A DYNAMIC MODEL STUDY OF A MILITARY PRODUCT DEVELOPMENT ORGANIZATION

by

Donald Curtis Beaumariage

B.E.E., Cornell University
(1946)

M.S. in E.E., Carnegie Institute of Technology
(1948)

D.Sc., Carnegie Institute of Technology
(1950)

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Signature of Author..
School of Industrial Management

Certified by...
Faculty Advisor of the Thesis

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April 28, 1960

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Sincerely yours,

Richard B. Maffei
Thesis Supervisor
School of Industrial Management

RBM:LB

May 6,1960

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 "A Dynamic Model Study of a Military Product Development Organization".

I would like to acknowledge the assistance and guidance provided by the members of the staff of the School of Industrial Management. The advice of Professors Jay W. Forrester and Richard B. Maffei was appreciated during the development of the thesis.

The staff of the Industrial Dynamics Research group provided valuable guidance and assistance during the development of the model. In particular, appreciative thanks are due A.J. Pugh, E.B. Roberts, and D.J. Howard. Model simulation was made possible through the use of the I.B.M. 704 computer at the Massachusetts Institute of Technology Computation Center and the assistance of the staff there is appreciated.

I should also like to express appreciation to the members of the Missile Electronics and Controls Division of the Radio Corporation of America, Burlington, Massachusetts for their aid.

I should finally like to acknowledge the invaluable assistance, encouragement and support provided by my wife Alma.

Sincerely,

Donald Curtis Beaumariage

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Donald Curtis Beaumariage

Submitted to the School of Industrial Management on May 6, 1960 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

A dynamic model study of a representative organization engaged in the design and development of custom equipment for the military customer is presented. The organization studied consists of six major functional departments - marketing, engineering, manufacturing, engineering-personnel, factory-personnel and financial control. A simplified representation of the customer is used which requests proposals from the organization and awards contracts after evaluating completed proposals. The percentage of proposals submitted which become contracts is made a function of proposal worth. This is a function of the organization's technical competance, work load, and efficiency of man-power utilization.

No attempt has been made in the model studied to include all aspects of detailed departmental functions such as market research and forecasting, project evolution, organizational growth cycles, debt and equity financing, etc. The emphasis rather has been to develop a complete but simple organizational structure of business flow and decision making. This model structure is used to study the interdependence of policy decisions in the functional departments and the basic system dynamics (such as time delays) on such typical criteria as profitability. In this manner an overall management research tool for total system study is provided. This can be made more realistic by subsequent removal of initial simplifying assumptions for more detailed analyses.

The method used in this research is that developed by the Industrial Dynamics Group at the School of Industrial Management, Massachusetts Institute of Technology. The significant flows (and levels) of orders, manpower, money, and information are represented by simple difference equations. The decision criteria governing rates of flow of these quantities are also represented in equation form. Functional relations between inter-department flows and decisions are represented mathematically. The resultant system of equations is expressed in a form suitable for digital computer programming. The response of the system to typical customer inputs is examined using the high speed digital computation facilities of the MIT Computational Center. In essence, this permits examination of many years of the system's operation under a given assumed organizational decision framework in minutes, permitting examination of repeated managerial changes in system policies.

The conclusions with respect to the particular military product development organizational model examined indicate the importance of the interdependence of department policies. The decision concerning utilization of engineering manpower on alternate efforts such as proposals, contract or research work is shown to have an important effect on profit level. The inherent time response of the system is such that decisions based on too short an averaging period can lead to wrong decisions.

With respect to the method itself it can be concluded that a powerful research tool is available to general management. The quantative study of the results of policy changes to assumed customer reaction on a convenient time basis to maximize actual system performance is possible.

Thesis Supervisor:........Jay W. Forrester........................

Title:.................Professor of Industrial Management..........

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CHAPTER I

INTRODUCTION, PURPOSE, AND RESULTS

Introduction

Mathematical models have been used extensively in the investigation of the behavior of various systems in scientific and engineering fields. The application of model studies to the fields of economics and business enterprises has increased markedly in recent years, aided by the availability of large capacity digital computational equipments. The tasks of management in modern business enterprises have required increasing emphasis upon the examination of the interdependence of the major functions in organizations. A systematic investigation of the interactions of the flows of information, work, manpower and capital on the behavior of various industrial firms has been underway at the School of Industrial Management, Massachusetts Institute of Technology by the Industrial Dynamics Group.[1,2,3] This work seeks to provide a quantitative method of analyzing the dynamic behavior of industrial systems using modern digital computational methods to simulate system performances over realistic time periods.

