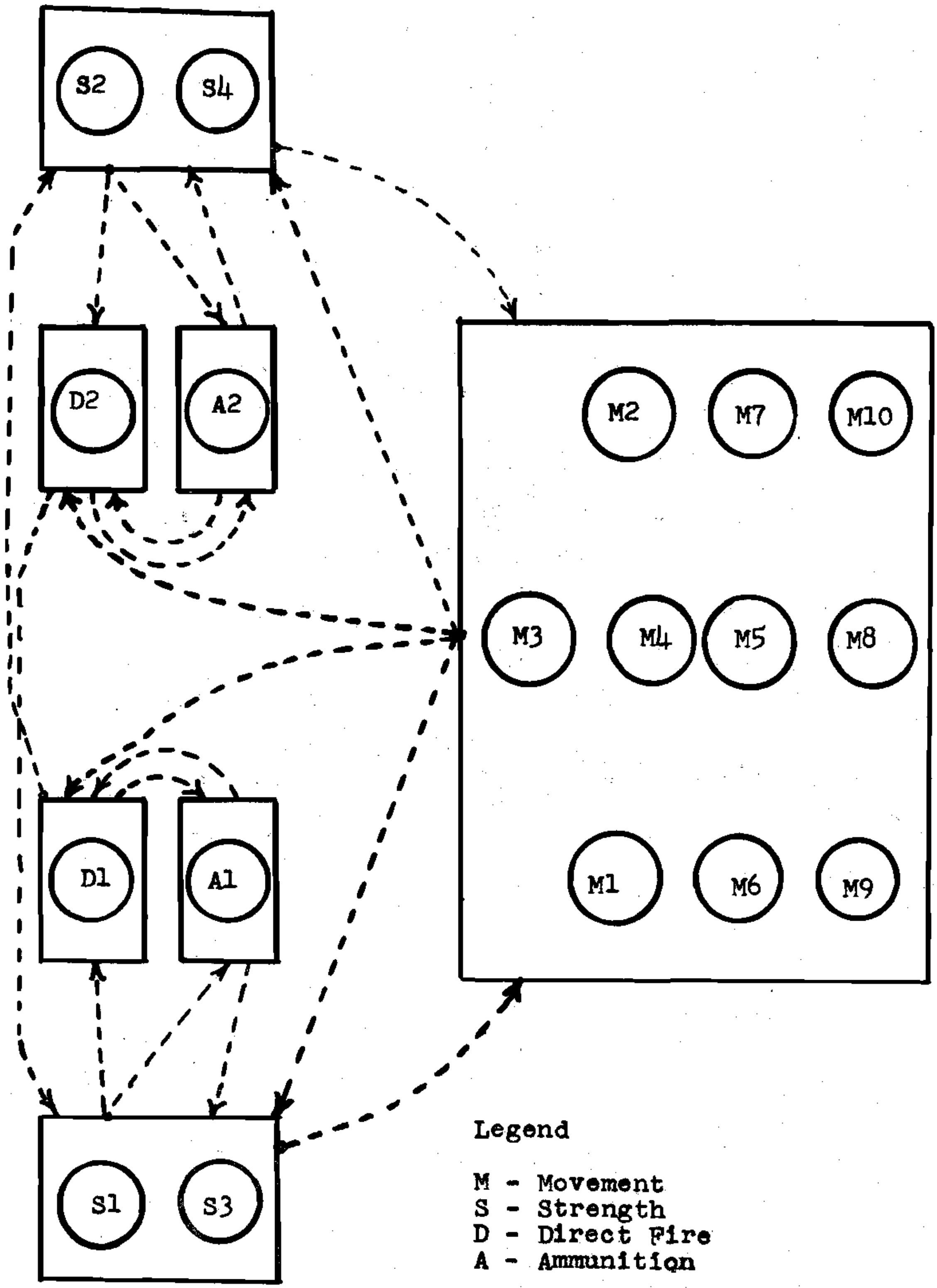
Figure 10. Master Flow Diagram of Krol Model

depicts the master flow diagram used with the model. The upper portion of the diagram is the direct fire segment (Primary System) and the lower portion is devoted to indirect fire (supporting weapons system).

Opposing Forces Model

The final combat model to be discussed is the work of Lt. Col. Donald L. Meyer. This model, which is entitled "Military Tactical Simulation Model" was also developed as a Master's Thesis within the Industrial Engineering Department of Georgia Institute of Technology. In part, it is a further extension of the previous model developed by Dr. Krol. Colonel Meyer used a modular concept in the construction of this model. The individual modules, each describing a particular factor of interest in the operation being simulated, were then tested as separate entities until they were performing the desired function. The separate modules were then coupled and retested. This use of individual modules as building blocks has some inherent advantages, among these are controlled growth of the model, readily identifiable system components and retention of a high measure of confidence in model structure at any point in the model synthesis. Figure 11 illustrates the modular concept.

The model itself is concerned with two opposing forces, Red and Blue; the former is approximately platoon size, the latter is of company strength but these strength



Legend

M - Movement
S - Strength
D - Direct Fire
A - Ammunition

Figure 11. Components of the Meyer Model Showing Modular Concept

assignments could be reversed if desired. Some of the considerations in this model are; unit strengths, casualties, ammunition supply and resupply, firepower and troop movements, each interacting with the other. Tests accomplished by use of the model include evaluating a proposed hypothetical light machine gun having an increased rate of fire to determine if there was a material change in combat effectivness. The criterion for combat effectiveness was the residual strength of the units. More detailed testing in which the proposed light machine gun had three alternative firing rates has also been investigated. This testing included the differing basic ammunition loads involved in the introduction of another weapons system. Other experiments included determining the proper time to execute a withdrawal and testing varied unit organizations. An example of the latter is the examination of a rifle platoon in defense with additional light machine guns in lieu of rifle strength.

