AN INVESTIGATION OF THE TECHNICAL EFFECTIVENESS OF A GOVERNMENT RESEARCH, DEVELOPMENT, TEST AND EVALUATION ORGANIZATION

by

George R. Wachold

BSAE, Purdue University, (1946)

Submitted in Partial Fulfillment of the

Requirements of the Degree of

Master of Science

at the

Massachusetts Institute of Technology

1963

Signature of Author ______________________
School of Industrial Management

Approved by ______________________
Faculty Advisor

Restricted Distribution

This thesis has been given limited reproduction with the permission of the School of Industrial Management. However, this copy is issued with the understanding that none of the data resulting from this investigation will be used for advertising or publicity purposes, and that the thesis is solely for the confidential use of the organization or individual to whom it is addressed.

ABSTRACT

AN INVESTIGATION OF THE TECHNICAL EFFECTIVENESS OF A GOVERNMENT RESEARCH, DEVELOPMENT, TEST AND EVALUATION ORGANIZATION

by George R. Wachold

Submitted to the School of Industrial Management on May 3, 1963, in partial fulfillment of the requirements for the degree of Master of Sciences.

The problem posed is how do the organizational relationships between a government agency and a remote RDT&E field activity effect the technical effectiveness of the activity? The agency controls the primary task assignments to the activity, and the activity controls the allocation of resources to accomplish the task assignments. The numerical resources of the activity remain fixed and the technology required to accomplish the assigned tasks is assumed to be increasing with time.

An Industrial Dynamics model is formulated that is based upon concepts developed by past Industrial Dynamics studies and upon the author's personal experience with the relationships considered. Over one hundred computer runs were conducted in the testing of the modeled organization.

Some of the more interesting organizational characteristics that are concluded from the investigation are: (1) to maintain the activity technical effectiveness at or in excess of the level of the increasing needed technology, the agency must overload the activity with task assignments, and provide a major shift in the activity's effort from test and evaluation to research and development; (2) when the agency underloads the activity with task assignments, the activity does not generate a sufficient quantity or mix of tasks to maintain the level of technical effectiveness when confronted with an increasing needed technology.

Extension of the present study, utilizing Industrial Dynamics and a research into existing organization behavior theory, is recommended to provide more policy-oriented decision rules than are included in this investigation.

Thesis Advisor: Edward B. Roberts
Title: Assistant Professor of Industrial Management

3 May 1963

Professor Philip Franklin
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled, "An Investigation of the Technical Effectiveness of a Government Research, Development, Test and Evaluation Organization."

I wish to acknowledge the direction and assistance given to me by my advisor, Professor Edward Roberts, and my committeeman, Professor Andrew Stedry.

Sincerely yours,

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Problem

The strength or effectiveness of our military weapon systems is a measure that can only be estimated, short of actual conflict. In the face of a militarily aggressive enemy, the absence of conflict can be assumed to be a reasonable indication of the adequacy of our present military strength and the belief that we will use the strength if necessary. Nevertheless, an estimate of the effectiveness of weapons now under development must be made to be able to judge whether or not the effectiveness that is believed to be required in the future is likely to be achieved or exceeded. One of the roles of Navy research, development, test and evaluation (RDT&E) laboratories is to evaluate weapon systems to derive estimates of weapon effectiveness. The weapon designs may originate either within the government laboratories or within private industry. In either case the evaluation is accomplished by the Navy laboratory.

It is assumed that the greater the technical effectiveness of a government laboratory, the better will be their evaluation of weapons. Unfortunately, technical effectiveness is no easier to measure than is the effectiveness of the weapon. However, technical effectiveness is an organizational characteristic believed to be related to other more identifiable characteristics of an organization.

The direction of nearly all the Navy RDT&E programs is accomplished by bureaus located in Washington, D. C. The direction normally assumes broad program responsibilities including: resources planning and justification, program planning and scheduling, definition and assignment of tasks, and coordination of the efforts required to accomplish the tasks. The responsibilities extend from the program's conception to the program's completion.

The resources that are required to accomplish the Navy RDT&E programs must be provided by private industry and/or government laboratories, and each sector, whether private or government, must allocate resources to support several programs at the same time. In addition to the responsibility for the allocation of resources, the government laboratories are responsible, as is private industry, for the efficient and effective use of current resources and for the continued development and improvement of the resources.

The purpose of this study is to investigate the effect of a government agency-field activity relationship on the technical effectiveness of the field activity. The primary mission of the RDT&E activity considered is the test and evaluation (T&E) of weapon systems. The technology required to accomplish the T&E tasks is increasing with time, although for the time period of interest to the study, the numerical resources of the activity are assumed to be constant.

Within the context of the hypothesized organizational relationship between the agency and the activity, this investigation is intended to answer several vital questions. Reasonable policies and organizational behavioral characteristics will be tested to determine whether or not they result in:

1. Decrease in the technical effectiveness of the field activity, implying a lower quality of weapon evaluation with the resultant less-than-desired effectiveness in weapon capability;
2. Decrease in the quantity of completed T&E tasks, implying a delay in delivery of a weapon system to the customer with the resultant less-than-desired effectiveness in weapon capability;
3. Shift in task assignments to achieve a balance between the implied quality and quantity, implying a recognition of the increasing complexity of the weapons being tested and evaluated and the belief that additional R&D is required to cope with future complex T&E tasks.

Approach

First it was necessary to define and relate the characteristics of the hypothesized organization. The organizational relationship envisaged is presented schematically in Figure 1. The activity and the agency are shown to be interacting through several channels of information and control. Both the agency and the activity are shown to be influenced by their respective perception of what tasks should be accomplished. In addition to the agency and activity characteristics that will determine the perceived needs, customer needs, technology, and budget constraints are implied as influencing organizational behavior. The solid lines depict regular information or order channels and the dotted lines represent subjective impressions of the quantities indicated.

Industrial Dynamics, developed by Jay W. Forrester of M.I.T. and described in reference (a), provides a philosophy and technique for studying an organizational system as depicted in Figure 1. The philosophy of Industrial Dynamics asserts that the experimental model approach that is applied to the solution of complex physical science problems can also be applied to complex social systems, i.e. organizations. The technique is to formulate the significant characteristics of the organization and their interrelations into a definitive model. The model provides a means for investigating the overall system behavior that results from the interactions of the formulated characteristics of the organization.

In the earlier applications of Industrial Dynamics to the system behavior of organizations, simplified and somewhat obvious production and distribution processes were given emphasis. The models described in reference (a) are examples of the earlier work. Later efforts, references (b) and (c), have considered possible models that include such variables as manufacturer's reputation, value of research effort, perception of product need and value. More restricted, but directly applicable to this study, are the models formulated in references (d), (e) and (f). The formulation of the model for the hypothesized organizational relationship in this study borrows directly from each cited reference, but particularly from references (d), (e) and (f).

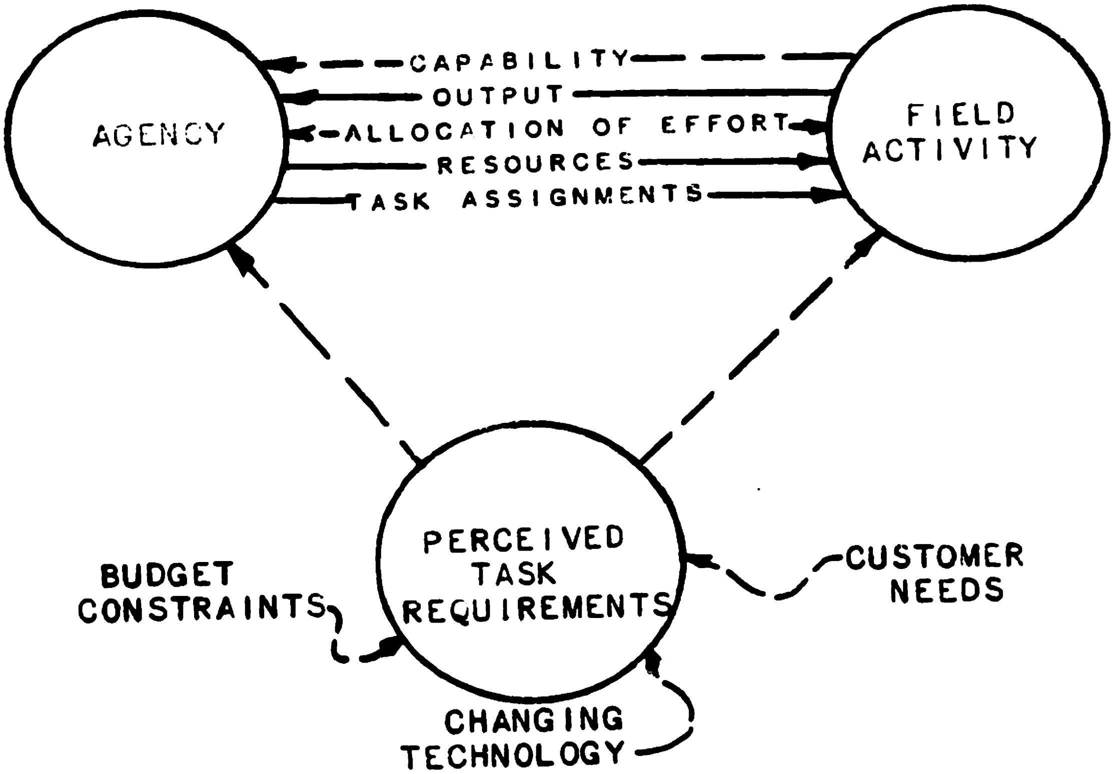


FIGURE 1

SCHEMATIC OF GENERAL AGENCY-ACTIVITY RELATIONSHIP

The omission of references to theories concerning the broad area of organizational and individual behavior is not to deny credit, nor for that matter to deny support, for the various concepts that are incorporated in the study. The omission is merely an honest reflection of the research that was not accomplished for the support of this study in the broad area of organizational behavior theory. The justification is that it was not felt necessary to sift the likely many offered theories for an initial look at the problem posed and for the approach chosen.

The model that was formulated as part of this study was based largely on the author's experience in the type of organizational relationship being investigated. As an adjunct to this experience, however, information was obtained from the technical directors of several Department of the Navy RDT&E activities that were believed to emulate in one way or another the characteristics of the hypothesized organization. A copy of the questionnaire and the forwarding letter are in the Appendix A. As suggested by the letter, general impressions were desired rather than detailed procedures and philosophies. The answers received were gratifying in that the technical leaders tended to confirm the author's general impression of the agency-activity relations on the key questions. The key questions were intended to be the last three on the questionnaire. One activity preferred not to answer the last three questions which concerned "pressures" to accomplish work and allocate effort and how the activity believed the agency viewed the activity's technical capability. Because the primary purpose of the questionnaire was to provide a check on the author's subjective impressions and not to provide data on the different activities' views of themselves and the agency, the information received in response to the questionnaire is not included as part of this study. Furthermore, the author accepts full responsibility for the reasonableness and aptness of the organizational characteristics assumed for this study.

To accomplish the study the first task was to identify the organizational policies and behavioral characteristics that are believed to be meaningful. The second task was to incorporate behavioral concepts that are intended to reflect the identified behavioral characteristics. The first two tasks are described in Chapter II. The third task was to formulate the policies, characteristics, and concepts into an Industrial Dynamics model, and involved nearly one hundred computer runs to accomplish the model and the design of the experiments that are described in Chapter III. The results and conclusion for the organizational relationships studied are presented in Chapter IV. This last task, generating data, analysing the data, and developing conclusions was compressed to accommodate the overrun in the time originally planned for the first three tasks. The result is a compromise in the content of the accomplishment of the last task.

All computer runs were accomplished on an IBM 7090 computer at the Computation Center at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

Conclusions

When an advancing technology is needed to accomplish the primary T&E tasks, the mix of tasks assigned to a field activity must be shifted to provide for more R&D effort in order to maintain a satisfactory organizational technical effectiveness. With resources fixed, both quality and quantity cannot be maintained at the initial level. Insistence on maintaining an initial quantity of T&E output will result in a decrease in the quality of the T&E product.

The assigned tasks from the agency provide the dominant determinant to the future position of the activity, and the greatest total output is maintained when the agency overestimates the capability of the organization and as a consequence "overloads" the activity with assigned tasks. When the agency "underloads" the activity, the activity's propensity to generate tasks is not sufficient to fully utilize the slack provided by the "underload" in assigned tasks. The result is that no organizational recovery from the impact of the changing needed technology is affected from within the activity.

To accomplish a better shift of the proportion of R&D and T&E tasks to accomplish an organizational recovery, an estimate, by the organization, of the level of the required technology appears to be needed and closer cooperation between agency, activity, and customer concerning needs and allocation of resources is suggested.

The conclusions stated are not unexpected and seem to support general feelings about government RDT&E agency-activity relationships. It is concluded that future investigation of the problem utilizing Industrial Dynamics and a research of organizational behavior theory is warranted to develop more detailed policy-oriented findings. Based on this study the following areas appear particularly worthwhile for future studies:

1. development of more explicit decision-oriented rules and/or policies for the behavior of the relationship;
2. development of a more realistic measure of customer satisfaction which in turn is more strongly coupled into the task assignments and resource allocation process;
3. expansion of the agency-single activity into an agency-multi-activity relationship which will include contributions to effectiveness through technical interchange between the different activities.

CHAPTER II

THE ORGANIZATION AND THE MODEL CONCEPTS

Introduction

The organization hypothesized for study is a government research, development, test and evaluation (RDT&E) activity whose resources and primary task assignments are provided by managers who are remote from the activity. These managers are employees of an agency that has several field activities to support; however the concern with the allocation of resources and assignments between the different field activities is not part of this study. The agency, in turn, is responsible to a higher level of management for the development and procurement of defense equipment and systems for the operational forces. The problems associated with the agency and the higher level is also excluded from the study. Only the relationships between the agency and one activity are considered.

The activity is assigned the primary mission to conduct the test and evaluation (T&E) of complex defense systems and their related components. Research and development work (R&D) is permitted to keep abreast of the technology, but only to the extent believed that the function of the primary mission is not hampered. The current level of permanent resources is considered to be the allowable ceiling with provisions for keeping equipment and facility capabilities current.

In the following sections the overview of the relationship that exists between the activity and the agency are described, the characteristics of the relationship are enumerated, and the concepts are discussed that incorporate the relationship and its characteristics.

<u>The Organizational Relationship</u>

Figure 2 presents an R&D cycle, hypothesized by Roberts in reference (c) that contains a manageable number of elements and flows to describe the military weapon development cycle. The flows depicting decisions made to invest company (in house) funds and/or to request customer (external) funds to pursue a given development are analogous to the agency decision to invest in house effort and/or to request external (industry) effort to pursue a given development. The balance of the elements of Roberts' R&D cycle are self explanatory in their aptness to the government R&D cycle.

The organization hypothesized participates in support of the agency role in two of the primary elements of Roberts' R&D cycle: the evaluation of progress and the perception of the need for the product (defense system). In the evaluation of progress the organization reviews contractor technical effort, performs independent studies, and conducts formal system hardware experiments and tests. The contribution to the perception of the need by the activity is the experience and awareness of the technology of defense systems that is gained from the evaluation of defense systems. Participation in these two elements comprise the activity's primary mission, i.e., T&E. The primary product of the activity is a value judgment on a tangible product that is proposed as an addition to the military capability.

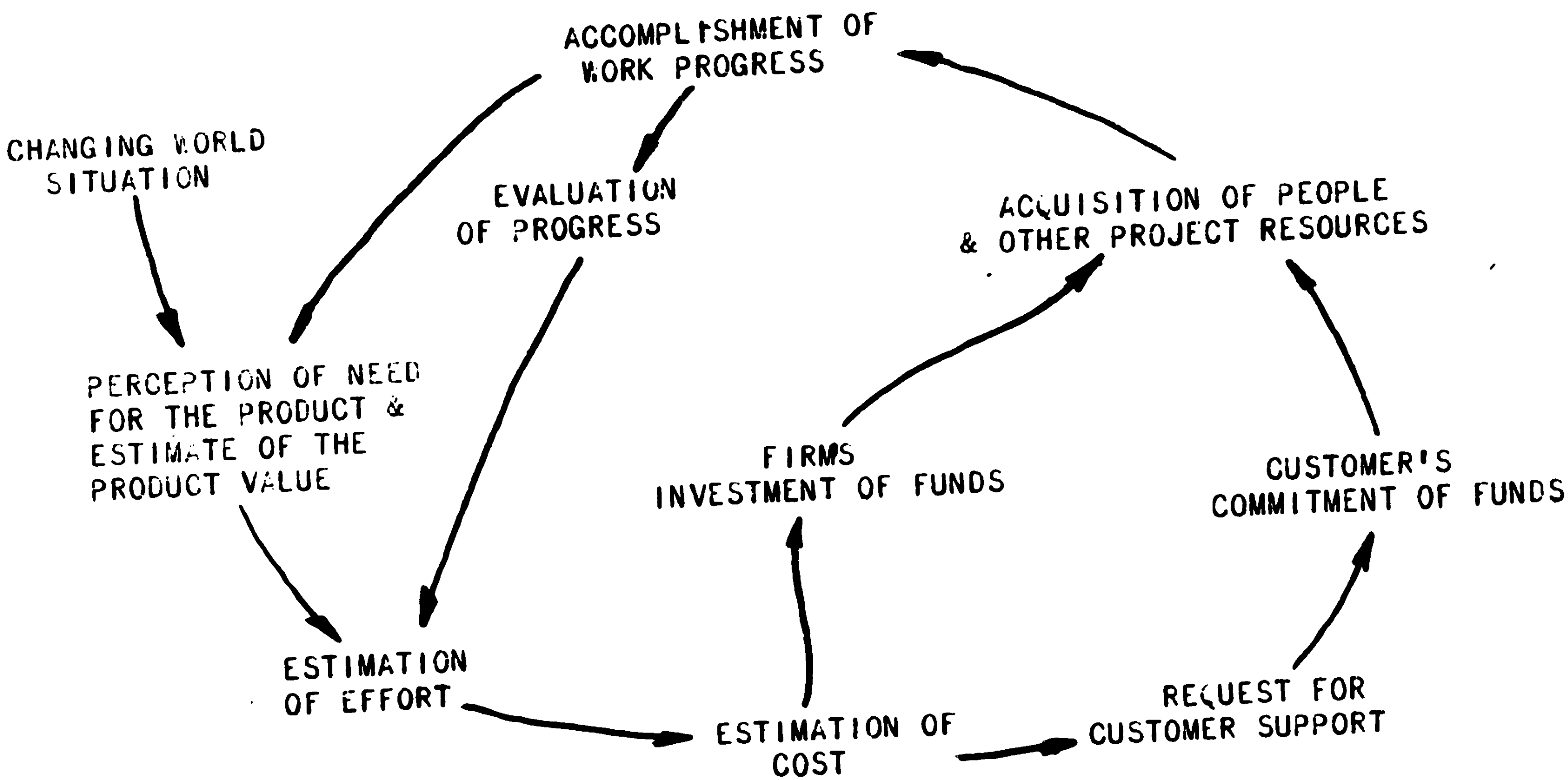


FIGURE 2

A R&D FLOW MODEL
(TAKEN FROM REFERENCE(C))

The quality of the value judgment is some function of the technical "know how" of the activity relative to the technology represented by the system being evaluated. It follows that the greater the activity's technical "know how" with respect to the required technology, the more meaningful the value judgment is likely to be. It is the primary responsibility of an activity to provide for the technical "know how" that is required.

How does an activity provide for technical "know how"? The technical "know how" of an activity is a function of the past work accomplished, and in an environment of a rapidly changing technological requirements it is believed that the accomplishment of current problems alone will not suffice. The activity must divert effort to anticipated problems, that is R&D work. The pay off of R&D effort, however, is in the future, and the diversion of current work effort can stretch out the accomplishment of current work.

The uncertainty of the nature of future problems adds to risk of diverting current work effort to R&D work. Forrester discusses the problems associated in the recognition of the need to divert current work effort to anticipated long term needs in reference (b). Figure 3 is taken from reference (b) and is presented here to provide the basis for the development of Figure 4. Figure 4 presents the flow cycle that is hypothesized for the agency-activity relationship.

The characteristic of Figure 3 embodied in Figure 4 is the channeling of two areas of assignments; one, R&D, which represents long term

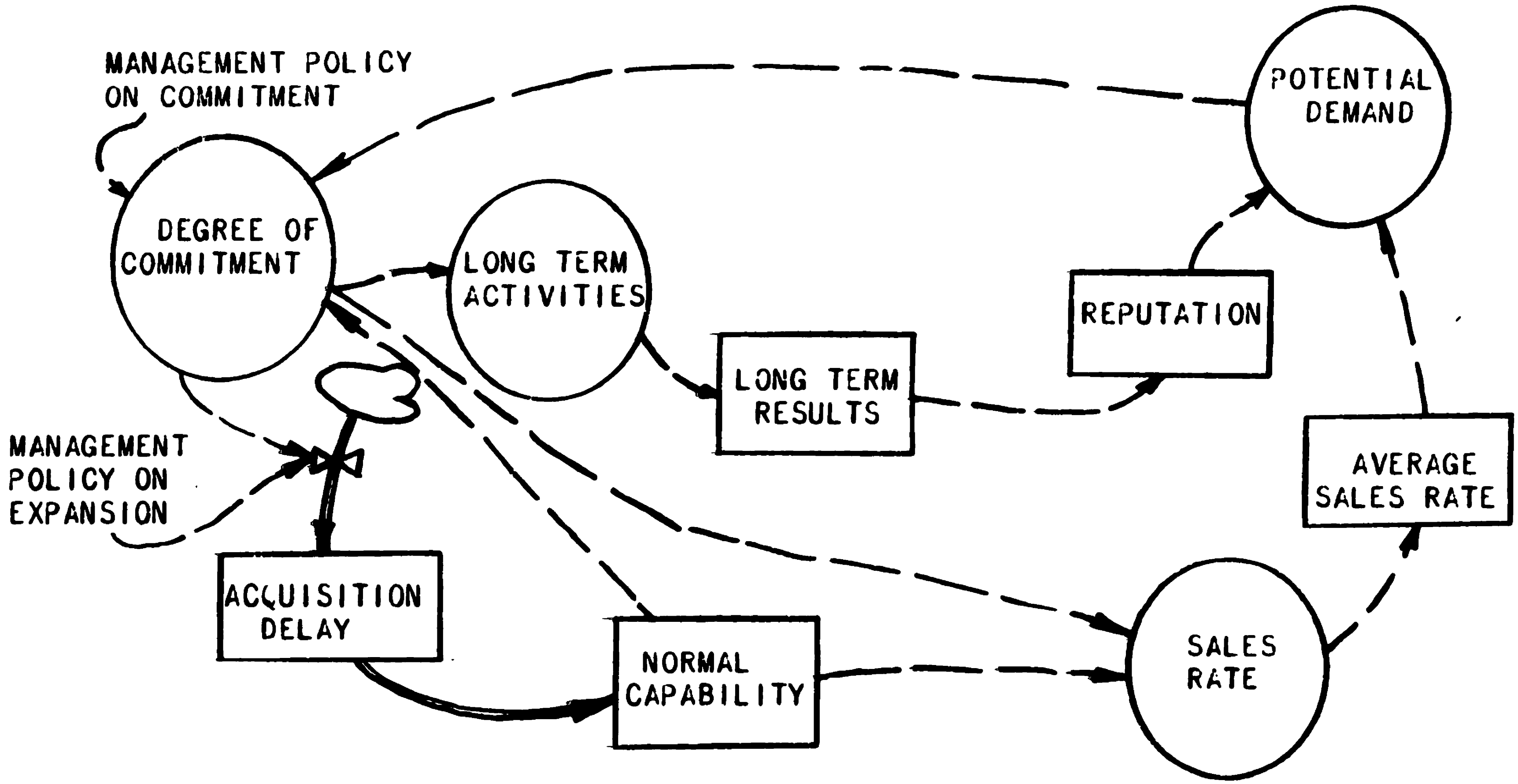


FIGURE 3

AN ALLOCATION OF RESOURCES FLOW MODEL
(TAKEN FROM REFERENCE(B))

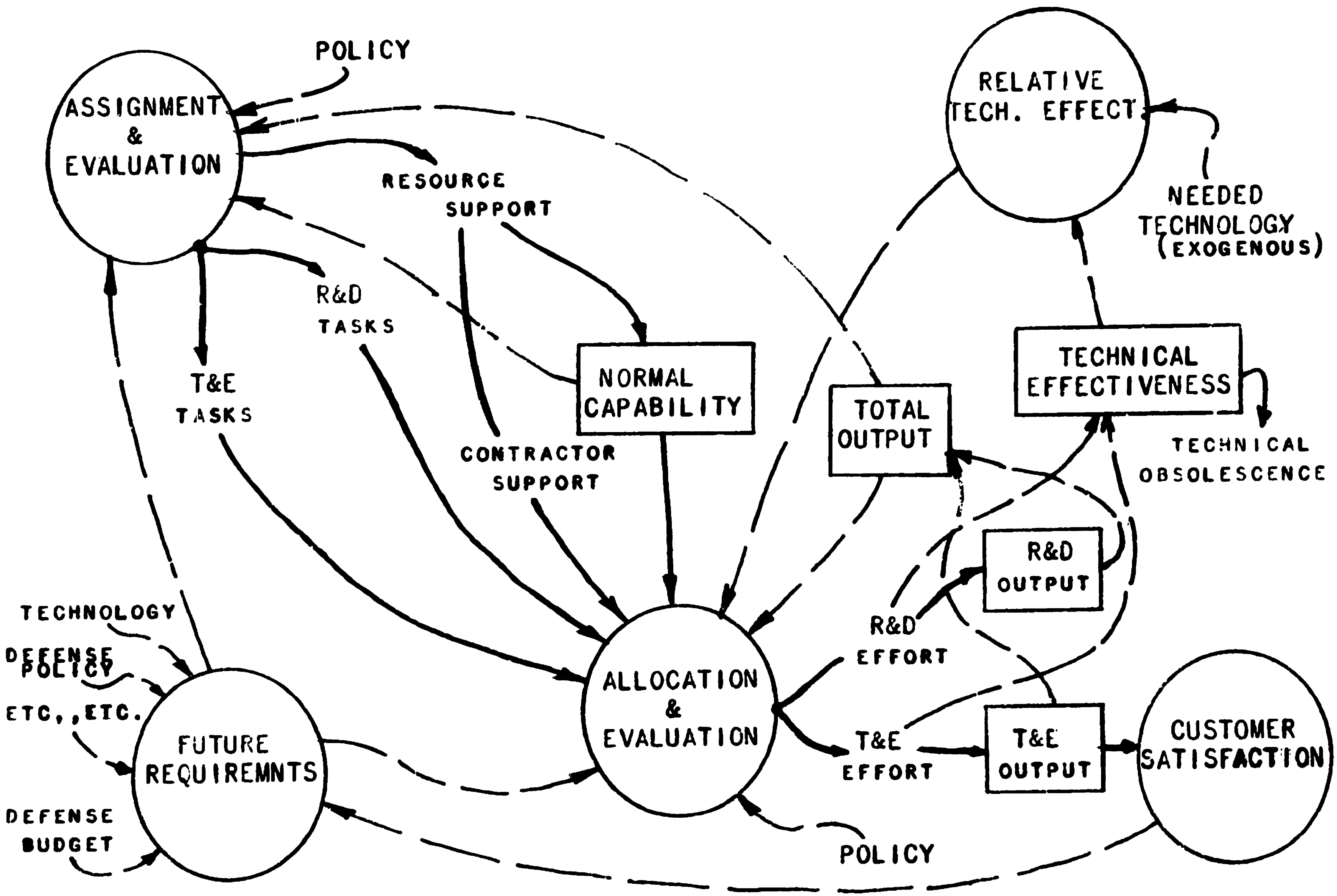


FIGURE 4

A GOVERNMENT RDT&E ORGANIZATION FLOW MODEL pay off, and, two, T&E, which represents short term pay off. Embellishments on Forrester's flow model are:

1. The responsibilities to commit assignments and allocate resources to accomplish the assignments are essentially distinct and separate.
2. The fruition of the divided responsibilities is an ambiguous quantity labeled customer satisfaction.

With these two variations clarified the relationship depicted in Figure 4 can be verbalized:

1. The commitment, or assignment of tasks are channeled into two categories, R&D and T&E by the agency. The amount directed into each channel is a function of the perceived needs of the customer, and the perceived capability of the activity.
2. The allocation of resources by the activity to accomplish the assignments is determined by the current work load, the perceived future needs of the customer, and the agency's perceived measure of the current work load.
3. The accomplishment of work provides products for the customer and technological "know how" for the future.
4. The agency perceives the consequence of past effort through the feedback of customer satisfaction with the quality of the product, and, if necessary, adjusts the amount of assignments in the two channels.

The agency also perceives changes in current or normal capability of the activity, and adjusts the overall task assignments accordingly.

The exogenous input to the model is the technology required to accomplish the assignments that have been made by the agency. An exogenous input is an external disturbance that is assumed to be independent of the system being disturbed.

The future needs of the customer embody complex considerations which are not to be explicitly included in the formulated model; however, the multiplicity of factors is implied by the manner in which the agency (task assignments) and the activity (effort allocation) support T&E and R&D.

Relationship Characteristics

There are several built-in characteristics that determine the dynamic behavior of the system. The characteristics are represented as being reasonable for the model hypothesized and are not intended to be duplicative of any actual organization. The characteristics are divided into two general groups. The first group is characteristics that reflect formulated policies that can be changed. The second group is behavioral characteristics that are believed to be inherent traits of the aggregate organization or of parts of the organization and are not readily changed.

Policy Characteristics.

Agency Policies:

1. The agency will not support additional manpower on a permanent basis.

2. The agency makes the basic task assignments.
3. The agency controls the maximum allowable contractor effort.
4. The agency specifies by task assignment the desired fraction of effort in both R&D and T&E.
5. The agency exerts pressure to align allocation according to the individual preferences of the R&D and T&E agency managers.

Activity Policies:

1. The activity determines the actual allocation of effort.
2. The activity obtains and allocates contractor effort.
3. The activity supports in-house generated tasks.
4. The activity is responsible for the technical effectiveness of the resources assigned.

Behaviorial Characteristics. The identification of the important behaviorial characteristics of an organization is a prime requisite to the adaptation of Industrial Dynamics to a system analysis of an organization. More fundamental, though, is the assumption, or in the instance of Forrester, reference (a), the assertion that organizations tend to develop, or evolve, rather rigid behavior patterns. These behavior patterns are not only difficult to change, according to Forrester, but it is possible to identify and model the significant behavior patterns into reasonably simple decision rules. An important qualification is over what time period does rigidity exist in important organizational behavior and how long in time is required to change an undesirable behavior pattern? This study accepts the view that rigid organization behaviorial patterns do exist and can be modeled, but does not investigate the change question. It is believed sufficient to conduct a conditional study on the basis that the results hold for behaviorial patterns that do not change or are not changed. It is felt to be important to know what might happen if certain policies and or characteristics are not changed.

Agency characteristics:

1. The total task assignment by the agency is made on the basis of the perceived capability of the activity.
2. The agency tends to either underestimate or overestimate the capability of the activity.
3. The fraction of task assignments to R&D and to T&E is a constant or is determined by the quality of the T&E product that is observed by the customer.
4. The customer's observed quality tends to be less than the inherent quality of the product.
5. Effort allocation pressures are exerted by the agency R&D and T&E managers on the activity to accomplish a desired output.
6. Contractor support is allowed when the desired output exceeds the perceived output but only to some fixed fraction of the total estimated capability of the activity.

Activity characteristics:

1. The reallocation of effort is made in response to internal pressures (activity project personnel), external pressures (agency managers), and value preferences based on perceived needs of the customer.
2. Effort allocation pressures are exerted by both the R&D and T&E effort areas to accomplish desired output.
3. An increase in "in-house" generated R&D tasks results when the agency "underloads" the activity with assigned tasks.
4. An increase in "in-house" generated T&E tasks results when the technical content of the T&E assignments exceeds the technical "know how" of the activity.

Model Concepts

The two concepts that are fundamental to the behavior of the model are the generation of technical effectiveness and the allocation of resources at the activity.

Technical Effectiveness. In the model technological "know how" is referred to as the relative technical effectiveness and is measured as the ratio of the technical effectiveness of the organization to the technology required to accomplish the assigned tasks. The required technology is treated as an exogenous input to the model. The basis for the effectiveness concept is provided by reference (f).

The technological "know how" of the organization is generated from past work. In the model the generated "know how" is related only to specific efforts; however, the implication is that any effort (training, education, association, etc.) will generate some "know how." The effect of generated "know how" for a unit of specific effort is assumed to take the shape of the curve in Figure 5 which shows a maximum impact at some time in the future, a zero effect for the present and zero again at some further time in the future. Each area of effort has a different curve. The total rate of technological "know how" generated is represented as a form of weighted resultant of the type of effort depicted. R&D has a larger weighting factor than does T&E. Contractor effort is permitted to generate "know how" for the organization but with less weight than is given T&E.

The organization with a constant division of effort and a constant total quantity of output in each area of effort will generate a constant rate of technological "know how." With the required technology changing, the relative technical effectiveness of the organization will change unless the allocation of effort between the areas of work change and/or the quantity of total output is changed. Without knowing explicitly the required technology or the organization's effectiveness, the organization is permitted to sense the deficiency and make conditioned decisions to change the allocation and quantity of output.