Unique movement modules used in this model enabled Col. Meyer to examine the case of the Red platoon in defensive positions, with different degrees of protection, under attack by the superior Blue force. Hasty and deliberate retrograde operations by the Red force, again opposed by Blue, were also studied. In all of these tests, the effectiveness of fire was a function of the distance between the opposing forces. The modular concept is shown in more detail in the movement modules shown in Figure 12. In the diagram, M4 is the Red Force Delaying Action Module. This is coupled with M1, the Red Force Movement Module, and to M2, the Blue Force Movement Module. Needless-to-say this is a complex model involving some 206 equations. However, there are features of this model of considerable interest to those involved in analyzing the effect of changes in equipment on mission performance.

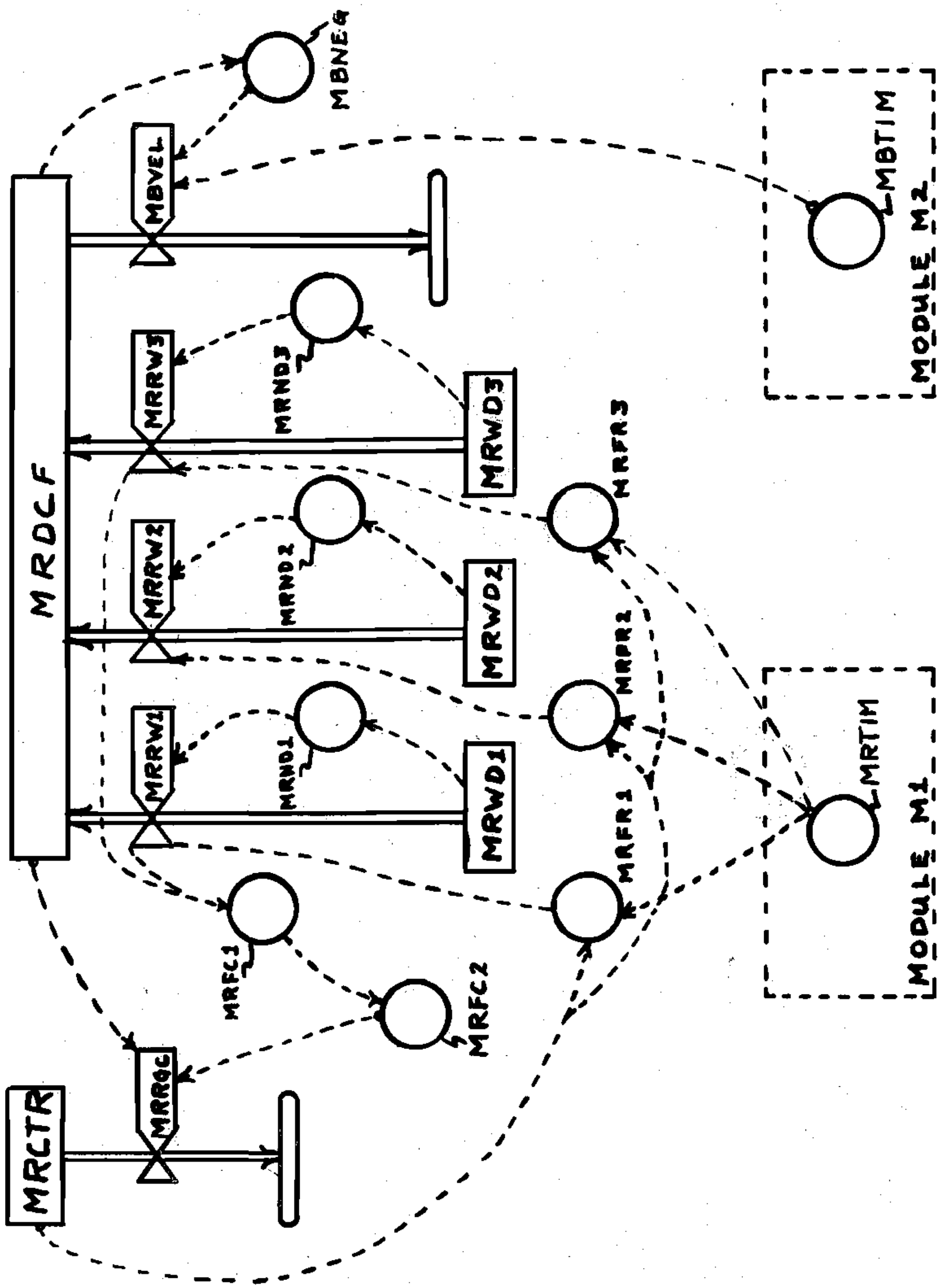


Figure 12. Modular Concept of Meyer Model Shown in Detail

CHAPTER V

NON-COMBAT MODELS

Personnel Studies

An unpublished study of U. S. Army specialist training was conducted in the summer of 1967 by Lt. Col. Kenneth J. Sweeney and the author for the purpose of examining the levels of qualified Army Operations Research/ Systems Analysis (OR/SA) specialists in light of several alternative training and utilization policies (29). The flow diagram developed for this study is shown in Figure 13. It was hypothesized that the increasing requirements for OR/SA specialists could not be attained within any reasonable time by the training policy then in effect and that alternative procedures would have to be established to meet these priority requirements.

The model was designed to reflect personnel flow, with control exercised by an information network tied to the personnel flow. Some difficulty was encountered in construction of the control mechanism (due principally to the inexperience of the co-authors) and the system was eventually controlled by an internal decision making device. This was merely a mathematical formulation in which the number of personnel in training was a function of the