Allocation Process. The allocation process is represented by reallocation preferences to pressures that are generated from within and from outside the organization. Lett, reference (d), developed a pressure

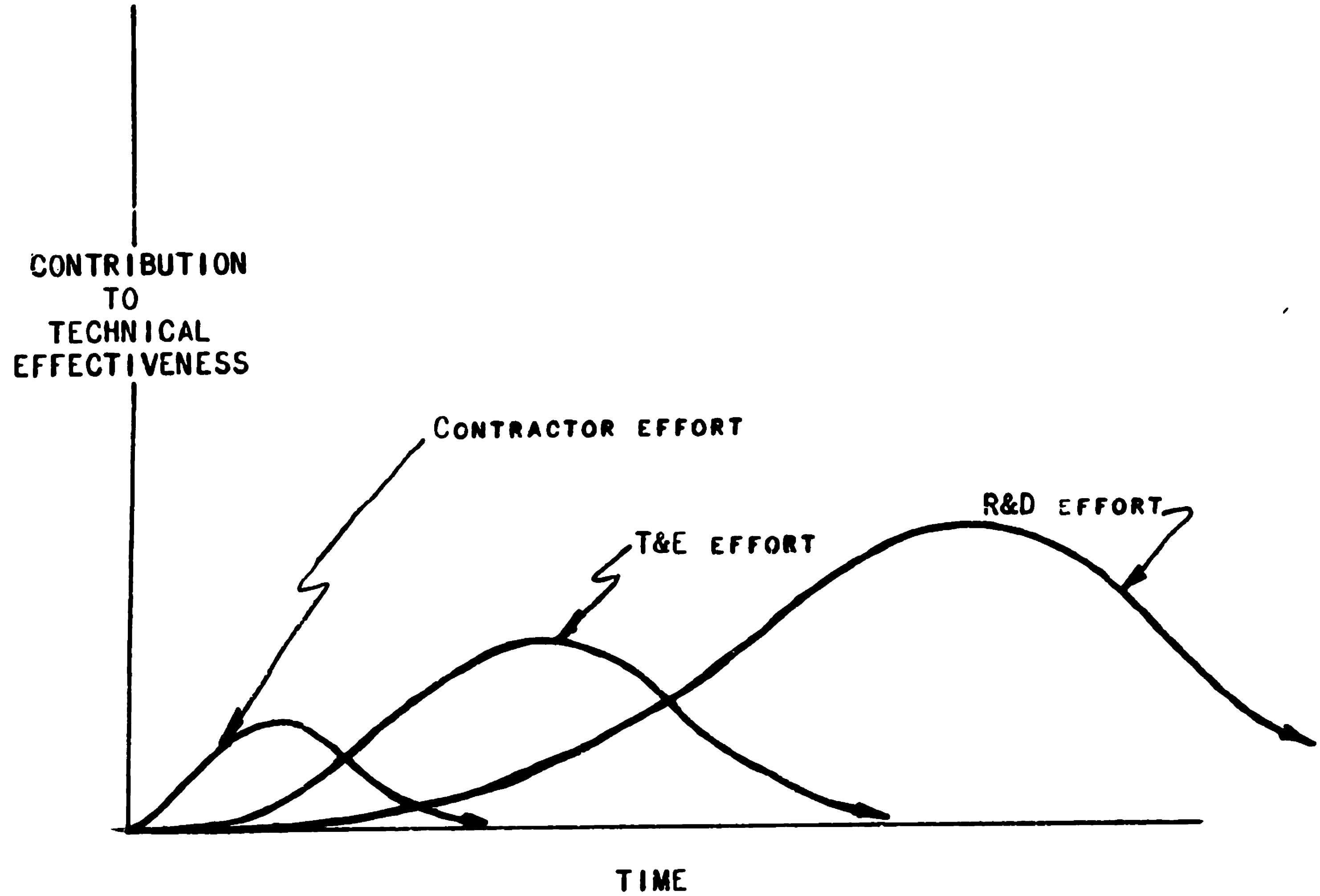


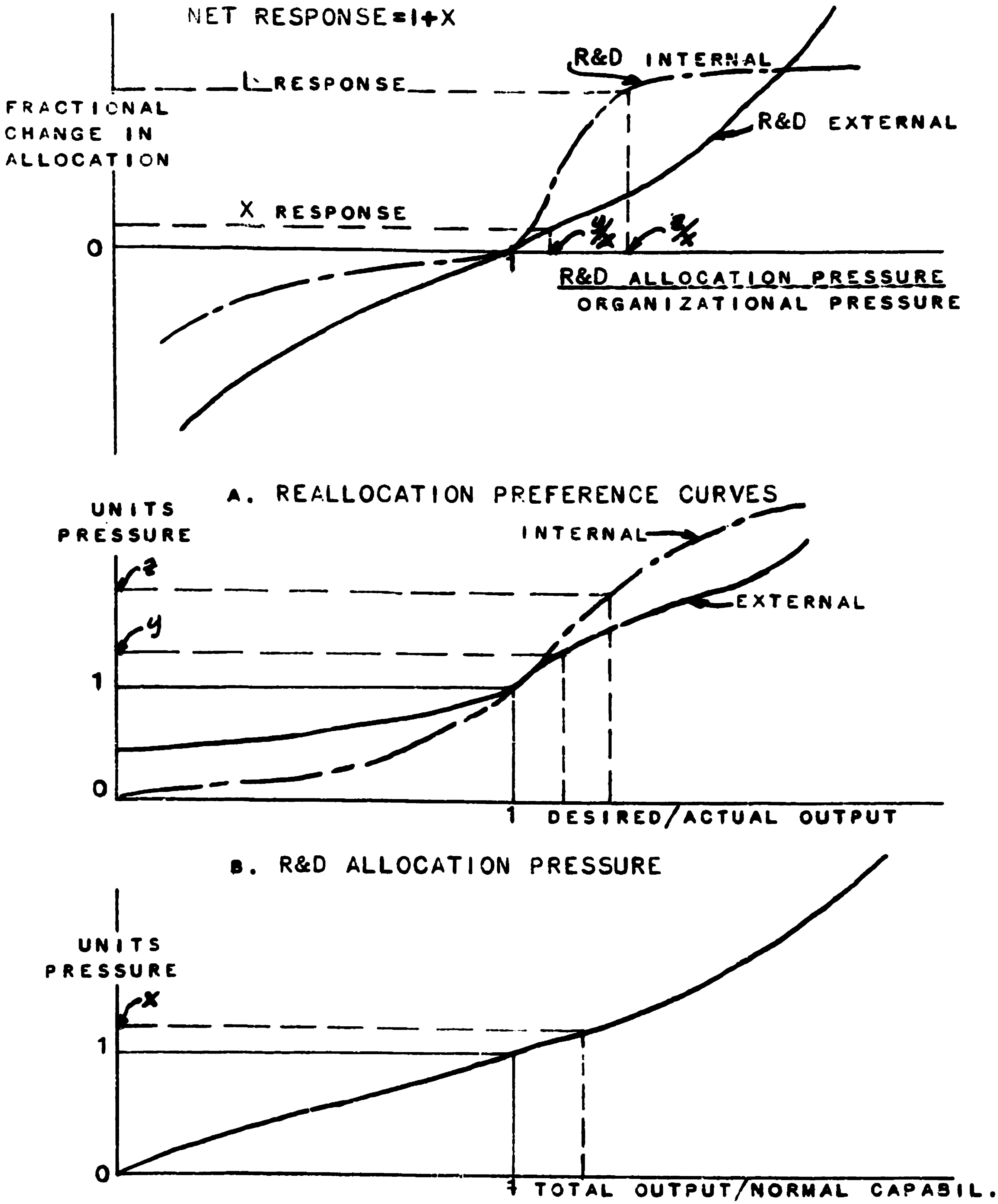
FIGURE 5

CONTRIBUTION TO TECHNICAL EFFECTIVENESS
FOR UNIT EFFORTS AS A FUNCTION OF TIME

equilibrium allocation response system, and Forrester, reference (e), and Roberts, reference (f), embellished and refined the pressure system. Added to the previous developments is the interaction of sets of pressures that are generated from different work areas and different levels of management. The reallocation preferences to the pressures from different levels of management are added to obtain the net response, or allocation, for a given area of work. Intuitively, the response phenomenon is more complex than is represented; however, the research effort allotted to the study did not provide for what is believed to be by itself a worthy topic.

The allocation process sub-model is represented by the curves presented by Figure 6. The model provides for an initial equilibrium by having all pressures at one which provides for an allocation response of zero. When the desired output exceeds the actual output the equilibrium is disturbed and allocation commences.

Figure 6(a) depicts a conditioned response to R&D allocation pressures. Figure 6(b) is the pressure generated by the respective levels of management, internal and external, that are concerned with the R&D output. Figure 6(c) is a representation of the organizational pressure. The allocation process can best be described by referring to the figures. An increase in the desired output generates R&D allocation pressures. As will be explained in the next chapter, the internal and external allocation pressures are not likely to be the same even if the allocation pressure curves were the same because the agency perception of the desired and actual output is different than is the activity's.



C. ORGANIZATIONAL PRESSURE

FIGURE 6

REALLOCATION OF RESOURCES PROCESS

Therefore two separate and different pressures are shown generated in Figure 6(b), and the conditioned allocation response show two fractional changes in allocation. The net response is assumed to be additive. To accomplish reallocation, either positive or negative, the allocation pressure must be different from the organizational pressure.

As reallocation is accomplished the change in output is reflected in both the allocation pressures and the organizational pressure. A positive allocation will decrease the allocation pressures and increase the organizational pressure. If the desired output does not change again the pressure system will approach a new equilibrium in which the allocation pressures are balanced by the organizational pressure.

The organizational pressure is an aggregate response of the total organization that represents the effects, or pressure, from "over or under loading" the organization. The "over loading" is descriptive of an output achieved that is greater than the output which has been determined, accepted, believed, or felt to be the normal output capability of the organization. The conjectured existence of an organizational pressure provides for varying the productivity of the numerically constant manpower that is assumed for the organization.

It is believed that the penalty for the increased productivity is decreased organizational efficiency. The efficiency of the organization is the ability to implement the inherent capability of the organization that is provided by organizational pressure and relative technical effectiveness. For the present study the efficiency of the organization is assumed to be constant and equal to one. This simplifying assumption will impose some restrictions on the meaning of the results, because the system as modeled can be pressured to a level of productivity that is limited only by the arbitrary scale assigned to the pressure curves.

To complete the description of the allocation process the T&E allocation pressure curves and conditioned allocation response curves must be added. For example, in the same time period as discussed for the R&D allocation process assume the desired T&E output does not change. In this instance the T&E allocation pressures would not change immediately; however, as additional effort is provided to R&D and is reflected in increased organizational pressure, the ratio of the T&E allocation pressure to the organizational pressure will decrease. The decrease of the T&E allocation pressure ratio will provide a decrease in the allocation to the T&E effort. With no further disturbances to the desired output in either R&D or T&E, the complete allocation process will approach a new equilibrium in which T&E has less and R&D has more allocated resources.

T&E Product Satisfaction. The primary mission of the activity is T&E. The model assumes no direct current contribution to the T&E output from current R&D effort. Nevertheless it is assumed that R&D effort is required to assure an effective relative technical effectiveness in the future. The required technological "know how" is increasing; therefore additional R&D effort will be required to attempt to keep pace. To divert current effort to R&D to gain future technical effectiveness will delay current T&E projects. The customer is awaiting completion of the current T&E projects to maintain his posture in a rapidly changing military requirement. Some indication of the trade-off between timeliness of the T&E product and the future technical effectiveness is required to complete the model concepts.

Figure 7 suggests a measure expressed as satisfaction units resulting from product timeliness and quality. The quality of the T&E product is defined to be related to the relative technical effectiveness of the organization at the time the product was in process. Therefore, the feedback from the customer reflects the technical effectiveness of the organization some time in the past. Furthermore, the feedback does not necessarily measure true quality but rather an indicated quality as suggested by customer reports on actual experiences with the use of the product.

The timeliness of the product is based on the estimated time requirement, and is a function of the quantity of T&E output. If the T&E backlog is maintained at a normal level the T&E project is on schedule. As the T&E backlog is greater or less than normal the T&E project is behind or is ahead of schedule. Satisfaction from timeliness is with respect to the scheduled delivery date and does not reflect satisfaction suggested by actual delivery and the actual need at the time as does Robert's in reference (g).

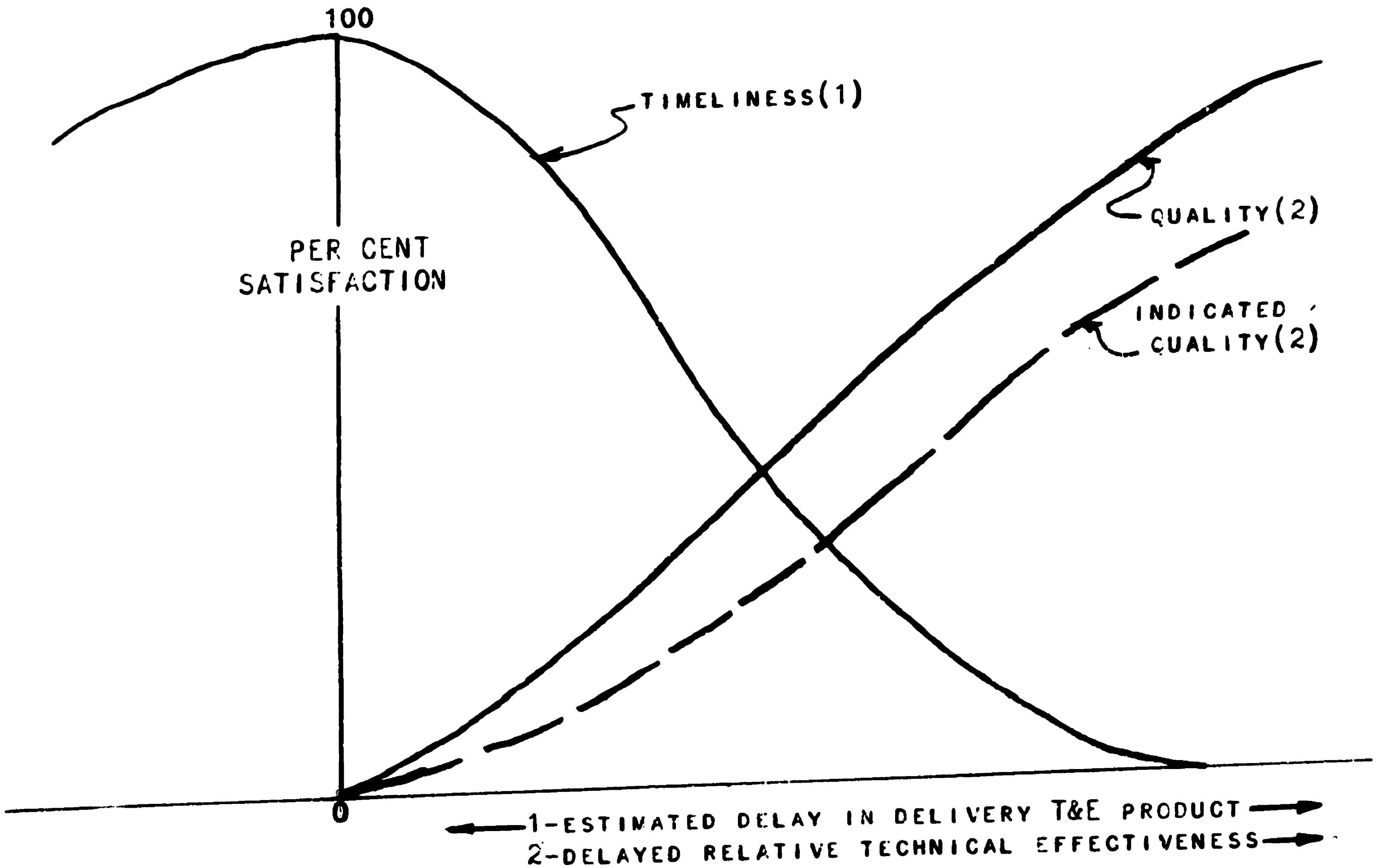


FIGURE 7

CUSTOMER SATISFACTION WITH TIMELINESS AND QUALITY

CHAPTER III

MATHEMATICAL FORMULATION OF THE MODEL

Introduction

In this chapter the mathematical model is developed and the experiment is described to study the model behavior. The model incorporates the concepts presented in Chapter II, and in addition, is supported by the following assumptions:

1. the inputs and outputs represent continuous flow quantities;
2. the manpower resources considered are homogenous and are equally effective in either area of effort;
3. a difference between tasks (assigned and generated) within a given area is not discernible.

The formulation is based on an equation form and an approach developed by the Industrial Dynamics Research Group of the M.I.T. School of Industrial Management and is described in detail in references (a) and (h). The formulation utilizes equal time periods designated as JK and KL. J is the beginning of the time period just passed, K is the present, and L is the end of the next time period. There are two basic quantity types considered in the formulation, levels (L) and rates (R). The present levels (L.K) are computed from past rates (R.JK) and past levels (L.J); the future rates (R.KL) are generated from present levels (L.K) and in turn will generate future levels (L.L). The rates are constant over a single time period.

For example:

$$LW.K = LW.J + (DT)(RLW.JK)$$

$$(\text{man-months}) = (\text{man-months}) + (\text{months})\ \frac{(\text{man-months})}{(\text{months})}$$

states that the present level of work (LW.K) is equal to the past level of work (LW.J) plus the rate of change of the level of work (RLW.JK) over the past time period times the solution interval (DT); and further,

$$RLW.KL = RW.K/DFR$$

$$\frac{(\text{man-months})}{(\text{months})} = (\text{man-months})/(\text{month})$$

states that the rate of change of the level of work for the next time period (RLW.KL) is equal to the present level of requests for work (RW.K) divided by the time delay to fill requests, a constant (DFR).

An additional equation form, the auxiliary (A), is used to simplify the equation content of the L and R type equations. The complete methodology provides for specification of a set of algebraic and difference equations which, when supplied with the appropriate constants (C), initial conditions (N), and solution interval (DT), are readily adaptable to a digital computer that is provided with the DYNAMO program, reference (h). The DYNAMO program will then carry out computer simulation studies of the model, printing and plotting the resulting model behavior as a function of time.

Mathematical Model

The complete model, in DYNAMO equations, with constants, initial conditions, and further discussion of the equations that are expressed as undefined functions of some variable are provided in Appendix B. In this section the key equations incorporating the characteristics and concepts presented in Chapter II are presented along with the flow diagrams for the agency, activity, and effectiveness/satisfaction sectors. The numerals and letters assigned are consistent with the flow diagrams and the DYNAMO equations, the letter denoting the equation type. Where appropriate, because of the similarity of the R&D and T&E area, equations are presented for the T&E area only.

Agency Sector. Figure 8 provides the flow diagram for the agency sector. Assigned tasks, contractor support control, perceived output, and allocation pressure equations comprise the agency sector.