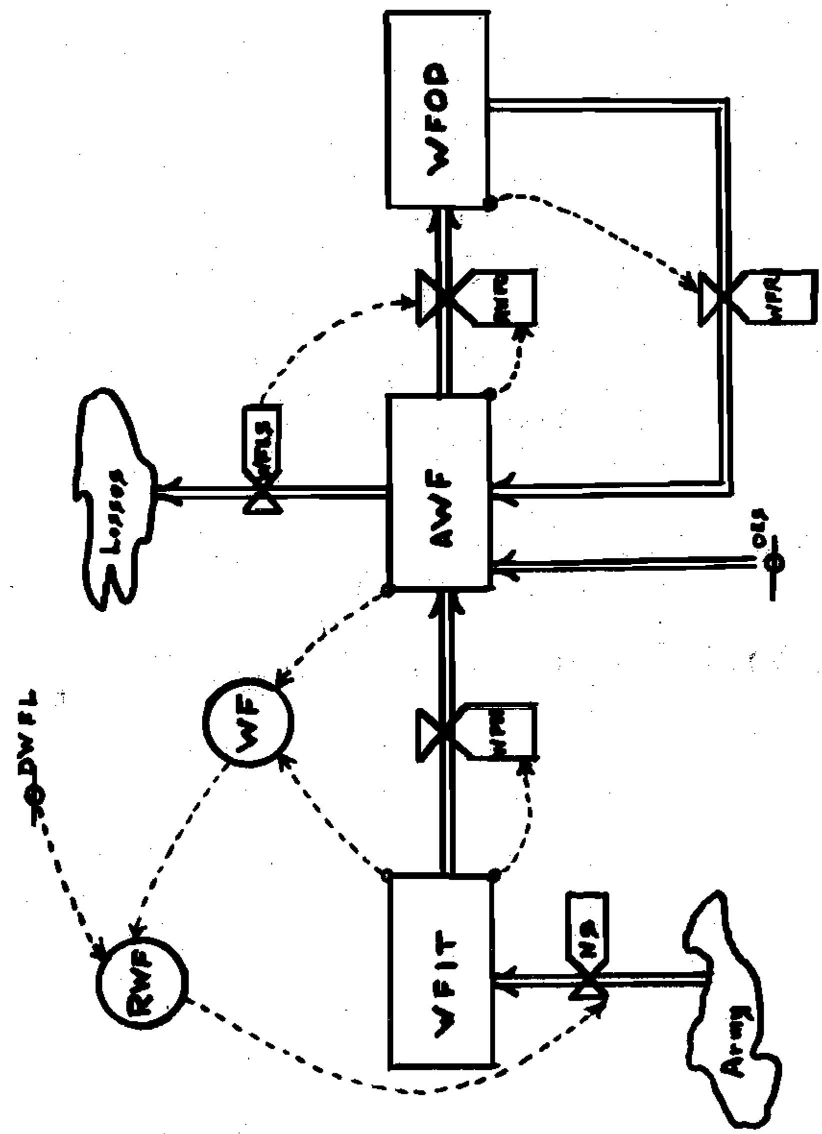


Figure 13. Flow Diagram of OR/SA Personnel Study

difference between the desired work force level (DWFL) and the actual work force (AWF).

This model was professed to be an Industrial Dynamics study at the time it was formulated. However, it can readily be seen that although it focused attention on feedback, the feedback addressed only the transition of personnel into and out of the actual OR/SA work force. There was little, if any, feedback control and actually no strong information-feedback system (as defined on page 14) was identified. This project was then a simulation using Dynamo rather than an Industrial Dynamics study.

Although not a very sophisticated model and notwithstanding the fact that the principles of Industrial Dynamics were not properly implemented, several interesting conclusions were derived from the model. The first of these supported the stated hypothesis; the then current and forecast training program for Operations Research/Systems Analysis specialists was inadequate in terms of quantity of specialists produced when compared with known and anticipated requirements.

A series of experiments was then conducted with the model, each experiment designed to examine the effect of a specific policy change on the long term availability of trained specialists. It was found that even such dramatic policy changes as permitting consecutive operations research tours, rather than alternating branch tours with specialist assignments, would not result in attaining the desired work force level. It was found that within the constraints imposed by delays in training coupled with increasing requirements, the only manner in which the required force of trained specialists could be obtained was by exogenous input to the system. Translating this into a real world solution was then simply a matter of drawing a parallel; the exogenous input could be accomplished by direct assimilation of college graduates, having the proper educational background, into the system. Of course this alternative suffered from the obvious disadvantage of failing to recognize, much less take into consideration, the requirements of grade and experience demanded by a number of the validated OR/SA positions. Nonetheless, it suggested the necessity of an active recruiting system to meet immediate needs of the Army. A side effect of this study was that it was the impetus for a separate OR/SA program analysis currently being conducted by Colonel Sweeney in conjunction with interested agencies of Department of the Army (30).

The next study to be examined is also concerned with personnel policies and again it is a group of personnel possessing a particular skill which is under consideration; in this case Army aviators. Although not necessarily obvious, it remains a fundamental fact that the bulk of personnel management policies are concerned with groups or categories of personnel classified by grade, military occupational specialty (MOS), branch, special skills and the like. To illustrate via the definition of information-feedback systems; such a system exists whenever the environment (e.g. level of trained radio repairmen) leads to a decision (increase number of trainees in military schools) that results in action which affects the environment (raises level of trained radio repairmen) and thereby influences future decisions (modify number of trainees in school).

Unfortunately no true Industrial Dynamics study which addresses itself to this made-to-order type problem is known to have been conducted. The study which follows was developed by the United States Army Management Systems Support Agency (USAMSSA) in cooperation with the Assistant Chief of Staff for Force Development (ACSFOR) in response to a requirement from the Deputy Secretary of Defense dated 11 October 1967 (31). The purpose of the model was to forecast training requirements for various force levels, developments and tour policies. The model was to be capable of forecasting:

1. Pilot output requirements.
2. Required number of pilots in the supplement.
3. Pilot transition training requirements.
4. Instrument, maintenance and safety training requirements.

It is to be noted that the requirements of this project are quantitative in nature thus suggesting the simulation approach. Had the purpose been slightly more generalized the Industrial Dynamics approach would be in order. For example, substitution of the word, investigate, for the word, forecast, in the expressed purpose would be sufficient basis for using the exploratory concept of Industrial Dynamics.

For basic data the Pilot Requirements Forecasting Models utilized computer tape listings of all pilot jobs throughout the Army and also listings of the current pilot inventory. Pilot jobs were categorized into; force, training, supervisory, supplement and others. Each of these categories was in turn subdivided into identifiable groups. Within these subdivisions the skills necessary for each pilot job, including aircraft qualifications, safety training, instrument training, maintenance training, test pilot training and the like, were identified. Likewise the pilot inventory listing was matched to the job categorizations. The data requirements used in the study are shown in more detail in Appendix A. Experimentation with the model is still in progress at this writing, consequently there is insufficient information on which to base an evaluation of the usefulness of the model.