Assigned tasks:

TAT.KL	= (FET.K)(PEC.K)	1-R
DAT.KL	= (FED.K)(PEC.K)	2-R
FET.K	= F(ISFQ.K)	3-A
FED.K	= 1-FET.K	4-A
ISFQ.K	= F(DRTE.K)	5-A
DRTE.K	= DRTE.J + (DT/TDRTE)(RTE.J-DRTE.J)	6-L
PEC.K	= PEC.J + (DT/TPEC)(BEC.J -PEC.J)	7-L
BEC.K	= (EBEC)(NEC.K)	8-A

TAT - T&E assigned task rate (man-months/month)
DAT - R&E assigned task rate (man-months/month)
FET - fraction of effort desired in T&E
FED - fraction of effort desired in R&D

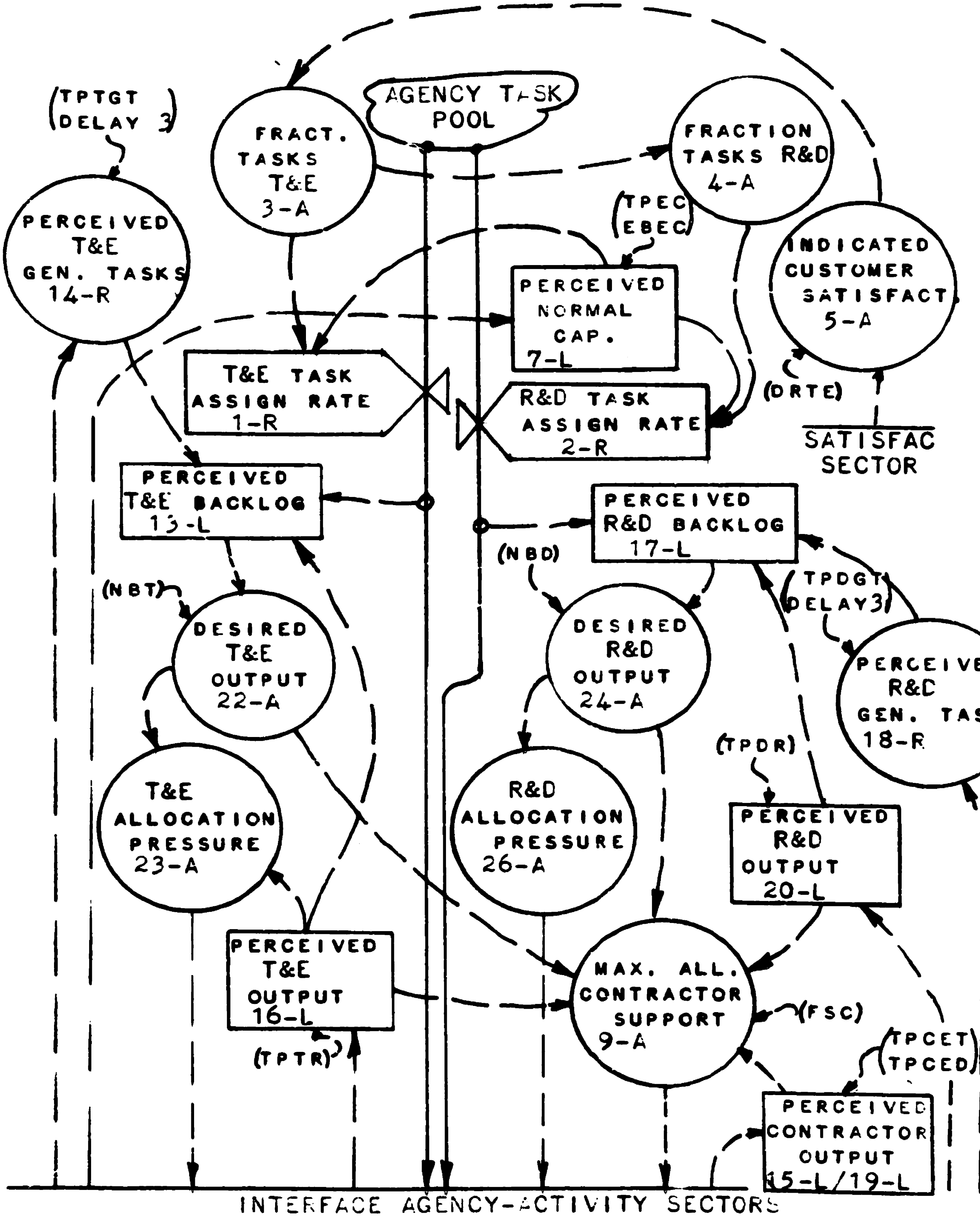


FIGURE 8

AGENCY SECTOR FLOW DIAGRAM

ISFQ - indicated satisfaction from quality
DRTE - delayed relative technical effectiveness
PEC - perceived engineering capability (man-months/month)
BEC - biased estimate of capability (man-months/month)
NEC - normal engineering capability (man-months/month)
TDRTE - time delay relative technical effective.(months)
TPEC - time to perceive engineer capability (months)
EBEC - error bias in estimating engineer capability

Equation 1-R states that the T&E assignment rate, in man-months/month, is equal to the fraction of effort desired in T&E times the perceived engineering capability. Equation 3-A states that the fraction of effort desired in T&E is equal to the function ISFQ. FET is made an increasing function of ISFQ. In DYNAMO equation form the function is represented by stored constants for different values of ISFQ which constants may be changed from one computer run to another. Both equation 6-L and 7-L are smoothing equations that effect first-order exponential smoothing (see reference (a) for detailed discussion). These two equations incorporate the behaviorial characteristic of over or under-estimating the capability of the activity.

Contractor Support control:

CES.K = MINIMUM (CEI.K, MACE.K) 9-A

CEI.K = DTRX.K + DDRX.K -PTR.K -PDR.K -PCED.K -PCET.K 11-A

MACE.K = (FSC)(PEC.K) 12-A

CES - contractor effort supported (man-months/month)
CEI - contractor effort indicated (man-months/month)
MACE - maximum allowable contractor effort (man-months/month)
DTRX - desired T&E resource effort (man-months/month)
DDRX - desired R&D resource effort (man-months/month)
PTR - perceived T&E resource output (man-months/month)
PDR - perceived R&D resource output (man-months/month)
PCED - perceived contractor effort (man-months/month)
PCET - perceived contractor effort T&E (man-months/month)
FSC - fraction capability allowed in contractor support

Equation 12-A represents the maximum contractor effort that the agency will support while equation 11-A measures the perceived need for additional support. Equation 9-A provides that the agency will actually support the lesser of the quantities measured by equations 11-A and 12-A and affects a very tight control on the allowable contractor effort. FSC is a constant and reflects a budgetary limit in terms of additional support to the activity.

Perceived output:

BTP.K = BTP.J + (DT)(TAT.JK + PTGT.JK -PTR.J -PCET.J) 13-L

PTR.K = PTR.J + (DT/TPTR)(TR.J -PTR.J) 16-L

BTP - backlog, perceived, T&E (man-months)
PTR - perceived T&E resource output (man-months/month)
PTGT - perceived T&E generated tasks (man-months/month)
PCET - perceived contractor effort T&E (man-months/month)
TR - T&E resources output (man-months/month)
TPTR - time to perceive T&E output (months)

Equation 16-L is a smoothing equation of the type discussed for the perceived engineering capability, PEC. Equation 13-L states that the perceived backlogs for T&E and R&D, respectively, are equal to the previously measured backlogs plus the difference between the assigned tasks, the perceived generated tasks and the perceived output of the activity over the time interval DT. This set of equations reflects the agency's behaviorial characteristic to over or under-estimate the output of the activity.

Allocation pressure:

DTRX.K = BTP.K/NBT 21-A

TRDAX.K = DTRX.K/PTR.K 22-A

TAPX.K = F(TRADX.K) 23-A

DTRX - desired T&E output-ext. (man-months/month)
TRDAX - T&E ratio desired to perceived, ext.
TAPX - T&E allocation pressure, ext. (units of pressure)
NBT - normal backlog, T&E (man-months)

The desired output control is affected through the maintenance of a normal backlog, equation 21-A. The desired output is compared to the perceived output, equation 22-A, and the T&E allocation pressure is affected by equation 23-A (Figure 6, Chapter II). The significant characteristic of these sets of equations is that the outputs are based on delayed and smoothed information and the pressure generated is felt by the activity in the present.

Activity Sector. The flow diagram for the activity sector is presented in Figure 9. Generated tasks, allocation pressure output, allocation response, and contractor effort comprise the activity sector. The activity equations for allocation pressure and backlog are not presented in this section for they are identical to those for the agency except for the time delays to perceive the appropriate quantity. In the case of the activity this time delay is assumed to be zero.

Generated tasks:

DGT.KL = (TT.K)(FDTG.K) 27-R

TGT.KL = (TR.K)(FTTG.K) 28-R

FDTG.K = F(TP.K) 29-A

FTTG.K = F(RTE.K) 30-A

DGT - R&D generated tasks (man-months/month)
TGT - T&E generated tasks (man-months/month)
FDTG - fraction R&D tasks generated
FTTG - fraction T&E tasks generated
TP - total organization pressure (units pressure)
TT - total output (man-months/month)

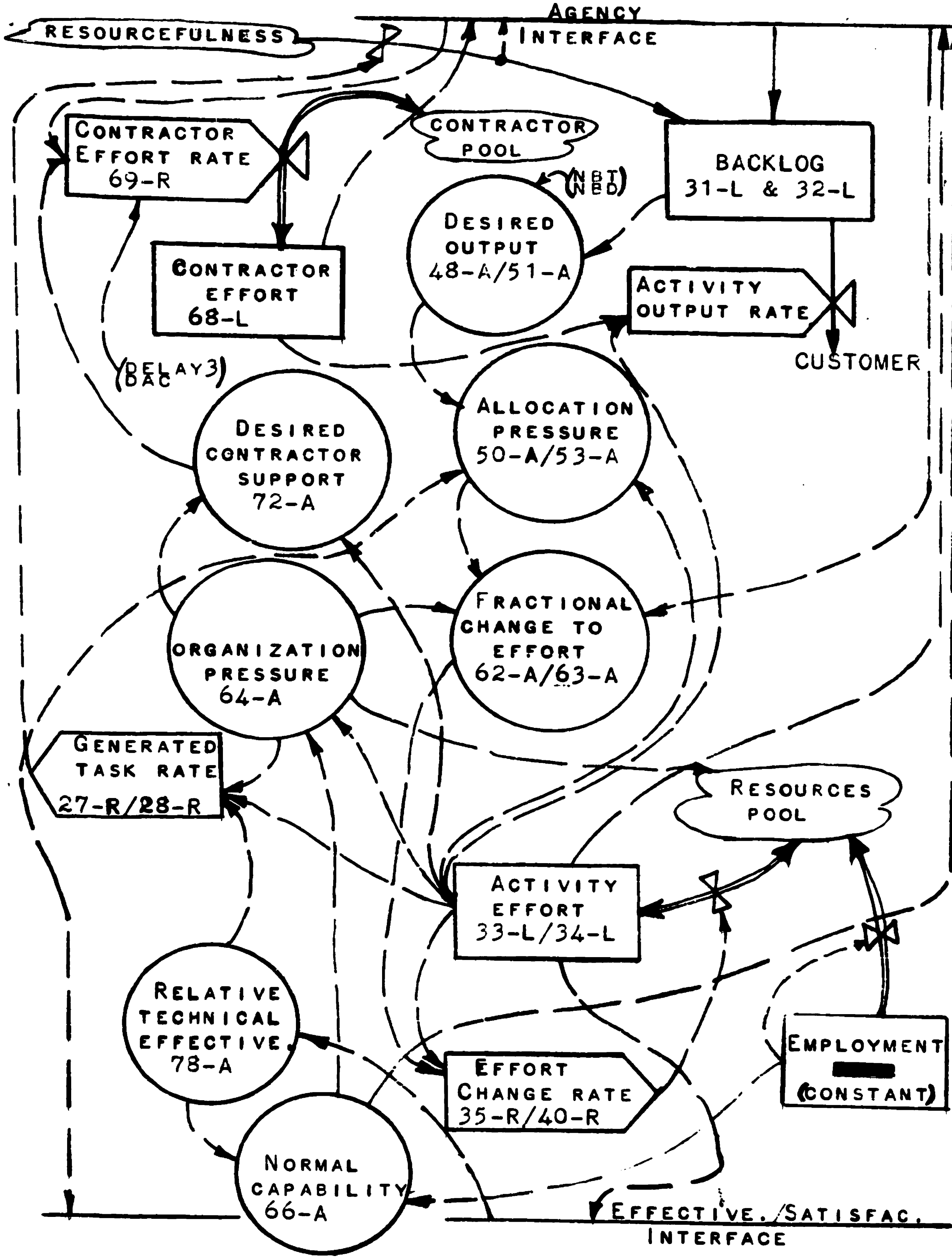


FIGURE 9

ACTIVITY SECTOR FLOW DIAGRAM

Equations 27-R and 28-R incorporate the behaviorial characteristics of the organization that provide for R&D generated tasks to be a function of the organizational "loading" from assigned tasks and the T&E generated tasks to be a function of the implied complexity of the assigned tasks, as measured by the organization's relative technical effectiveness (RTE). Both the R&D and T&E generated tasks are a function of subjective quantities, RTE and TP (total organization pressure). Both FDTG and FTTG are decreasing functions of their respective variable. For the R&D generated tasks the influencing factor is selected to be TP rather than some perceived difference between the effort required to accomplish the assigned tasks and the normal capability of the activity which would suggest a conscious effort to estimate the slack. TP or the organizational pressure is assumed to be felt equally by the entire organization; therefore, what is provided by equation 27-R is a behaviorial response to generate R&D tasks by the entire organizational effort (TT). T&E generated tasks, equation 28-R, are provided only by the T&E effort (TR). In other words everybody will tend to generate R&D tasks but only the T&E effort area will generate T&E tasks.

Activity Output:

TE.K = TE.J + (DT)(TC.JK) 33-L

TC.KL = (TR.K)(TFT.K) 36-R

TR.K = TE.K -EDCET.K 42-A

TT.K = TR.K + DR.K 46-A

TE - T&E effort (man-months/month)
TC - T&E change rate (man-months/month/month)
TFT - T&E fractional change (1/Month)
TR - T&E resources output (man-months/month)

EDCET - effort to direct contractor effort (man-months/month)
TT - total output (man-months/month)

Only the output of permanent resources of the activity are included in the activity output equations, 42-A and 46-A. The contractor output, which reduces activity resources output by EDCED and EDCET, is considered separately. Equation 36-R expresses the rate of allocation change as determined by the reallocation fractional change.

Reallocation response:

TFT.K = TFI.K +TFX.K 63-A

TFI.K = F(TPRI.K) 59-A

TPRI.K = TAPI.K/TP.K 54-A

TFX.K = F(TPRX.K) 60-A

TPRX.K = TAPX.K/TP.K 56-A

TP.K = F(TRNC) 64-A

TRNC.K = TT.K/NEC.K 65-A

NEC.K = (EE.K)(RTE.K) 66-A

EE.K = EEI 67-A

TFT - T&E fractional change, total (1/month)
TFI - T&E fractional change, internal (1/month)
TPRI - T&E allocation pressure ratio internal
TFX - T&E fractional change, external (1/month)
TPRX - T&E allocation pressure ratio, external
TP - total organizational pressure (units pressure)
NEC - normal engineering capability (man-months/month)
EE - engineering employment rate, constant (man-months/month)
TRNC - total output ratio to normal capability

The reallocation concept is explained in detail in Chapter II; the equations formulated in this section directly incorporate that concept. Equation 63-A accomplishes the addition of the T&E reallocation preference responses to the internal and external T&E reallocation preference response, equations 59-A and 60-A respectively (Figure 6, Chapter II). The input to the T&E reallocation preference curves are provided by equations 54-A and 56-A (Figure 6, Chapter II) which are the ratios of the T&E allocation pressures. Equation 55-A and equation 57-A (not given here) provide the inputs to the R&D reallocation preference curves. The allocation pressures do not compete directly with each other but rather with the organizational pressure, which in turn is determined by the present total output of the activity and the normal capability of the activity. This relationship is given by equation 65-A. The precise shape of the organizational pressure is an organizational behavior characteristic, and is assumed to be an increasing function of the total output ratio to normal capability, TRNC (Figure 6, Chapter II).

The numerical resources of the activity are expressed as output units of man-months of effective effort per month. Inasmuch as the model begins in equilibrium the relative technical effectiveness (RTE) is initially equal to one (an efficiency of one is assumed), and the total output (TT) is equal to the normal capability; therefore, the number of effective employees is numerically equal to the employment rate. An organizational resource strength of one thousand men is used in the model. In this instance NEC, the normal engineering capability (equation 66-A), initially is equal to one thousand man-months per month and EE, the engineering employment rate (equation 67-A), is also constant at one thousand man-months per month. As RTE changes NEC changes, reflecting a changing technical capability of the resources with respect to the needed technological "know how." The effects of NEC changes are felt by the activity through the organizational pressure.

Contractor effort:

CE.K = CE.J + (DT)(CC.JK) 68-L

CC.KL = DELAY 3 (CCI.K, DAC) 69-R

CCI.K = (TT.K)(CFC.K) 72-A

CFC.K = F(TP.K) 73-A

CE - contractor effort (man-months/month)
CC - contractor change rate (man-months/month/month)
ACC - agency contractor change rate (man-months/month/month)
DAC - time delay for third order delay (months)
CCI - contractor change impending (man-months/month/month)
CFC - contractor fractional change (1/month)

The contractor effort, equation 68-L, is a level that is determined by the change rate, equation 69-R. The impending change rate, equation 72-A, is delayed to represent the time required to acquire the services of a contractor. The impending change rate is an increasing function of the total effort level of the activity and the organizational pressure, equations 72-A and 73-A. Like the generated tasks, contractor effort is determined by a behaviorial response rather than from an estimate of the actual need. However, as shown in the agency sector, equations 9, 11, and 12-A, the agency actually attempts such a measure and compares the estimated need with the fixed allowance. The activity must operate within the agency contractor effort allowance. Contractor effort is distributed in constant proportions between the R&D and T&E efforts; .9 to T&E and .1 to R&D in the simulations run with the model.

Effectiveness Sector. The flow diagram for the effectiveness sector is presented in Figure 10.