Logistics

Next to be considered is the obvious extension of the Industrial Dynamics concept of a production-distribution system to its military counterpart, logistics.

In Chapter 15 of his book, Industrial Dynamics, Professor Forrester develops system equations for a production-distribution system. This is further subdivided into equations for three separate sectors of that overall system; that is, the retail, distribution and factory sectors. Two U. S. Army officer students, while attending an intensive two week course of study in Industrial Dynamics at Massachusetts Institute of Technology, developed a rudimentary model of "The Army Logistic System," (32) by direct analogy with Professor Forrester's production-distribution system. The retail sector of the industrial model was considered analogous to the direct support units of the Army logistical system. Likewise, the distribution sector of industry corresponds closely to general support units (depots) within the Army system, and the factory sector, with some modification, to a National Inventory Control Point. Figure 14 shows the flow diagram for the direct support units (DSU) (33). These similarities were then used to develop the model and to obtain the initial computer runs. Since this model was intended as a training vehicle, rather than as a refined finished product, neither the results obtained nor their significance will be discussed here. It suffices to serve as an example of a military application and, in this instance, perhaps the most direct comparison with the industrial use most often associated with Industrial Dynamics.

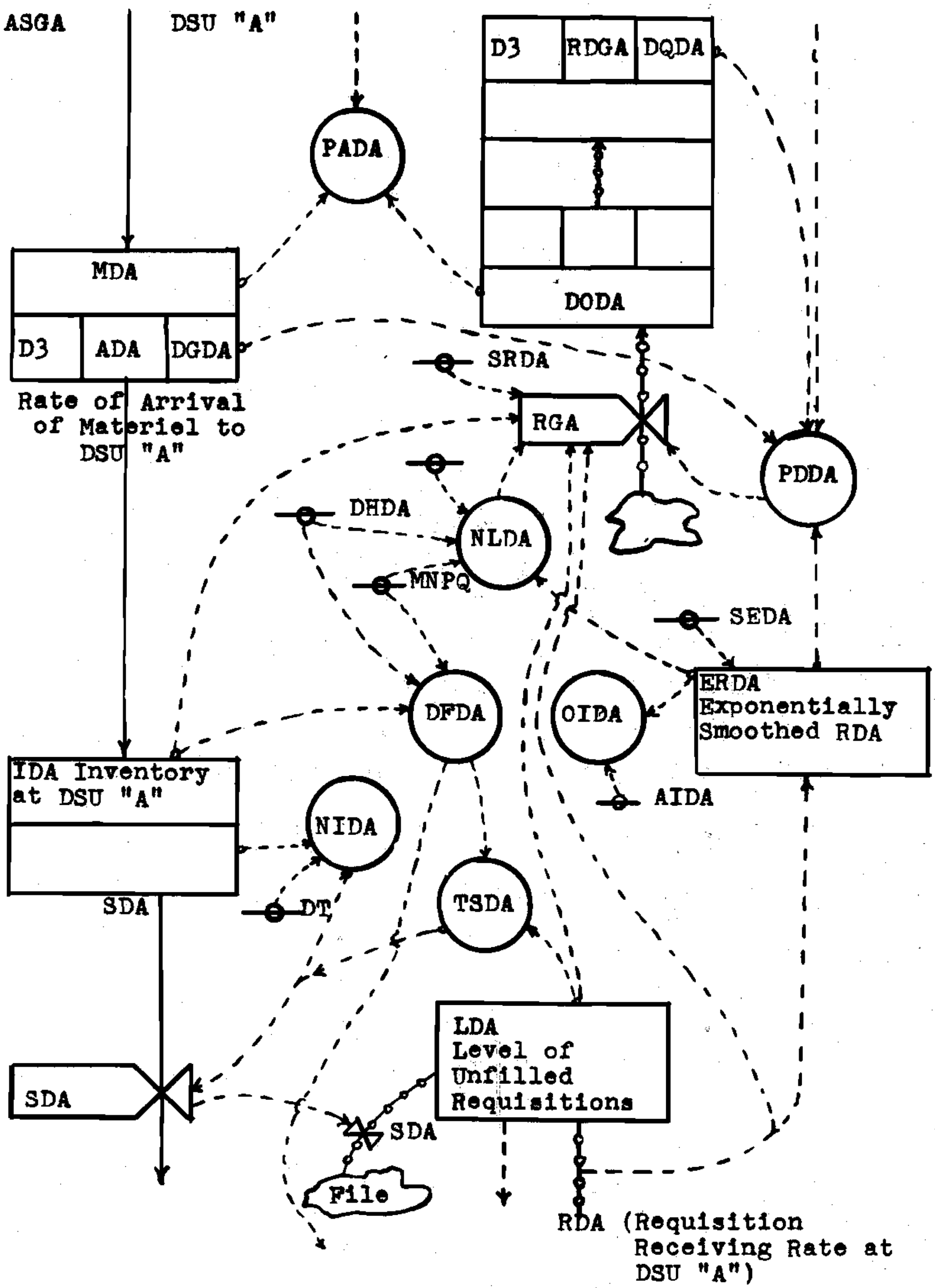


Figure 14. Flow Diagram for Direct Support Units

Examination of control processes have also been approached in a logistical framework. The United States Air Force had implemented a sophisticated control system for high cost Air Force material, a system intended to provide for conservative initial procurement and detailed line item management of these items throughout their useful life cycle. This system of control was itself studied via an Industrial Dynamics model (34). The resulting analysis revealed that even the conservative approach to the Hi Valu System, as it was called, could result in periodic overstatement of requirements resulting in excess procurement, unnecessary item repairs and, after a time, the converse, which included shortages. As excesses of equipments are deplorable, shortages can be intolerable; the apparent requirement again is for dampening of the pattern of oscillations and it was to this end that the study recommendations were directed. Changes in basic policy as well as in use of available information were proposed by this study. The salient point, for purposes of Dynamo applications, is that systems, once developed, can be tested and evaluated by the Industrial Dynamics analysis procedures. This idea of process control is discussed further in Chapter VI albeit in a personnel stabilization situation.