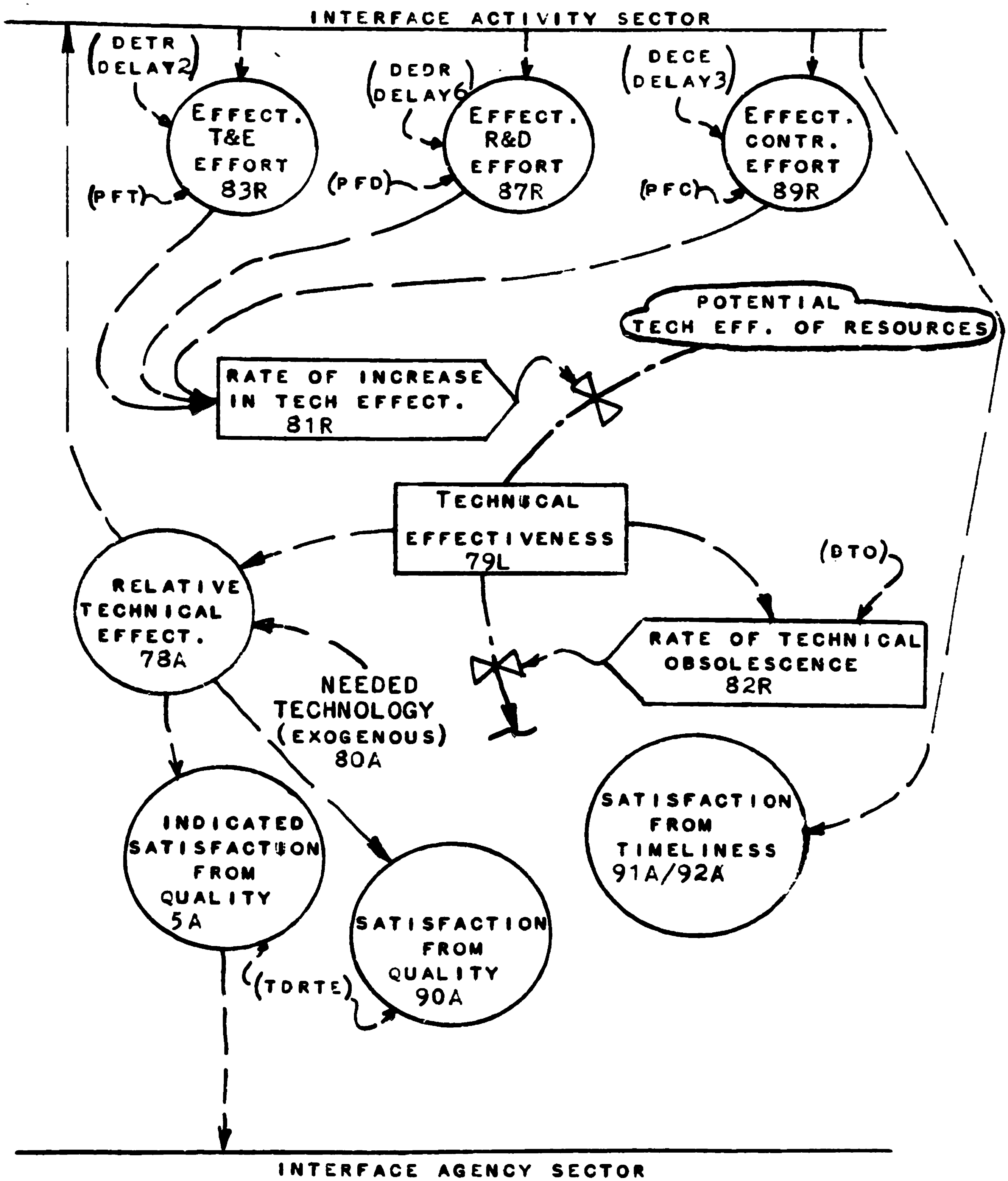


FIGURE 10

EFFECTIVENESS/SATISFACTION SECTORS

RTE.K = TTE.K/NTE.K 78-A

TTE.K = TTE.J + (DT)(RTTE.JK -RTO.JK) 79-L

NTE.K = EXOGENOUS INPUT 80-A

RTE - relative technical effectiveness
TTE - total organizational technical effectiveness (units effectiveness)
NTE - needed technical effectiveness

The relative technical effectiveness, equation 78-A, expresses the organizational technical capability with respect to the needed technical effectiveness. The total technical effectiveness, equation 79-L, is a level that is changed by a difference in the rate of change of technical effectiveness, equation 81-R, and the rate of technological obsolescence, equation 82-R. The time delay for technological obsolescence is assumed to be fifty months. The generation of the rate of change of technical effectiveness is discussed with the next group of equations. The needed technical effectiveness, or needed technological "know how" (the exogenous input to the model), is assumed to be increasing with time. The model does not require that NTE be measured or estimated. The impact of NTE, through RTE and the normal capability, is felt on the organizational pressure, equation 64-A. The consequence is the reallocation behavior of the activity will be similar to that when the reallocation is first initiated by the effort allocation pressures. RTE of one or greater indicates that the organization is keeping abreast or ahead of the technical requirements that are implied by the assigned and generated tasks.

RTTE.KL = (PFT)(ETR.JK) + (PFD)(EDR.JK) + (PFC)(ECE.JK) 81-R

RTO.KL = TTE.K/DTO 82-R

ETR.KL = DELAY 2 (TR.K,DETR) 83-R

EDR.KL = DELAY 6 (DR.K,DEDR) 87-R

ECE.KL = DELAY 3 (CE.K,DECE) 89-R

RTTE - rate of change of technical effectiveness (units effectiveness/month)
RTO - rate of change of technical obsolescence (units effectiveness/month)
ETR - effective T&E output (man-months/month)
EDR - effective R&D output (man-months/month)
ECE - effective contractor output (man-months/month)
PFT - proportionality factor T&E (units effectiveness/man-month)
PFD - proportionality factor R&D (units effectiveness/man-month)
PFC - proportionality factor contractor (units effectiveness/man-month)

The respective delays in equations 83-R, 87-R and 89-R approximate the time shapes of the relative impact of each area of effort on technical effectiveness. These are shown in Figure 5, Chapter II. The delay times, DETR, DEDR, and DECE were selected to provide peak impact on organizational effectiveness from effective T&E effort in twenty-four months, effective R&D effort in forty-eight months, and effective contractor effort in twelve months. The proportionality factors for T&E, R&D, and contractor effective output are 0.01, 0.05 and 0.005 respectively. This provides the total contribution to effectiveness from R&D effort to be five times that from T&E effort and ten times that from contractor effort.

<u>Satisfaction Sector</u>. The flow diagram for the satisfaction sector is given in Figure 10.

SFQ.K = F(DRTE.K) 90-A

SFT.K = F(DPT.K) 91-A

DTP.K = -1.5 + (TRDAI.K)(1.5) 92-A

SFQ - satisfaction from quality (fraction of 1.0)
SFT - satisfaction from timeliness (fraction of 1.0)
DTP - estimated delay to T&E product (years)
TRDAI - T&E ratio desired to actual output

Equations 90-A and 91-A incorporate the curves presented in Figure 7 of Chapter II. DRTE is given by equation 6-L in the agency sector and provides that the quality T&E product delivered to the customer reflects the technical capability of the organization some time in the past. The time delay assumed for DRTE is twenty-four months. The delay in delivery of T&E product is a measure of the T&E backlog that is in excess of the normal backlog. If the current backlog equals the normal backlog there is no anticipated slippage in the planned delivery date of the T&E product to the customer.

Experiment

The number of equations used to describe the modeled organization, including constants, initial conditions, and behaviorial characteristics, exceeds one hundred. To conduct a parametric study to determine the effect and interaction of different levels of the constants, initial conditions, and behaviorial characteristics on the model variables would require considerably more time than is available for this study. However, the intention is not to optimize the entire range of all the arbitrary inputs, but to concentrate on a few to which it is believed the model behavior is particularly sensitive.

The construction of the model represents over one hundred separate runs. The test runs are not part of the experiment but do provide insight to which parameters the model is sensitive. The primary parameters that are investigated are error in estimating the normal capability and the determination of the proportion of T&E and R&D assigned tasks. These parameters have each been identified as to behaviorial characteristics; therefore, when they are changed a different organization and/or organizational relationship is created.

Four basic relationships are investigated:

1. Relationship A - the agency effects tight control by overloading the activity through overestimating the normal capability of the activity, i.e., EBEC > 1.0; the activity presents a conditioned reallocation response that gives preference to the agency T&E allocation pressure;
2. Relationship B - same overloading as A; however, the activity presents a conditioned reallocation response that gives preference to the activity R&D reallocation pressure for the initial part of the pressure ratio rise;
3. Relationship C - the agency effects loose control by underloading, i.e., EBEC < 1.0; reallocation response same as A;
4. Relationship D - same underloading as C; reallocation response same as B.

For each relationship the effects of the following characteristics are tested:

1. FET and FED, fraction of effort desired in each area; a constant fraction and a varying fraction;
2. Reallocation pressure: reallocation made in response to agency only, and made in response to activity only.
3. Needed Technology: two rates of increasing technology are considered, 5% and 10% per annum.

The runs will be judged by recording and studying the following subjective values for time periods of 5, 10 and 15 years of organizational life:

1. Relative Technical Effectiveness
2. Satisfaction From Quality
3. Satisfaction From Timeliness
4. Total Output
5. T&E Output
6. Contractor Support Required
7. Organizational Pressure

CHAPTER IV

RESULTS AND CONCLUSIONS

Introduction

In this chapter the results are presented, the the results and the variables in the model are relate are discussed, and recommendations for further extens are offered.

The reallocation process of the model, as desc II, is represented by a pressure system that is initi the equilibrium is disturbed and response of the mode studied. In equilibrium all pressures, external and tion (TAPX, DAPX, TAPI, and DAPI) and organizational to one, and the activity reallocation preferences (TF are zero. The equilibrium position of the organizati point at which all flows, levels, and characteristics The initial balance is disturbed in two ways: first, task assignment rates (TAT, DAT) and/or the mix of th and second, by changing the needed technology (NTE) quired to accomplish the tasks. The results presente and figures are responses of the modeled organizatio initial balance.

Results

The results are presented in Tables I and II through 13. The tabular presentations provide a rea comparison of the different relationships and the resultant effect on the performance of the organization. The time plots (DYNAMO plots) provide an overview of the dynamic characteristics of the organizational response. The organizational relationships A, B, C, and D, defined in Chapter III, are repeated for convenience in Table III. A glossary of symbols, Table IV, is placed at the end of this chapter to aid in the interpretation of the tables and figures.

The data that are presented in Table I are the results of the basic experiment described in Chapter III. Data for the relationships in which either the external reallocation preference (TFX and DFX) or the internal reallocation preferences (TFI and DFI) and remain equal to zero are not presented, for the results do not vary significantly from the other cases. Furthermore, the inability of the organization to cope with a 5 per cent per annum change in needed technology makes investigation of the 10 per cent per annum change premature. A select number of relationships are investigated which provide for increased sensitivities for the reallocation process, generated tasks, and proportion of assigned tasks in the modeled organization. These results are summarized in Table II.

The data in Table I show clearly that the "underloaded" organization (error in estimating capability, EBEC = .7) degenerates more rapidly after the fifth year than do the "overloaded" situations (EBEC = 1.3) for both a constant and a variable proportion of T&E task assignments. The only appreciable difference indicated in the response data for the different relationships with the same task

TABLE I

ORGANIZATIONAL PERFORMANCE FROM THE EXPERIMENT

TASK MIX	FET=constant				FET=variable			
EBEC	1.3		.7		1.3		.7	
RELATIONSHIP	A	B	C	D	A	B	C	D
5th YEAR								
RTE	.82	.82	.79	.80	.82	.82	.80	.80
SFQ	.59	.59	.57	.57	.58	.59	.57	.57
SFT	.86	.91	.99	.96	.86	.95	.98	.96
TT	1079	1109	724	715	1070	1111	720	714
TR	968	996	634	620	931	975	609	593
CE	79	62	0	0	83	55	0	0
TP	1.15	1.17	.92	.91	1.14	1.18	.92	.91
10th YEAR								
RTE	.68	.70	.57	.57	.71	.71	.58	.58
SFQ	.35	.37	.27	.24	.38	.38	.29	.25
SFT	.76	.87	.92	.98	.76	.87	.93	.98
TT	935	982	523	526	945	992	530	530
TR	840	884	460	462	761	786	400	404
CE	82	51	0	0	85	59	0	0
TP	1.20	1.23	.93	.93	1.16	1.18	.93	.93
15th YEAR								
RTE	.56	.57	.38	.38	.63	.64	.44	.45
SFQ	.17	.18	0	0	.24	.26	0	.01
SFT	.66	.86	.62	.91	.66	.80	.64	.91
TT	801	831	384	389	847	871	416	420
TR	723	750	345	349	647	670	289	291
CE	80	58	0	0	80	58	0	0
TP	1.24	1.27	1.00	1.00	1.16	1.19	.96	.95

loading is satisfaction from timeliness (SFT) which reflects the difference between current T&E task assignments and current T&E effort. The differences in satisfaction from timeliness for the different relationships are consistent, although arbitrarily magnified, with the differences in T&E effort (TR). The only other difference apparent is the greater organizational pressure in the "overloaded" than in the "underloaded" cases. None of the relationships presented by Table I affect a recovery for the organization as indicated by satisfaction from quality (SFQ) and relative technical effectiveness (RTE). Figures 11 and 12 are typical time plots of the cases shown in Table I.

Comparison of the data shown in Table II with the data presented in Table I indicates that only the selected relationship number one provides results that are appreciably different from the others. Case number one, Table II, is compared with the fifth case given in Table I. The faster change to the variable proportions of task assignments is the only characteristic difference, and presents the only case in which a significant reversal to the trend is affected. A distinct oscillatory organizational response is apparent. The effect of delays are seen in Figure 13 because of the relatively fast changes that are affected by the variable proportions of task assignments.

Case number two, Table II, is an attempt to accomplish a significant change of organizational response by providing a "severe" counter T&E reallocation preference. The severity is represented by providing relatively insensitive positive reallocation preference and relatively sensitive negative reallocation preference to both the agency and loading is satisfaction from timeliness (SFT) which reflects the difference between current T&E task assignments and current T&E effort. The differences in satisfaction from timeliness for the different relationships are consistent, although arbitrarily magnified, with the differences in T&E effort (TR). The only other difference apparent is the greater organizational pressure in the "overloaded" than in the "underloaded" cases. None of the relationships presented by Table I affect a recovery for the organization as indicated by satisfaction from quality (SFQ) and relative technical effectiveness (RTE). Figures 11 and 12 are typical time plots of the cases shown in Table I.

Comparison of the data shown in Table II with the data presented in Table I indicates that only the selected relationship number one provides results that are appreciably different from the others. Case number one, Table II, is compared with the fifth case given in Table I. The faster change to the variable proportions of task assignments is the only characteristic difference, and presents the only case in which a significant reversal to the trend is affected. A distinct oscillatory organizational response is apparent. The effect of delays are seen in Figure 13 because of the relatively fast changes that are affected by the variable proportions of task assignments.

Case number two, Table II, is an attempt to accomplish a significant change of organizational response by providing a "severe" counter T&E reallocation preference. The severity is represented by providing relatively insensitive positive reallocation preference and relatively sensitive negative reallocation preference to both the agency and

TABLE II

ORGANIZATIONAL PERFORMANCE FOR SELECTED CASES

	1 (FIGURE 13) EBEC 1.3, RELATIONSHIP A FASTER VARIABLE FET	2 EBEC 1.3, RELATIONSHIP B FIXED FET; HIGH R&D REALLOCATION PREFERENCE	3 EBEC .7, RELATIONSHIP D FIXED FET; HIGH R&D REALLOCATION PREFERENCE; HIGH PROPENSITY TO GENERATE R&D TASKS
5th YEAR			
RTE	.82	.83	.80
SFQ	.59	.59	.56
SFT	.92	.88	.96
TT	1057	1096	760
TR	741	981	630
CE	64	66	0
TP	1.13	1.17	.96
10th YEAR			
RTE	.81	.70	.60
SFQ	.45	.38	.30
SFT	.78	.81	.96
TT	1008	978	580
TR	326	881	483
CE	47	62	0
TP	1.09	1.21	.96
15th YEAR			
RTE	1.09	.57	.44
SFQ	.73	.19	.02
SFT	.97	.72	.96
TT	1288	839	439
TR	890	758	377
CE	12	61	0
TP	1.07	1.28	.98

TABLE III

DEFINITION OF RELATIONSHIPS A, B, C, and D

1. RELATIONSHIP A: The agency effects tight control by overloading the activity through over-estimating the normal capability of the activity, i.e., EBEC > 1.0; the activity presents a conditioned reallocation response that gives preference to the agency T&E allocation pressure;
2. RELATIONSHIP B: Same overloading as for A; however the activity presents a conditioned reallocation response that gives preference to the activity R&D allocation pressure for the initial part of the pressure ratio rise;
3. RELATIONSHIP C: The agency effects loose control by underloading, i.e., EBEC < 1.0; reallocation response same as for A;
4. RELATIONSHIP D: Same underloading as for C; reallocation response the same as for B.

activity T&E allocation pressures. The reallocation preference sensitivities to both agency and activity R&D reallocation preferences are the reverse of the T&E reallocation preference sensitivities. In effect the activity reluctantly reallocates additional effort to T&E but is very willing to reallocate additional effort to R&D. Reality is suggested by reversing the positive preferences when the T&E allocation pressure exceeds the organizational pressure by an arbritrary amount. The values for the "severe" counter T&E allocation preference are given in Appendix B. A comparison of case number two, Table II, with the first case in Table I indicates no appreciable difference in the data shown.

In addition to the counter T&E allocation pressure, a greatly increased activity propensity to generate R&D tasks (FDGT) was provided to attempt an organizational recovery in an "underloaded" situation. Comparison of case number three, Table II, and the fourth case in Table I indicates that only slight changes in relative technical effectiveness are affected.

Discussion

From the brief description of the results it is clear that none of relationships presented effect a recovery of the modeled organization. The task overloading merely slows the degeneration of relative technical effectiveness and subsequently the customer satisfaction from quality. A shift of the proportions of the task assignments does arrest the decline in the performance parameters; and if the shift is made rapidly enough the performance parameters can be seen to exceed the initial values. However, the oscillatory nature of effort and output parameters of the modeled organization suggest a stability problem, and certainly an implementation problem. The increased R&D reallocation preferences and propensity to generate R&D tasks appear to have no significant effect on the declining performance parameters. In this sectinn the reasons for the demise of the modeled organization are explored.

The only way to effect a recovery to the modeled organization is to increase the total technical effectiveness of the activity in order to catch up and eventually match the increasing needed technology. To increase the total technical effectiveness the total effort must be maintained at or near the initial level and a larger proportion of the total effort must be shifted to the area of effort that affords the greater contribution to technical effectiveness, i.e., R&D effort.

The characteristics of the relationships presented in Figures 11 and 12 do not provide for increasing the total effort or for shifting the proportions of effort when confronted with a rising needed technology. On the contrary the implicit decisions are to reduce total effort by reducing total assignments while holding the proportions of the effort constant. The differences in the two organizational responses are attributed to the initial "overload" that provides the relationship presented in Figure 11 with a larger total effort than for the "underloaded" relationship presented in Figure 12. If an organization efficiency (assumed to be 1.0 for this study) were included as some function of

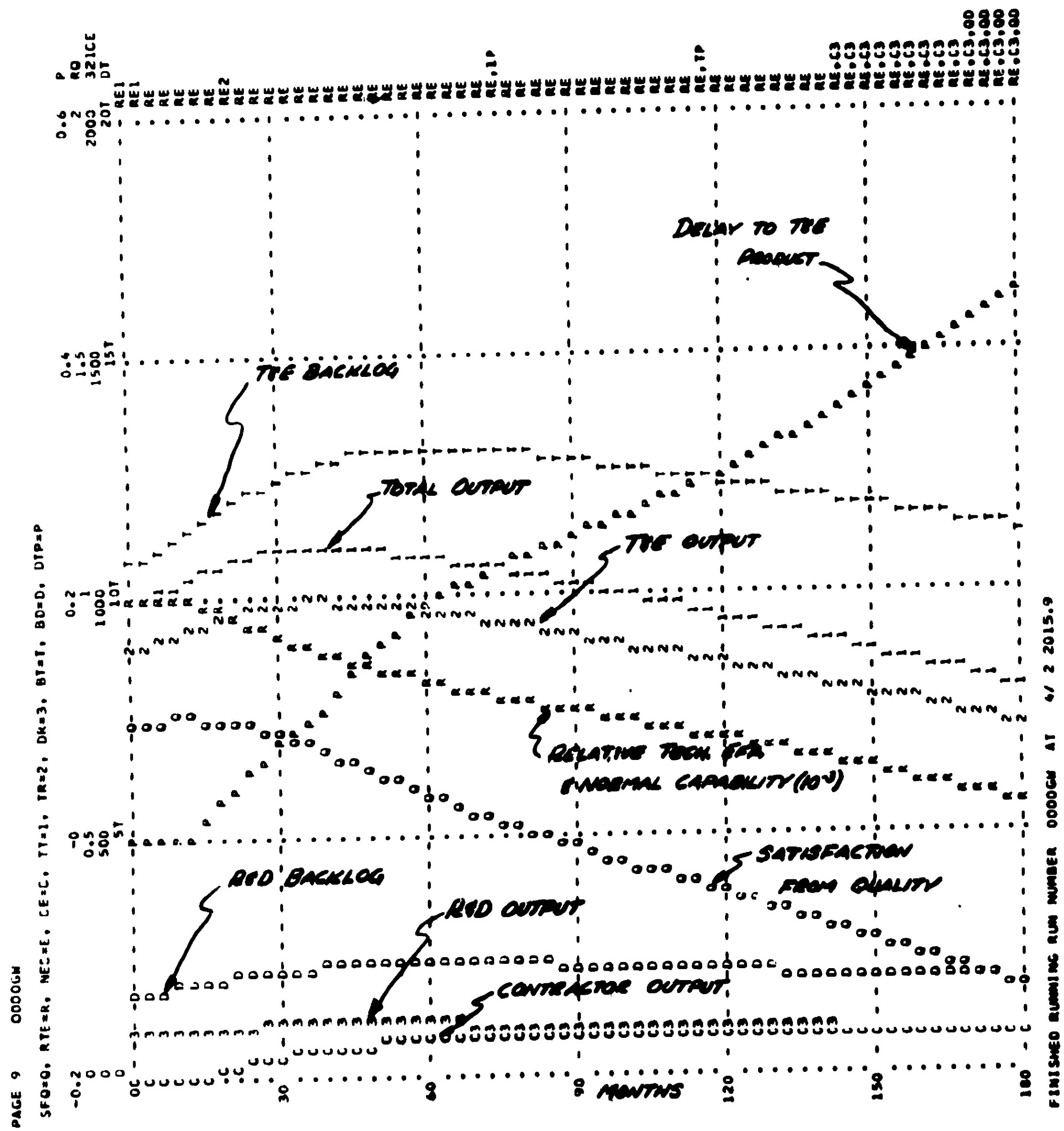


FIGURE 11

RESPONSE FOR RELATIONSHIP A, ACTIVITY OVERLOADED AND PROPORTION OF ASSIGNED TASKS CONSTANT, AS A FUNCTION OF TIME

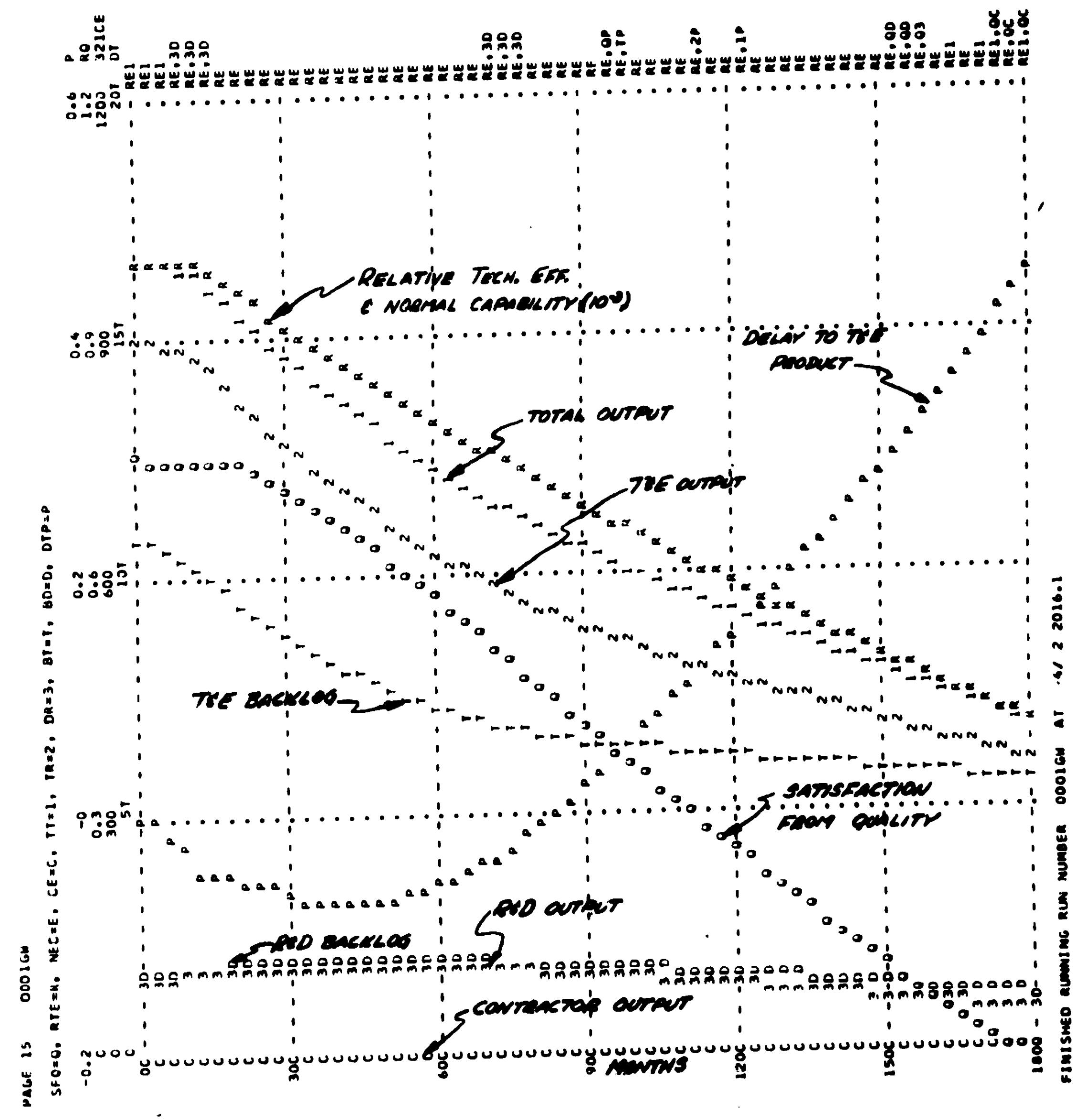


FIGURE 12

RESPONSE FOR RELATIONSHIP D, ACTIVITY UNDERLOADED AND PROPORTION OF ASSIGNED TASKS CONSTANT, AS A FUNCTION OF TIME organization pressure, the differences between the "overloaded and "underloaded" organizational responses would be less than is now indicated.

In the relationships presented in Figures 11 and 12 nothing is done by the modeled organization to counter the increasing needed technology. The quantity of the total task assignments is equal to perceived capability (PEC) which is a biased and delayed function of the activity's normal capability (NEC). The normal capability is a function of the relative technical effectiveness. When the relative technical effectiveness begins to decline, the normal capability of the activity will decline. After a delay, the perceived capability will decline and as a consequence so will the total task assignments. The lowering of the total task assignments causes a reduction of the total effort (TT) by the activity which will further decrease the relative technical effectiveness.

The only way the modeled organization can attempt to compensate for the reduction in the total effort of the activity when the relative technical effectiveness is declining is to generate tasks from within the activity. Generated R&D tasks (DGT) are not directly dependent upon the normal capability but are a function of organizational pressure. However, for the relationships studied, the agency's task assignments account for 85 to 95 per cent of the total task loading on the activity. This preponderance of task loading enables the agency to determine the general quantity and proportions of the activity's efforts. The roles of the generated R&D tasks and the activity reallocation preferences are discussed later.

An explicit decision rule is provided in the relationship presented by Figure 13. The decision rule is to increase the proportion of R&D assignments and decrease the proportion of T&E assignments as an arbitrary function of the indicated quality of the T&E product (ISFQ) that has been delivered to the customer (equation 3-A). The rule, conceived as a serious decision criteria, appears to present implementation difficulties. First, the shifts indicated to accomplish the recovery probably would be difficult to accomplish; and second, given the total shift indicated, the T&E effort deteriorates to a very low quantitative level.

An important characteristic of the modeled organization is vividly portrayed by the responses presented in Figure 13. The rate of increase in needed technology is a constant quantity and at the outset is a 6 per cent increase per annum. The constant 42 units of increased needed technology per annum must be equaled by increases to the total technical effectiveness (TTE) to arrest a decreasing RTE. How easily can this be accomplished? For the case presented by Figure 13 the rate of change of total technical effectiveness (RTTE) must be increased by 42 units per annum, or approximately 4 units per month. Assuming a constant total effort of one thousand man-months per month, the increased rate of change of total technical effectiveness can be obtained by providing approximately 80 per cent T&E task assignments and 20 per cent R&D task assignments. Referring to Figure 13, the 80/20 mix is achieved within 33 months after the needed technology begins

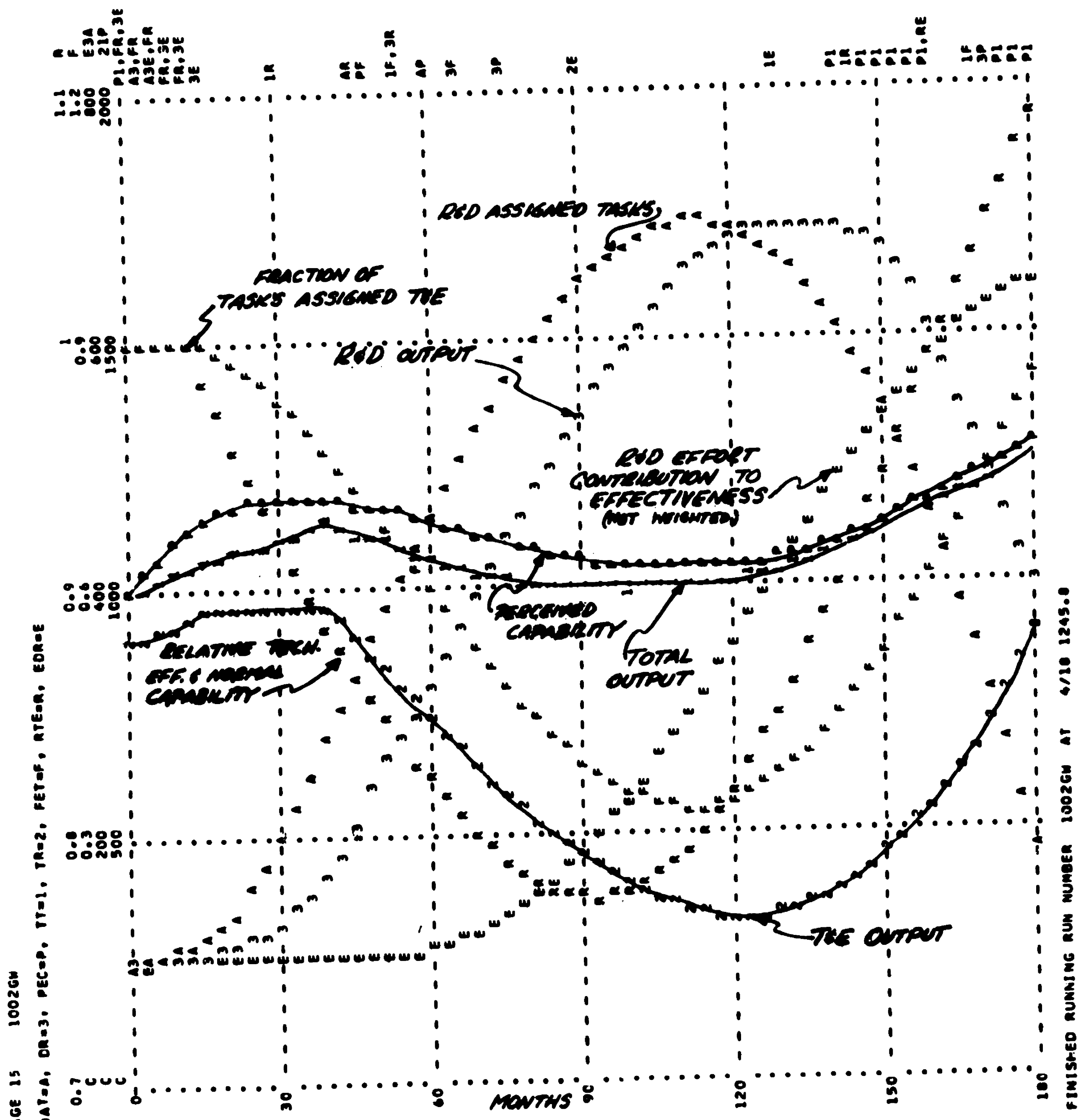


FIGURE 13

RESPONSE FOR RELATIONSHIP A, ACTIVITY
OVERLOADED AND PROPORTION OF ASSIGNED

to increase, but the declining relative technical effectiveness is not arrested until nearly 48 months after the mix is achieved. In other words, even though the required shift is accomplished in a little over two years, the modeled organization requires over six years to overtake the rate of change of the needed technology. To overtake the needed technology requires in excess of eleven years. The cause for the long delay is partially the response of the assignment shift to the customer's indicated declining quality of the T&E product (ISFQ) and the response of the reallocation process; however the total delay chargeable to these two areas is a little over two years (18 months for the proportions of the assignments to change and approximately 15 months for reallocation). The balance of time required is the delay "built-in" to the contributions to organizational effectiveness from activity effort. Peak contribution to effectiveness is assumed to be 24 months and 48 months for T&E and R&D efforts respectively. The longer peak delay of 48 months prevails, for the recovery is not accomplished until the R&D effort contribution to effectiveness is obtained.

The four year delay for peak contribution to effectiveness from present R&D effort does not by itself seem long; therefore no other values for the delay were investigated. The ratio of R&D to T&E contribution to effectiveness was investigated. When changed from five to ten, in the relationship just discussed, the time to overtake the rate of change of NTE was still over five years. Relationships where recovery is attempted through a shift of the proportion of the T&E and R&D tasks are confronted in the model with a four year delay regardless of how fast the required assignments are shifted or how rapidly the reallocations are accomplished.

Attempts to effect a recovery from within are shown in Table II, cases two and three. Both attempts are unsuccessful. However, another facet of the characteristic portrayed by Figure 13 is revealed. Both relationships improve the sensitivity of the activity reallocation preference to R&D effort and the relationship shown in Table II, case three, includes a greatly increased propensity to generated R&D effort. Comparison of Table II with Table I reveals the increased R&D effort of the relationship given in Table II, case three, over the R&D effort of the equivalent case shown by Table I. After five years the R&D efforts are 130 man-months per month to 90 man-months per month, nearly a 50 per cent increase; however, the total efforts are 760 man-months per month and 715 man-months per month respectively, less than a 7 per cent increase.