Research and Development

Research and development has also been studied by application of the Industrial Dynamics approach. It is to the field of management of research and development that Edward B. Roberts addressed his attention in his book, The Dynamics of Research and Development (35). Although this work was not focused strictly on military R and D activities, they are an important aspect of R and D work conducted in this country and by the very nature of their ties with industry it is appropriate to consider military projects as part and parcel of the overall R and D effort. Emphasis is placed, however, on research and development for military and space purposes.

Professor Roberts justifies the use of the Industrial Dynamics approach in the introduction to his book.

> Industrial Dynamics is particularly suited for the study of complex systems problems, in which a multitude of factors are interrelated through organizational information feedback paths. It is similarly aimed at dynamic problems in which the process tends to evolve and reveal itself over a period of time. These two characteristics of system complexity and time orientation are clearly typical of research and development activities. (36)

The procedural steps of an Industrial Dynamics study, shown in Chapter III of this paper, form the outline of the development of Robert's book. Since the models created do not depict any particular R and D organization or effort, only broad policy implications with regard to R and D work in general can be derived. These are discussed at length and the nature of these findings is substantially as follows:

1. That there is a dynamic system underlying project life cycles (Figure 15).

2. That timing is of significant importance in research and development decisions.

3. That there is low correlation between scheduled events, such as completion times, and observed events.

4. That project costs increase significantly when the research organization must be expanded to handle the project.

5. That system models of socio-economic activities laden with intangible but consequential influences are both feasible and effective.

Some interesting "specific findings" were also developed as were "factors of consequence" in research and development which of course were used in arriving at all of the findings. It is not the purpose of this study to enumerate these conclusions but rather to illustrate the nature of results which can be expected by use of these methods and the areas of study in which the methodology has been applied. Thus the specific field of R and D, as a system, is but an example of type systems appropriate for Industrial Dynamics investigations.

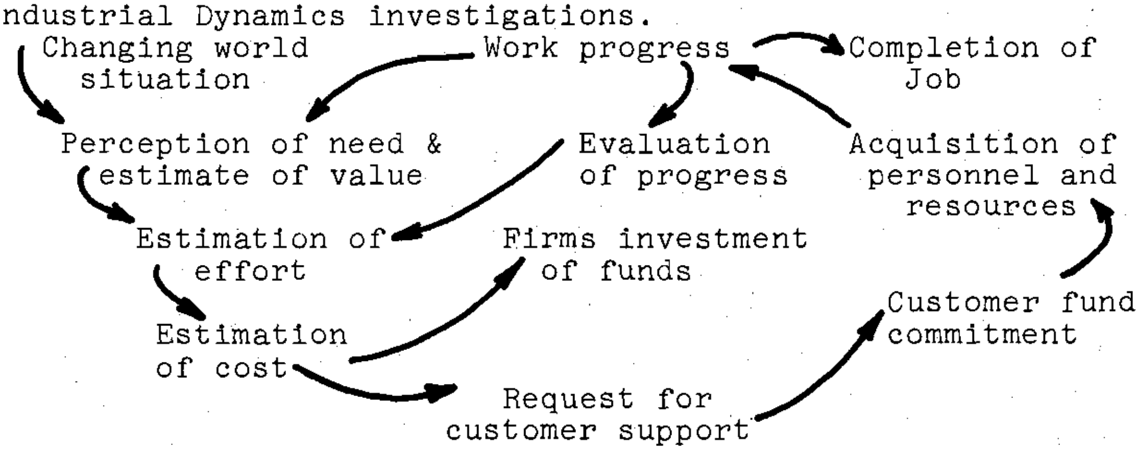


Figure 15. Dynamic System Underlying R and D Project Life Cycles (37)

Weapons Systems

The subject of weapons system design and evaluation has been recently approached by Carl V. Swanson of M. I. T. (38). This endeavor was categorized by its author as a dynamic analysis using the ideas and techniques developed in the field of Industrial Dynamics. In substance, the model developed centers on the comparison of helicopter and fixed-wing aircraft in the attack and destruction of a target. The purpose of the study was to illustrate the use of this form of dynamic analysis, consequently the model was hypothetical both with respect to the aircraft being compared as well as to the conclusions obtained.

Essentially the model illustrates the concepts of the Industrial Dynamics technique to include the representation, analysis and design of a model with particular emphasis on the feedback process and the feedback loops identified with these processes. The illustrative purpose is accomplished in part; the development and explanation of decision making as a feedback process; equation formulation; and feedback loop analysis are shown in detail. However, the choice of systems under comparison and the factors considered prejudiced the comparison. A basic tenet for using the Industrial Dynamics approach is that the system being studied consist of a complex set of interrelationships, the net affects of which are not apparent to the analyst, as this is the purpose of the investigation. In this instance the factors favoring the helicopter were such that intuition, coupled with a few readily available statistics, foretold the general outcome, thus system behavior per se was not a study objective. The resultant system in fact exhibits several of the characteristics of a Dynamo Simulation notwithstanding the concentrations of effort on the feedback philosophy. The principal point to be derived from this illustrative model is that there exists the capability of weapons system comparison by the use of the Dynamo language. Selection of methodology to use would seem to be somewhat dependent upon the sophistication of the particular weapons system; the more complex systems normally involve more extensive and elaborate control mechanisms and their degree of complexity could militate against pure simulation techniques.

To recapitulate the military applications of Dynamo as so far addressed in this study, there were four fundamentally different combat models:

1. An Assault River Crossing.
2. An Insurgent Activity Model.
3. An examination of an infantry rifle platoon in defense.
4. An Opposing Forces Engagement.

In the area of logistics two models were briefly described:

1. The Army Logistics System
2. The Air Force Hi Value Logistic System

Under the heading of personnel operations there were also two models discussed.

1. A study concerning operations research personnel.

2. A study of pilot requirements forecasting.

In the general category of miscellaneous military models there were two separate discussions.