With reference to the initial activity effort levels, 900 and 100 man-months per month for T&E effort and R&D effort respectively, the five year position of the relationship presented in Table II, case three, is 630 man-month per month for T&E effort and 130 man-months per month for R&D effort. For each R&D unit of effort gained the activity has decreased the T&E effort by nine units. The relative contribution to effectiveness from R&D effort and T&E effort is only five to one! Relationships where recovery is attempted from within by generating R&D tasks are confronted with the consequences of not maintaining an appropriate level of total effort, in addition to the four year delay to contributions to effectiveness from changes to present effort.

The reallocation system was intended to provide a significant variable to the modeled organization. It does not. The reallocation preference effects a delay on allocation pressures and the allocation pressures are determined by the mix implied by the task assignments. Short of providing a no reallocation response to a given area of allocation pressure, the modeled reallocation preference can only vary the time at which an actual reallocation of effort is accomplished. The reallocation delay, as previously discussed, is quite small compared to the contributions to effectiveness delay; therefore, any transient effects accomplished by delaying the mix of effort implied by the task assignments are insignificant. The fourth case in Table I and case three in Table II represent the extremes of the reallocation preferences that are investigated.

Conclusions

Only the agency, for the modeled organization, has the means, the task assignment mix, to respond to an increasing needed technology. However, the agency is confronted with delays that are not anticipated by the modeled organization: the feedback delay in quality information from the customer; the reallocation delay of the activity; and the delay to contributions to effectiveness from changes to present effort. As a consequence, the remedial action is late and the recovery, if any, is slow. Furthermore, for the relationship presented by

Figure 13, as the effectiveness of the activity improves and actually exceeds the needed technology, the agency continues to treat an erstwhile patient.

In the relationships where the agency maintains a constant proportion of task assignments no recovery is accomplished. The immediate effects of the increasing needed technology as reflected in the relative technical effectiveness is to reduce the total task assignments made by the agency. Whether the agency is underestimating (Figure 12) or overestimating (Figure 11) the capability of the activity at the time, the downhill trend is set.

The activity is provided with an implicit decision rule, generated tasks, that slows down slightly the deteriorating effect of the increasing needed technology. However, an appreciable quantity of generated R&D tasks occur only when the agency grossly underestimates the normal capability of the activity. When the agency underestimates the normal capability, the total output of the activity deteriorates more rapidly than the generated tasks can overcome. Furthermore the activity's reallocation preferences are shown to only delay the mix of tasks and do not modify, for any significant time, the mix of tasks implied by the assignments. For the modeled organization, therefore, the activity, by itself, can not accomplish a recovery when confronted by an increasing needed technology.

The modeled organization, with the constraint of fixed numerical resources and provided with primarily implicit decision rules, cannot cope with an increasing needed technology. The modeled organization, more than less, conducts the business by "the seat of its pants," and the results bear out the folly of this technique. No provisions, other than the change of the mix of task assignments by the agency, are provided to coordinate the total effort of the modeled organization with respect to the problems generated by the deteriorating relative technical effectiveness of the activity.

At the outset of the study, one of the objectives was to develop explicit decision-oriented rules and/or policies as might be indicated from the study of the modeled organization. While this objective was not accomplished, it is concluded that a continuation of the present study utilizing Industrial Dynamics and coupled with a research of the theories of organizational behavior would be fruitful.

Explicit decision rules and/or policies are required to replace the arbitrary decisions rules that seem to control the behavior of the model organization. These decision rules should be coupled with some estimate of the anticipated needed technology and the time delay indicated to accomplish an increased effectiveness. A more realistic measure of customer satisfaction and need is suggested. Lastly, it appears that it will be necessary to include possible interactions with other field activities that are controlled by the agency. Possible interactions are task assignments, contributions to effectiveness, and sharing of resources.

The conclusions are summarized as follows:

1. When an increased technology is needed to accomplish the primary T&E tasks, the mix of tasks assigned to

a field activity must be shifted to provide for an increased R&D effort in order to maintain a satisfactory organizational technical effectiveness. With resources fixed, both quality and quantity cannot be maintained at the initial level. Insistence on maintaining an initial quantity of T&E output results in a decrease in the quality of the T&E product.

2. The assigned tasks from the agency provide the dominant determinant to the future position of the activity, and the greatest total output is maintained when the agency overestimates the capability of the organization and "overloads" the activity with assigned tasks. When the agency "underloads" the activity, the activity's propensity to generate tasks is not sufficient to fully utilize the work load slack provided by the underload. The result is that no organizational recovery to the impact of the changing needed technology can be accomplished from within the activity.

3. To accomplish a better shift of the proportions of R&D and T&E tasks to effect an organization recovery, an estimate, by the organization, of the level of the required technology appears to be needed; and closer cooperation between the agency, activity, and the

customer concerning the needs and allocation of resources is suggested.

The recommendations for further investigation utilizing Industrial Dynamics and a research of organizational behavior theory are summarized as follows:

1. development of more explicit decision-oriented rules and/or policies for the behavior of the relationship;
2. development of a more realistic measure of customer satisfaction which in turn is more strongly coupled into the tasks assignments and resource allocation process;
3. expansion of the agency-single activity into an agency-multi-activity relationship which will include contributions to effectiveness through technical interchange between the different activities.

TABLE IV

GLOSSARY OF SYMBOLS

The following definitions are repeated to aid the interpretation of the Tables and Figures:

RTE	Relative Technical Effectiveness
SFQ	Satisfaction from Quality
STF	Satisfaction from Timeliness
TT	Total Output, (man-months/month)
TR	T&E output, (man-months/month)
CE	Contractor Effort, (man-months/month)
TP	Organizational Pressure
NEC	Normal Engineering Capability, (man-months/month)
BT	Backlog, T&E tasks, (man-months)
BD	Backlog, R&D tasks, (man-months)
DTP	Delay T&E product, (years)
TPEC	Time to perceive Engineering Capability, (months)
TDRTE	Time to perceive Relative Technical Effectiveness, (months)
EBEC	Error Bias in estimating Engineering Capability

APPENDIX A

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
School of Industrial Management
SLOAN Cambridge 39, Massachusetts

Executive Development Program

In Reply Write To

George R. Wachold
11 Hunt Road
Lexington 73, Massachusetts

Dear Sir,

My name is George R. Wachold. I am an employee of the U. S. Navy, Bureau of Naval Weapons, Naval Missile Center, Pt. Mugu, California. I am currently attending MIT for one year, and as part of my program I am conducting an investigation on "The Technical Effectiveness of Government RDT&E Organizations." As part of the research for the study, I am hopeful to obtain some general comments from the individuals in charge of the respective Bureau of Weapons technical field activities.

Attached is a questionnaire which identifies the type of questions I believe to be pertinent; however, the list is not intended to be all inclusive and any additional points or comments will be welcomed. Each question could entail considerable effort to answer; however it is not my intent to obtain analytical, detailed answers. I have included sample answers of the length and content that I believe will be meaningful.

I would like your answers by 22 February 1963; however it will be possible to include the information in the study if I receive your response by 10 March 1963. All answers will be treated in confidence and strict anonymity will be maintained in the analysis.

THIS CORRESPONDENCE IS A PART OF THE RESEARCH WORK BEING DONE FOR A MASTER'S THESIS

1. WHAT DO YOU CONSIDER TO BE YOUR ACTIVITY'S PRIMARY MISSION?
"We are responsible for the conduct of basic research in solid and nuclear rocket propulsion."

2. WHO DETERMINES AND ASSIGNS PROJECTS TO YOUR ACTIVITY?
"The Ass't Chief for RDT&E/the respective project officers under the Ass't Chief."

3. HOW DO YOU ASSIGN YOUR WORK?
"We use a priority system and we work on the top priority work first."

4. WHO DO YOU THINK APPRAISES THE TECHNICAL EFFECTIVENESS OF YOUR ACTIVITY?
"The Ass't Chief for RDT&E."

5. HOW DO YOU THINK THE APPRAISAL IN QUESTION #4 IS MADE?
"By comparison with accomplishments of established deadlines and customer (fleet) satisfaction."

6. HOW DO YOU DETERMINE THE TECHNICAL PROGRESS OF WORK WITHIN YOUR ACTIVITY?
"Monthly progress reports from departments from which the staff compares effort with progress and scheduled milestones."

7. HOW DO YOU DETERMINE HOW MUCH EFFORT TO PUT ON A GIVEN TASK?
"We obtain estimates from project engineers, then at the Command level adjust the estimates to be compatible with the overall work load."

8. HOW DO YOU ESTIMATE YOUR ACTIVITY'S TECHNICAL EFFECTIVENESS?
"By subjective comparison with technical contemporaries and by the number of technical papers by our personnel that are published."

9. HOW DO YOU DEVELOP AND MAINTAIN YOUR ACTIVITY'S TECHNICAL EFFECTIVENESS?
"Rotation of technical personnel, private consultants, college recruiting, and in-house tasks directed to improving our knowledge and techniques."

10. HOW DO YOU APPORTION YOUR ACTIVITY'S EFFORT BETWEEN ASSIGNED TASKS AND IN-HOUSE TASKS?
"We direct approximately 10%, including Foundational Research, of our total effort to tasks other than assigned tasks."

11. HOW DO YOU DETERMINE WHEN? AND HOW MUCH? TO REAPPORTION EFFORT?
"When in the judgement of the department heads we are behind schedule on a priority task and additional manpower appears to be the proper action, I will shift effort to the priority task."

12. HOW FREQUENTLY, AND WITH WHOM, DO YOU REVIEW YOUR EFFORT DISTRIBUTION?
"Generally monthly, with departments and selected project engineers."

13. HOW DOES THE BUREAU NORMALLY AFFECT PRESSURE ON YOU AND HOW RESPONSIVE ARE YOU TO THE BUREAU PRESSURE?
"Bureau project officers continually monitor their respective programs and remind us when we are behind schedule; if we agree with the appraisal we take corrective action."

14. DO YOU FEEL THAT THE BUREAU TENDS TO OVER OR UNDER ESTIMATE YOUR ACTIVITY'S TECHNICAL EFFECTIVENESS?
"Over estimate; we are assigned more work than we can accomplish within the prescribed time limits."

15. HOW DO YOUR DEPARTMENT HEADS AFFECT PRESSURE ON YOU AND HOW RESPONSIVE TO THIS INTERNAL PRESSURE ARE YOU?
"By continually reminding me, verbally & memorandum, how understaffed they each are and how important their assigned work is; I utilize staff analysis, Bureau confirmation, and attempt to respond where and when my judgement indicates."

Technical effectiveness is defined to be: "The ability/capability to accomplish the technical problems that are assigned, or that occur, within the estimated timeliness of the need, to a degree sufficient to satisfy the estimate of the need."

Thank you for your very valuable time and important help to this study. If you would like to have a composite analysis of the answers received from the questionnaire, I will be pleased to provide a copy to you. YES NO

APPENDIX B

THE MODEL IN DYNAMO EQUATIONS

Introduction

The equations in Chapter III that were expressed as follows:

TP.K = F(TRNC) (equation 42A)

are written in DYNAMO as:

TP.K = TABLE (TTP,TRNC.K,0,2,0.25)

which states that the organizational pressure is equal to a tabled quantity, TTP, that is a function of the ratio of total output to normal capability, TRNC. The tabled quantities are presented for values of TRNC from 0 to 2 at intervals of .25, and are given by the following equation form:

C TTP* = .0/.4/.4/.8/1.0/1.1/1.3/1.6/3.0

The DYNAMO program makes a linear interpolation for values that fall between the tabled values.

Tabled Functions

The following tabled functions are used in the model:

1. Fraction of effort desired in T&E, FET, (equation 3A)

   FET.K = TABLE (TFET,ISFQ.K,0,1,0.25)

   TFET* = .9/.9/.9/.9/.9 (when constant)

   TFET* = .7/.8/.9/.9/.9 (variable, Table I)

   TFET* = .1/.2/.9/.9/.9 (variable, Table II)

2. Indicated satisfaction from quality, ISFQ, (equation 5A)

   ISFP.K = TABLE (TISFQ,DRTE.K,0,2,0.5)

   TISFQ* = 0.0/0/.5/.9/.92

3. Agency T&E allocation pressure, TAPX, (equation 23A)

TAPX.K = TABLE(TTAPX,TRDAX.K,0,2,0.25)

TTAPX* = .2/.4/.7/.9/1/1.3/1.7/2/2.5

4. Agency R&D allocation pressure, DAPX, (equation 26A)

DAPX.K = TABLE(TDAPX,DRDAX.K,0,2,0.25)

TDAPX* = 0/.5/.7/.9/1.2/1/1.4/1.7/2

5. R&D generated tasks fractional change, FDTG, (equation 29A)

FDTG.K = TABLE(TFDTG,TP.K,0,2,0.25)

TFDTG* = .9/.7/.5/.2/.01/.002/0/0/0 (normal propensity)

TFDTG* = .9/.7/.6/.5/.01/0/0/0/0 (high propensity)

6. T&E generated tasks fractional change, FTTG, (equation 30A)

FTTG.K = TABLE(TFTTG,RTE.K,0,1.5,0.25)

TFTTG* = .3/.2/.1/.03/0/0/0

7. Activity T&E allocation pressure, TAPI, (equation 50A)

TAPI.K = TABLE(TTAPI,TRDAI.K,0,2,0.25)

TTAPI* = 0/.5/.7/.9/1/1.2/1.4/1.7/2

8. Activity R&D allocation pressure, DAPI, (equation 53A)

DAPI.K = TABLE(TDAPI,DRDAI.K,0,2,0.25)

TDAPI* = 0/.5/.7/.9/1/1.2/1.4/1.7/2

9. Activity reallocation preferences, DFI, TFI, TFX, DFX, (equations 58A through 61A)

DFI.K = TABLE(TDFI,DPRI.K,0.7,1.3,.05)

TFI.K = TABLE(TTFI,TPRI.K,0.7,1.3,.05)

TFX.K = TABLE(TTFX,TPRX.K,0.7,1.3,.05)

DFX.K = TABLE(TDFX,DPRX.K,0.7,1.3,.05)

Tabled values for relationship A:

TDFI* = -.18/-.09/-.03/0/.02/.07/.14

TTFI* = -.18/-.09/-.03/0/.02/.07/.14

TTFX* = -.27/-.1/0/0/.2/.35/.4

TDFX* = -.32/-.28/-.28/0/0/.02/.08

Tabled values for relationship B:

TDFI* = -.07/-.02/0/0/.25/.25/.25

TTFI* = -.07/-.02/0/0/.18/.29/.35

TTFX* = -.27/-.1/0/0/.2/.35/.4

TDFX* = -.32/-.28/-.08/0/0/.02/.08

Tabled values for "severe" counter T&E preference:

TDFI* = -.06/-.02/0/0/.3/.3/.3

TTFI* = -.35/-.2/-.15/0/.13/.2/.3

TTFX* = -.55/-.4/-.25/0/.07/.4/.4

TDFX* = -.06/-.02/0/0/.3/.3/.3

10. Total organizational pressure, TP, (equation 64A)

(See introduction this Appendix.)