1. A comparision of alternative weapons systems.

2. A study of research and development as a system.

CHAPTER VI

CURRENT STUDY

Management Improvement

The variety and scope of the previously discussed applications is evident. Logical extensions of these topics or analogous situations should also be apparent to the reader. The nature of such conceptual applications would, of course, be dependent on the individual areas of interest to the reader. The diverse fields of applicability are too extensive to attempt to explore all of them; however, some insight may be obtained by examination of current areas of interest and emphasis at Department of Army level. Doing this results in "dating" this paper to some degree but since the purpose of this section is to give appreciation to the scope of possibilities to which Industrial Dynamics and Dynamo Simulation may find application, it is included nonetheless. The vehicle to illustrate these potentialities is project PRIMAR, an in-progress plan to tie a host of management system improvement projects together into a fully integrated Army Resource Management System (39).

PRIMAR stands for "Program to Improve Management of Army Resources." Essentially, this Army initiated project is designed to first identify shortfalls in the present system of management and define improvement needs. This portion of the project was Phase I. It included:

1. Designing a limited number of new systems.
2. Building on existing systems and improvement efforts currently underway.
3. Producing an integrated system.

Phase II, which began Jan 1968 marked the onset of execution of the plan to design the total system. This plan has as its objectives (40):

1. An ability within the Department of the Army to determine available resources.
2. Control of allocation and adjustment of Army resources at Department of the Army level.
3. A capability to assess implications of resource allocation changes on the over-all effectiveness of the Army. This will include means to conduct a centralized evaluation of the optimum use of Army resources assuring the readiness of Army forces and their adequate support.
4. Delegation of threshold authorization to permit Army activities and field commands to perform their missions effectively while still maintaining management control at Department of the Army level.
5. Efficient direction and coordination of the Army's planning, programming, and budgeting efforts.
6. An effective interface, both in time phasing as well as in format between Army planning, programming and budgeting and corresponding OSD requirements in order to improve the Army's ability to obtain appropriate influence in the OSD decision-making process.
7. Rapid responsiveness within the Office of the Chief of Staff to OSD information requests. These responses should provide the best available data and include appropriate military judgment, rationale, and available evidence.

8. Establishment of an efficient management information storage and retrieval system matched by storage and retrieval systems elsewhere in the Army.

9. A concept of integrated management of Army resources which invests in the General Staff the responsibility for assuring the timely accomplishment of internal Department of the Army activities.

Phase III of the project, the testing and installation of both subsystem and total system recommendations, is scheduled to commence in June 1968. Before examining any of the twenty three individual management projects comprising PRIMAR, the first Dynamo application possibility is evident. Recall that research and development, as a dynamic operating system, is an area of possible investigation as suggested by Professor Roberts in Chapter V of this paper. There is little doubt that Project PRIMAR has many of the characteristics of an, in fact, is a research and development effort.

Progressing only a little further into Project PRIMAR, another opportunity to use Industrial Dynamics can be seen in the purpose of the Phase I portion of the project, that is, in the identification of shortcomings in the present system. A properly constructed model of the present system could be used to effect this identification of problem areas and suggest improvement policies.

The objectives mentioned earlier themselves suggest possible areas of study, especially those designated as numbers 2, 3, 5 and 9, and to a lesser degree, objectives

6 and 7. Rephrasing these objectives as problems perhaps clarifies the potential applicability of the methodology being discussed. For example, rephrasing the fifth objective might result in the following problem description: "Investigate the interrelationships between the Army's planning, programming and budgeting efforts to determine the critical points of control within the system, and suggest policy changes which would result in more efficient direction and planning of these efforts." This is admittedly a broad base on which to initiate a study, however, it must be borne in mind that the expectation of the value of results obtained cannot exceed the scope of the subject being studied. The potential benefits to be derived from the study of significantly important topics are extensive; the converse is also true.

The third phase of the project, testing of system recommendations, is an off-shoot of the two previous application possibilities. A model of the proposed system could be manipulated to test the behavior of the system with regard to the considerations of interest. This could all be done without changes in the actual system until such time as the proposed system has undergone final modification, as a model, and is ready for implementation.

The twenty three projects of PRIMAR cover a wide spectrum of subject matter, ranging through personnel, readiness, logistic, budgetary and other considerations.

A listing of the specific topics is included in the Appendix. Of these projects, there are two to which the methodologies of this study appear to have application; the first of these is Project 3-1: Defining, Integrating, and Directing a Responsive Program/Budget/Distribution System.

The intent of this project is to synthesize an integrated system, of the three components mentioned, which will meet the demands of the real world environment. Included are considerations of timing for in-cycle and out-of-cycle demands, detail level required, and procedures for top management direction. This project is also to develop a performance measurement system to isolate causes of shortfalls in attaining readiness goals in terms of resource acquisition and distribution.

The second project, "Developing Techniques for Assessing the Impact of Personnel Policies on Deployability," Project 5-1, has as one of its stated purposes, that of insuring that ongoing projects such as, "Simulation Model of Personnel Operations" (SIMPO), are actually capable of determining the impact of personnel policy changes on force readiness.

Several of the other projects, notably 1-1, 3-5 and 3-7, have aspects to which Industrial Dynamics or Dynamo Simulation might have application. However, the two projects described appear to be most suited for such study.

Without considering those projects of which only portions may have application, five study areas have then been identified within the framework of PRIMAR which appear amenable to study by one or another of the techniques under discussion.

In the preceding examination of PRIMAR projects, mention was made in one case of developing a performance measurement system. This was with regard to the Program/ Budget/Distribution system: there is also a project under examination at this time which is similar in nature but differs in what is to be measured. The proposed project is called, "Combat Operations Measured by Econometric Techniques" (COMBET) (41). The sponsoring agency for this proposed project is Force Planning Analysis, Office of the Vice Chief of Staff of the Army. The proposal centers on the development of a model of "low intensity warfare," to measure the success of military operations. For input data the model would use that concerning Vietnam but the model is to be applicable to other potential areas of operation.

As proposed, this study would employ econometric techniques to derive the coefficents of selected variables. This approach would involve the extensive use of multiple linear and nonlinear regression analyses to deduce the relationships among the variables involved. The resulting coefficients would then be used in the development of a model based on the principles of Industrial Dynamics. The latter point is noteworthy; its significance is discussed in the final chapter. Continuing with discussion of the proposal itself; it would be oriented on the broad, overall objectives of low intensity combat and would confine the examination of data to only those variables of significance at theater level.

Carswell and Vandiver, consultants to the Army, have conducted research in measures of effectiveness. Their research proposed a lattice-like structure of combat objectives and subobjectives which is adaptable to expansion through the definition of subordinate tasks stemming from the subobjectives. Figure 16 illustrates the lattice structure. The study plan formulation only requires consideration of this approach in the development of the logical structure of the conflict. It is required that political, economic, psychological, as well as military considerations be included in the proposed model structure.

Personnel Distribution

The personnel distribution system of the Army may also be an area of investigation by use of Industrial Dynamics. There are of course a number of studies which are directly concerned with the problems of minimizing turbulance in Army operating forces, minimizing transients, maximizing operating strength within the constraints of authorizations, minimizing costs, and the like. Investigation has revealed, however, that a necessary first step is to

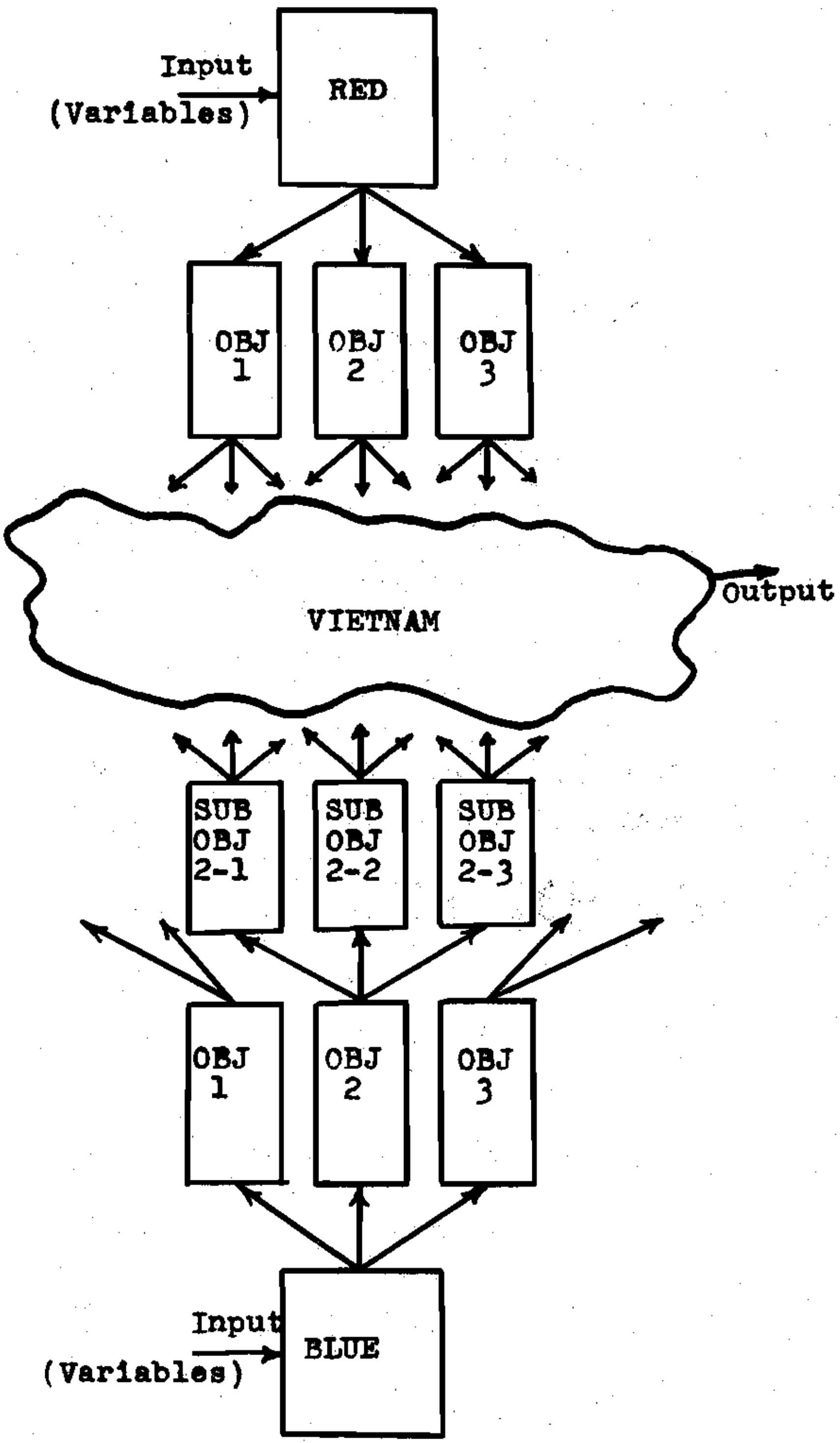


Figure 16. Lattice Structure

consider decision techniques to plan strength accessions in such a manner as to insure that the flow of personnel is reasonably free of wide strength fluctuations. Ideally, these flows will match the trained and operating strength losses when authorizations and separate individual categories are held constant.

When authorized strengths are changing and there are significant variations from the mean expected strengths, (as there are because of the present practical state of the art with regard to asset accounting), there are continually higher or lower demands for personnel than are planned and programmed. There is at present no "inventory" or "Deployment Training Center" to act as a surge tank of trained strength. The present method of handling personnel "inventory" is through such administrative measures as creating transient, student, patient, and other accounts. Guidelines for these accounts is historical data of overages adjusted by factors which are also based on past data. This results in a system which is perhaps statically stable, but dynamically unstable. When there is an incremental or pulse increase or decrease in new personnel, as demand for personnel occurs, the training base unfortunately either under or over reacts.

There is an obvious need to dampen the oscillations occurring in the system as a result of the deviations between actual and predicted gains and losses. The dynamic stability required would apparently be more attainable by consideration of present conditions using feedback of information possibly modified by historical factors, and future needs.

The author is not aware of any proposal to study this problem by the technique of Industrial Dynamics. Some consideration has been given to approaching the situation through the use of differential equations along the lines suggested in reference (42). This avenue has been a matter of discussion by the Manpower and Reserve Affairs department of the office of Assistant Secretary of the Army. To date no study has been initiated using the differential equations concept. It would appear that an Industrial Dynamics or Dynamo Simulation study, based upon difference equations, might be most satisfactorily employed on this subject.