11. Contractor fractional change rate, CFC, (equation 73A)

CFC.K = TABLE(TCFC,TP.K,0,2,0.25)

TCFC* = -.4/-.3/-.2/-.05/0/.03/.05/.15/.25

12. Satisfaction from quality, SFQ, (equation 90A)

SFQ.K = TABLE(TSFQ,DRTE.K,0,2,0.5)

TSFQ* = 0/0/.75/.95/1

13. Satisfaction from timeliness, SFT, (equation 91A)

SFT.K = TABLE(TSFT,DTP.K,-1,3,0.5)

TSFT* = .9/.95/1/.6/.3/.25/.05/0/0

```
*       M2547-2097,DYN,TEST,1,1,0,0              TECH. EFF. MODEL

SPEC    DT=0.25/LENGTH=180/PRTPER=6/PLTPER=3
        TECHNICAL EFFECTIVENESS MODEL - G. R. WACHOLD
                      AGENCY SECTOR
                  AGENCY TASK ASSIGNMENTS
12R     TAT.KL=(FET.K)(PEC.K)                     TASK ASSIGN RATE T+E       1
12R     DAT.KL=(FED.K)(PEC.K)                     TASK ASSIGN RATE R+D       2
59A     FET.K=TABLE(TFET,ISFQ.K,0,1,0.25)         FRACT EFFORT T+E           3
7A      FED.K=1-FET.K                             FRACT EFFORT R+D           4
C       TFET*=.9/.9/.9/.9/.9
                INDICATED SATISFACTI ON FROM QUALITY
58A     ISFQ.K=TABHL(TISFQ,DRTE.K,0,2,0.5)    IND SATISF FROM QUALITY        5
3L      DRTE.K=DRTE.J+(DT)(1/TDRTE)(RTE.J-DRTE.J)   DELAYED TECH EFF         6
6N      DRTE=RTE          INITIAL DELAYED EFF
C       TISFQ*=0.0/0.0/.50/.90/.92
C       TDRTE=24                     TIME DELAY TECHNICAL EFF
        PERCEIVED CAPABILITY
3L      PEC.K=PEC.J+(DT)(1/TPEC)(BEC.J-PEC.J)   PERC. ENG. OUTPUT CAP.       7
12A     BEC.K=(EBEC)(NEC.K)                       BIASED OTPUT CAPABILITY    8
        INITIAL CONDITIONS AND CONSTANTS
6N      PEC=BEC                      INITIAL PERC. ENG. OUTPUT
6N      BEC=NEC                      INITIAL BIASED PERC ENG EFFORT
C       TPEC=24           TIME TO PERC OUTPUT CAP
C       EBEC=1.3
        AGENCY CONTRACTOR CONTROL
54A     CES.K=MIN(CEL.K,MACE.K)                   CONT EFFORT SUPPORTED      9
56A     CEL.K=MAX(CEI.K,0)                        CONT SUPP LIMIT            10
10A     CEI.K=DTRX.K+DDRX.K-PTR.K-PDR.K-PCED.K-PCET.K  CONT SUPP IND         11
12A     MACE.K=(FSC)(PEC.K)                       MAX ALLOWABLE CONT EFFORT  12
C       FSC=.1                       FRACTIONAL SUPPORT CONTRACTOR
                   PERCEIVED OUTPUT, AGENCY
52L     BTP.K=BTP.J+(DT)(TAT.JK+PTGT.JK-PTR.J-PCET.J)   T+E BLOG PERC        13
39R     PTGT.KL=DELAY3(TGT.JK,DPTGT)             PERC GEN T+E TASKS          14
3L      PCET.K=PCET.J+(DT)(1/TPCET)(CET.J-PCET.J)    PERC CONT OP T+E        15
3L      PTR.K=PTR.J+(DT)(1/TPTR)(TR.J-PTR.J)  PERC T+E OUTPUT                16
52L     BDP.K=BDP.J+(DT)(DAT.JK+PDGT.JK-PDR.J-PCED.J)    R+D BACK L PER      17
39R     PDGT.KL=DELAY3(DGT.JK,DPDGT)             PERC GEN R+D TASKS          18
3L      PCED.K=PCED.J+(DT)(1/TPCED)(CED.J-PCED.J)  PERC CONTR OP R+D         19
3L      PDR.K=PDR.J+(DT)(1/TPDR)(DR.J-PDR.J)   PERC R+D OUTPUT               20
        INITIAL CONDITIONS AND CONSTANTS
6N      BTP=BT                       INITIAL PERC T+E BACKLOG
6N      PTR=TR                       INITIAL PERC T+E OUTPUT
6N      BDP=BD                       INITIAL PERC. R+D BACKLOG
6N      PDR=DR                       INITIAL PER. R+D OUTPUT
6N      PCET=CET                     INITIAL PERC CONTR OP T+E
6N      PCED=CED                     INITIAL PEC CONR OP R+D
C       DPDGT=12
C       DPTG[illegible]5
C       TPTR=3
C       TPDR=6
C       TPCED=1
C       TPCET=1
                   AGENCY ALLOCATION PRESSURE
20A     DTRX.K=BTP.K/NBT              DESIRED T+E OUTPUT EXT.                21
20A     TRDAX.K=DTRX.K/PTR.K          T+E OUTPUT DESIRED TO ACT. EXT.        22
58A     TAPX.K=TABHL(TTAPX,TRDAX.K,0,2,0.25)     T+E ALLOCATION PRESS,EXT    23
20A     DDRX.K=BDP.K/NBD            DESIRED R+D OUTPUT EXT.                  24
```

```
20A   DRDAX.K=DCRX.K/PDR.K          R+D OUTPUT DESIRED TO ACT. EXT.          25
58A   DAPX.K=TABHL(TDAPX,DRDAX.K,0,2,0.25)  R+D ALLOCATION PRESSURE,EXTE26
C     TTAPX*=0.2/.4/.7/.9/1/1.3/1.7/2.0/2.5
C     TDAPX*=0.0/.5/.7/.9/1/1.2/1.4/1.7/2.0
                    ACTIVITY SECTOR
                 ACTIVITY GENERATED TASKS
12R   DGT.KL=(TT.K)(FDTG.K)                 R+C GENERATED TASKS RATE        27
12R   TGT.KL=(TR.K)(FTTG.K)                 T+E GENERATED TASKS             28
58A   FDTG.K=TABHL(TFDTG,TP.K,0,2,0.25)    R+C FRACTIONAL CHANGE           29
59A   FTTG.K=TABLE(TFTTG,RTE.K,0,1.5,0.25)  FRACT CHANGET+E GEN TASKS      30
C     TFTTG*=0.30/.20/.10/.03/0/0/0
C     TFDTG*=.90/.70/.50/.20/.01/.002/0/0/0
                 ACTIVITY OUTPUT
52L   BD.K=BD.J+(DT)(DAT.JK+CGT.JK-CR.J-CED.J)      R+D BACKLOG            31
52L   BT.K=BT.J+(DT)(TAT.JK+TGT.JK-TR.J-CET.J)       T+E BACKLOG           32
1L    TE.K=TE.J+(DT)(TC.JK+O)               T+E EFFORT                      33
1L    DE.K=DE.J+(DT)(DC.JK+O)               R+C EFFORT                      34
56R   TC.KL=MAX(TCI.K,-TCRL)       T+E CHANGE RATE ACTUAL                   35
12A   TCD.K=(TR.K)(TFT.K)          T+E CHANGE RATE DESIRED                  36
54A   TCI.K=MIN(TCD.K,TCRL)        T+E CHANGE RATE LIMIT                    37
54A   DCI.K=MIN(DCD.K,CCRL)       R+D CHANGE RATE LIMIT                     38
12A   DCD.K=(DR.K)(DFT.K)         R+D CHANGE RATE DESIRED                   39
56R   DC.KL=MAX(DCI.K,-CCRL)       R+C CHANGE RATE ACTUAL                   40
7A    TOE.K=TE.K+DE.K                       TOTAL TECHNUCAL EFFORT          41
7A    TR.K=TE.K-EDCET.K                     T+E OUTPUT                      42
7A    DR.K=DE.K-EDCED.K                     R+C OUTPUT                      43
12A   EDCET.K=(PCERD)(CET.K)       EFF REQ TO DIR CONT EFF T+E              44
12A   EDCED.K=(PCERD)(CED.K)       EFF REQ TO DIR CONT EFF R+D              45
7A    TT.K=TR.K+DR.K               TECHNICAL OUTPUT TOTAL                   46
      INITIAL CONDITIONS AND CONSTANTS
12N   BT=(TR)(NBT)                 INITIAL T+E BACKLOG
12N   BD=(DR)(NBD)                 INITIAL R+D BACKLOG
12N   DI=(FED)(1000)               INITIAL R+D OUTPUT
7N    TI=1000-DI                   INITIAL T+E OUTPUT
6N    DE=DI                        INITIAL R+D EFFORT
6N    TR=TI
6N    DR=DI
6N    TE=TI                        INITIAL T+E EFFORT
C     NBD=18                       NORMAL R+C BACKLCG
C     NBT=12                       NORMAL T+E BACKLCG
C     TCRL=20                     T+E CHANGE RATE LIMIT
C     DCRL=10                      R+D CHANGE RATE LIMIT
C     PCERD=.05                    PER CF CONTR OUTPUT REQ TO DIR
                 ACTIVITY ALLOCATION PRESSURE
20A   DTR.K=BT.K/NBT               DESIRED T+E CUTPUT                       48
20A   TRDAI.K=DTR.K/TR.K           T+E OUTPUT RATIO DESIRED TO ACTUAL,INT.  49
58A   TAPI.K=TABHL(TTAPI,TRDAI.K,0,2,0.25)    T+E ALLOCATIE5 P9E2S,I5T.     50
20A   DDR.K=BD.K/NBD               DESIRED R.D CUTPUT                       51
20A   DRDAI.K=DCR.K/CR.K           R+D OUTPUT DESIRED TO ACTUAL,INTERNAL    52
58A   DAPI.K=TABHL(TCAPI,DRDAI.K,0,2,0.25)    R+C ALLOCATION PRESS.,INT     53
20A   TPRI.K=TAPI.K/TP.K           T+E ALLOCATION PRESS. RATIO,INTERNAL     54
20A   DPRI.K=DAPI.K/TP.K           R+D ALLOCATICN PRESS. RATIO, INTERNAL    55
20A   TPRX.K=TAPX.K/TP.K           T+E ALLOCATICN PRESS RATIO,EXTERNAL      56
20A   DPRX.K=DAPX.K/TP.K           R+D ALLOCATION PRESS. RATIO,EXTERNAL     57
              REALLOCATICN PRESSURE SYSTEM
58A   DFI.K=TABHL(TDFI,DPRI.K,0.7,1.3,0.1)        R+D FRAC CHANGE INT       58
58A   TFI.K=TABHL(TTFI,TPRI.K,0.7,1.3,0.1)        T+E FRAC CHANGE INT       59
58A   TFX.K=TABHL(TTFX,TPRX.K,0.7,1.3,0.1)          T+E FRAC CHANGE EXT     60
```

```
58A   DFX.K=TABHL(TDFX,DPRX.K,0.7,1.3,0.1)   R+D FRAC CHANGE, EXT          61
7A    DFT.K=DFI.K+DFX.K              R+D FRAC. CHANGE,TOTAL                62
7A    TFT.K=TFI.K+TFX.K              T+E FRAC. CHANGE TOTAL                63
                    ACTIVITY ORGANIZATIONAL PRESSURE
59A   TP.K=TABLE(TTP,TRNC.K,0,2,0.25)  TECHNICAL PRESSURE,TOTAL            64
20A   TRNC.K=TT.K/NEC.K                       OUTPUT RATIO ACTUAL TO NORM  65
12A   NEC.K=(EE.K)(RTE.K)                    NORM EFFORT CAP               66
6A    EE.K=EEI                       ENGINEERING EMPLOYMENT RATE           67
      INITIAL CONDITIONS AND CONSTANTS
21N   EEI=(1/RTE)(TI+DI)             INITIAL ENG. EMPLOY. RATE
C     TTAPI*=0.0/.5/.7/.9/1/1.2/1.4/1.7/2.0
C     TDAPI*=0.0/.5/.7/.9/1/1.2/1.4/1.7/2.0
                    ACTIVITY REALLOCATION PREFERENCE      8
C     TDFI*=-0.07/-.02/0/0/.25/.25/.25
C     TTFI*=-0.07/-.02/0/0/.18/.29/.35
C     TDFX*=-0.32/-.28/-.08/0/0/.02/.08
C     TTFX*=-0.27/-.10/0/0/.20/.35/.40
C     TTP*=0.0/.4/.5/.8/1.0/1.1/1.3/1.6/3.0
      CONTRACTOR OUTPUT
1L    CE.K=CE.J+(DT)(CC.JK+ACC.JK)          CONTRACTOR OUTPUT              68
39R   CC.KL=DELAY3(CCL.K,DAC)          CONTR CHANGE RATE                   69
56A   CCL.K=MAX(CCU.K,-CE.K)                CONTR CHANGE LIMIT             70
51A   CCU.K=CLIP(0,CCI.K,CE.K,CES.K)        CONT CHANGE UPPER LIMIT        71
12A   CCI.K=(TT.K)(CFC.K)          CONTR CHANGE RATE IMPEND                72
59A   CFC.K=TABLE(TCFC,TP.K,0,2,0.25)       CONTR FRACT CHANGE             73
51R   ACC.KL=CLIP(0,DAA.K,DAA.K,0)          AGENCY CONT CHANGE RATE        74
7A    DAA.K=CES.K-CE.K                      DIFF ALLOW AND ACTUAL CE       75
12A   CET.K=(FECT)(CE.K)                    CONT EFFORT T+E                76
12A   CED.K=(FECD)(CE.K)                    CONT EFFORT R+D                77
      INITIAL CONDITIONS AND CONSTANTS
6N    CE=0                           INITIAL CONTR EFFORT
7N    FECD=1-FECT                           FRACT CON EFFORT TO R+D
C     FECT=.9                        FRACT EFFORT T+E
C     TCFC*=-.40/-.30/-.20/-.05/0/.03/.05/.15/.25
C     DAC=6                          DELAY ACCUIR CONTRACTOR
                    TECHNICAL EFFECTIVENESS SECTOR
20A   RTE.K=TTE.K/NTE.K              RELATIVE TECH. EFFECTIVENESS          78
                 TOTAL ACTIVTY TECHNICAL EFFECTIVENESS
1L    TTE.K=TTE.J+(DT)(RTTE.JK-RTO.JK)     TOTAL TECH. EFFECTIVENESS       79
47A   NTE.K=RAMP(RNTE,TBI)           NEEDED TECH. EFF                      80
16A   RTTE.K=(PFT)(ETR.JK)+(PFD)(EDR.JK)+(PFC)(ECE.JK)+(0)(0)  RATE TE     81
20R   RTO.KL=TTE.K/DTO               RATE OF TECHNICAL OBSUL.              82
20R   ETR.KL=LETR2.K/DETR1                                                 83
1L    LETR2.K=LETR2.J+(DT)(ETR1.JK-ETR.JK)                                 84
20R   ETR1.KL=LETR1.K/DETR1                                                85
1L    LETR1.K=LETR1.J+(DT)(TR.J-ETR1.JK)                                   86
39R   EDR.KL=DELAY3(EDR1.JK,DEDR1)                                         87
39R   EDR1.KL=DELAY3(DR.K,DEDR1)                                           88
39R   ECE.KL=DELAY3(CE.K,DECE)      EFFECTIVE CONTR EFFORT                 89
      INITIAL CONDITIONS AND CONSTANTS
12N   TTE=(RTTE)(DTO)                INITIAL ENG EFFECTIVENESS
20N   NTE=TTE/RTE                    INITIAL NEED TECH EFF
12N   RNTE=(FCCE)(RTTE)              RATE OF CHANGE OF NEEDED TECH. EFF.
6N    RTE=1.0                        INITIAL REL TECH EFF
C     TBI=12                         TIME TO BEGIN INPUT
C     FCCE=.25            FRAC CHANGE OF CHANGE IN EFF
C     DTO=50              DELAY TECH OBSOLESENCE
            EFFECTIVENESS SECTOR CONST AND INITIAL CONDITONS
```

```
      12N     DECE=(1.5)(TPECE)              DELAY IN CONTR EFFORT EFF
      12N     DETR=(2.0)(TPETR)              DELAY IN TOE EFFECTIVE.
      12N     DEDR=(1.2)(TPEDR)              DELAY IN R+D EFFECTIVE.
      20N     DEDR1=DEDR/2.0
      20N     DETR1=DETR/2.0
      12N     LETR1=(TR)(DETR1)
      12N     LETR2=(TR)(DETR1)
      C       TPETR=24                       TIME TO PEAK EFF. T+E
      C       TPEDR=48                       TIME TO PEAK EFF R+D
      C       TPECE=12                       TIME TO PEAK EFF CE
      C       PFT=.01                        PROP.FACTOR T+E
      C       PFD=.05                        PROP. FACTOR R+D
      C       PFC=0.005                      PROP FACTOR CONTRACTOR
                          SATISFACTION SECTOR
      59A     SFQ.K=TABLE(TSFQ,DRTE.K,0,2,0.5)       SATESFAC FROM QUALITY     90
      59A     SFT.K=TABLE(TSFT,DTP.K,-1,3,0.5)     SATISF FROM TIMELINESS      91
      17A     DTP.K=(-1.5)(1)(1)+(TRDAI.K)(1)(1.5)+(C)(0)(0)  DELAY T+E PROD   92
      C       TSFQ*=0.0/0.0/.75/.95/1.0
      C       TSFT*=0.90/.95/1.00/.60/.30/.25/.05/0/C
      44S     TET.K=(TE.K)(1000)/TOE.K               ENG ASSIGNED T+E
      44S     TER.K=(DE.K)(1000)/TOE.K               ENG ASSIGNED R+D
      PLOT    DAT=A,DR=3/PEC=P,TT=1,TR=2/FET=F/RTE=R/EDR=E
      PRINT   1)DRDAI,DAPI,DPRI,DFI/2)DRDAX,DAPX,DPRX,DFX/3)TRDAI,TAPI,TPRI,TFI
      PRINT   4)TRDAX,TAPX,TPRX,TFX/5)DR,TR,TT,TP/6)BTP,BT,BDP,BD
      PRINT   7)NTE,TTE,RTE,DRTE/8)PEC,NEC,TAT,DAT/9)ETR,EDR,RTTE,TRNC
      PRINT   10)TFT,TC,DFT,DC/11)PDR,PTR,DGT,TGT/12)CED,CET,FET
      PRINT   13)SFQ,SFT,ISFQ,DTP/14)TE,DE,TET,TER
```

APPENDIX C

REFERENCES

a. Forrester, Jay W., "Industrial Dynamics" (The M.I.T. Press, Cambridge, Mass. and John Wiley & Sons, Inc., New York, 1961).

b. _______. "Thoughts on Forces Inducing Corporate Growth," Internal Memorandum D-487, Industrial Dynamics Research Group, School of Industrial Management, Massachusetts Institute of Technology, October 4, 1962.

c. Roberts, Edward B., "Toward a New Theory for Research and Development," Industrial Management Review, School of Industrial Management, Massachusetts Institute of Technology, Fall 1962.

d. Lett, Philip W., "An Industrial Dynamics Analysis of a Defense Product Development Organization" (unpublished Thesis, School of Industrial Management, Massachusetts Institute of Technology, June 1961).

e. Forrester, Jay W., "Economic Development Equations--Goods Allocation Pressure--Tentative Working Paper," Internal Memorandum D-381, Industrial Dynamics Research Group, School of Industrial Management, Massachusetts Institute of Technology, March 15, 1962.

f. Roberts, Edward B., "Model of a Research and Development Organization," Internal Memorandum D-511, Industrial Dynamics Research Group, School of Industrial Management, Massachusetts Institute of Technology, October 23, 1962.

g. _______. "A Dynamic Model of a Research and Development Organization" (unpublished Doctor's Dissertation, Massachusetts Institute of Technology, June 1962).

h. Pugh, Alexander L., III, "DYNAMO User's Manual" (The M.I.T. Press, Cambridge, Mass. 1961).