Other subjects known to have been examined or undergoing study, and which are militarily oriented include:

1. The application of Industrial Dynamics to the study of an artillery engagement.

2. A study of the interrelationships of maintainability, reliability, cost and combat effectiveness, as they apply to military equipment, to test alternative replacement or overhaul policies.

3. An examination of future Army Communication Systems using Dynamo to model these systems.

Not to conclude this chapter on a negative note but rather to include all known military applications and attempts at the use of these techniques, it is to be noted that at least one research consultant firm reports no success in identifying military problems for which Industrial Dynamics techniques should be used (43). This firm conducted an investigation of the applicability of these techniques to problems of munitions management for the Logistics Directorate, Joint Chiefs of Staff. The results of their investigations were negative. It is to be noted, however, that if quantitative data were required for this task then this author would concur in the specific finding. If, however, the problem was in fact a question of management analysis for which rigid quantitative data were not required, then it would seem that the conclusions could well have been in error. The inferences which can be made from this negative response include the possibility that this firm was not prepared to accept the uniquely new ideas of Industrial Dynamics. Although that is a matter of conjecture, there is often opposition to philosophies or methods which are significantly different from conventional approaches and Industrial Dynamics is an unconventional technique.

CHAPTER VII

CONCLUSIONS

The brief examination and discussion of the separate studies makes it possible to generalize to some degree about military applications of Dynamo and about the manner of approach appropriate to a given problem.

It has been shown that there are many functional areas of application to which the computer programming system, Dynamo, is a useful tool for military analysts. The spectrum of these applications has been such that it would appear that there are few, if any, subject areas which could not be investigated from some aspect through proper use of this tool.

The principal limitation of either of the two philosophies on the use of Dynamo is that for strict, quantitative results in optimizing-type studies, their use is limited. Advantages, on the other hand, are numerous. They range from ease of understanding and use to extensive area of application.

In order to classify and give substance to the differances which exist between Industrial Dynamics and Dynamo Simulation and at the same time provide a ready means of method selection, the classification shown in Figure 17 is offered. It should be realized that this taxonomy is expressed in rather general terms and the choice of words may lack scholarly precision yet they are considered descriptive.

Comparison Factors	Industrial Dynamics	Dynamo Simulation
1. Classification with regard to desired nature of investigation	Exploratory (understanding system behavior)	Decision (numerical solutions to simultaneous difference equations)
2. Level of primary study interest	Top Management	Middle Management
3. Classification of method orientation	Systems Analysis	Operations Research
4. Method of approach	Analysis (formulation of dynamic hypothesis based on verbal description of system)	Synthesis (formulation of closed dynamic model based on cause-and-effect relationships between system variables)
5. Scope of investigations into the dynamic system	Macrodynamic	Microdynamic
a. Level of Aggregation	High	Low
b. Data Requirements	Minimal	Extensive
c. Influence of intangibles	Considered	Omitted
6. Nature of results	Qualitative	Quantitative

Figure 17. Comparison of Methods of Approach

Although this classification is intended primarily for method comparison it may be useful in determining a method of problem attack based upon the particular characteristics of the problem, the nature of desired results, and the level of perspective at which the problem is viewed.

This suggests, as an area for further study, an extensive investigation of problem analysis to determine appropriate methods to apply in the solution of specific problem types. In the examination of Industrial Dynamics and Dynamo Simulation, it was seen that these techniques are applicable to closed, continuous and essentially deterministic, dynamic systems. Within these constraints it was also apparent that when information feedback is a dominant influence of the system and when continuous input to the system can be assumed to be time sequences, as in economic and managerial analysis, then the techniques discussed are applicable.

It was found that despite the work of educational institutions, the military services have not yet recognized the potential offered by Dynamo and the philosophies of its use, at least not to the point of incorporating these subjects into the curricula of the service schools which present techniques of Operations Research and Systems Analysis. The technically oriented military schools considered to be in this category are:

United States Naval Postgraduate School, Monterey, California.
United States Air Force Institute of Technology, Wright Patterson Air Force Base, Ohio.
United States Army Management School, Ft. Belvoir, Va.

It is understood that a few instructors at some of these schools do integrate "Industrial Dynamics" into their classes but this is apparently an individual, rather than official, recognition of the field.

In conclusion, the computer programming system, Dynamo, and the two approaches to its use, Industrial Dynamics and Dynamo Simulation, have extensive applicability in military problem areas. The value of these research tools has not been adequately recognized by the military services to date as evidenced by both the lack of applied usage and by absence of their mention in scientific military methodology literature. Of course no simulation technique or analytical device is a substitute for judgement and experience, but, by the same token, intuition and guess work should not be relied upon to assist in making decisions when uncomplicated techniques exist which can provide logical and meaningful foundations for these decisions.

APPENDIX A

DATA REQUIREMENTS

Pilot Job Data

a. Skills necessary to hold each pilot job. This will include aircraft qualifications, safety training, instrument training, maintenance training, test pilot training, and other special training deemed applicable.

b. The force pilot category will be subdivided into:

(1) TOE

(2) TDA (less training pilots)

c. The supervisory category will be subdivided into:

(1) TOE

(a) Company level

(b) Battalion level

(c) Group level

(d) Above group level

(2) TDA

d. The training category will be subdivided into:

(1) Instructor pilots for undergraduate aviator training.

(2) Instructor pilots for formal graduate aviator training.

(3) Rated instructors required for classroom instruction in formal aviator training.

Pilot Inventory Data

a. Grade

b. Category: (OBV, RA, OTRA)

c. Branch of Service

d. Date of birth

e. Years of service

f. Date of initial rating

g. Estimated date of separation

h. Date returned from RVN

i. Date returned from other short-tour area

j. Current aircraft qualifications

k. Current skills to include instrument qualifications, safety training*, maintenance training*, and test pilot training*.

l. Rotary wing flight time*

m. Fixed wing flight time*

* Data elements not available for initial submission to OSD, but will be added at subsequent updates of the tape.

APPENDIX B

PRIMAR PROJECT LIST

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