The behavior of a firm engaged in the design, development, and production of equipment for the military customer differs from that of the usual commercial firm most often studied in model form. The military product development organization is essentially a producer of custom equipment for which the usual inventory and distribution problems are considerably modified. The line organization is usually the engineering department and the main commodity to be sold is often engineering effort. Practically all of the work load results from competitive bidding. The delays in proposal evaluation and the criteria of customer acceptability of submitted proposals affect the behavior of the military product development organization greatly. Technical competence resulting from research work sponsored by the government and by

1 Superscripts refer to the publications listed in the List of References

the organization itself is important in its effect upon this acceptability and the overall system performance.

Studies of company growth, research and development management, and military project evolution have recently been published using the Industrial Dynamics method of research.[4,5,6] The operation of a representative organization engaged in military products development has not yet been examined quantitatively. In particular the manner in which the organization responds to changes in customer rates of proposal requests, the effects of delays in recruiting technical personnel and the subsequent decisions concerning utilization of available personnel on the various efforts done in parallel are of interest but have not been examined quantitatively. This thesis extends the Industrial Dynamics method to the study of these problems as discussed in the following paragraphs.

Statement of Thesis Problems and Scope

The purpose of this thesis is to study the operation of a representative business organization engaged in design, development, and manufacturing for the military market using the method of Industrial Dynamics. The overall objective is to develop a mathematical model which can provide management with a research tool to examine in a quantitative manner the interaction of policy decisions in the organization.

The emphasis has been on establishing a complete system description to include those policies and organizational characteristics which are expected to have the greatest influence upon the system's dynamic behavior. Thus, when a given policy can be questioned as to its exact formulation, degree of completeness, or particular quantitative accuracy, the attempt has been to state the assumptions and restrictions carefully but to use only what are considered to the most significant system decisions in formulating that policy. The resultant financial control functions, for example, may seem to be too limited in their formulation since such details as those of debt and equity financing, cash management, standard cost accounting techniques, and the like are totally left out. Such refinements can be added to any of the functions, since the limitations of the method lie not in the programming or actual computational techniques or computer equipment capacity but mainly in the effort which can be expended upon the model formulation by the researcher.

An accurate description of a representative military product development organization is sought, rather than a description of what the best set of policies it is thought should be used. This leads to the construction of a model based on six major functional departments - marketing, engineering, manufacturing, engineering-personnel, factory-personnel, and operations (financial) control. Each is considered as a sector of the complete mathematical model of the organization.

A simplified customer sector is formulated in which a percentage of the total continuing flow of requests for proposals is channeled to the organization under study. The completed proposals of the organization's engineering department are evaluated and contracts are awarded providing the income to the firm.

In addition to the overall objective of developing a total quantitative model for possible use as a management research tool, a more direct purpose exists. This is to use the particular model formed to examine quantitatively the following: the response of the system to changes in customer business requests; the effect on profits of policy changes concerning the relative priority of engineering manpower uses on proposals, contracts or research; the inherent time response of the overall system and its dependence on priority of engineering manpower use; and the relative importance of government or company sponsored research on profit levels.

Research Methods

As stated, the research methods of Industrial Dynamics as developed under the direction of Professor Jay W. Forrester at Massachusetts Institute of Technology are used in this study. This method consists of describing the significant flows (and levels) of orders, manpower, money, and information in the organization and its departments by simple difference equations. Decision criteria governing the rates of flow of these quantities are represented in mathematical form also. These may be expressed as time delays for accomplishing engineering study programs, equations describing policies concerning the procurement of additional personnel in response to increases in work load, or functional relations between quantities represented by graphical or tabular relations. The mathematical expressions describing the day by day operation and policy formation of the organization are written in a form suitable for digital computation. The operation of the system is then simulated using the digital computer facilities of the MIT Computation Center to note the behavior of the flow of business over a number of years.

A complete investigation of this type could occupy a staff of specialists including those of the technical, financial and behavioral sciences for several years and would follow the general pattern outlined below.

1. The nature of the business of the organization is stated and the key elements which govern its behavior noted. In a limited study such as this thesis, this results in essentially a description of the representative organization as it exists. A thorough research program would probe more fundamentally into the purposes of the firm and its motivating drives.

2. The major flows within the organization are noted such as those of manpower, money, equipments, specifications, information on activity levels, etc., and these are described in mathematical form. The formulation of various decision criteria, implicit as well as explicit, is a vital part of this process. Again in this limited study, attention is focused on the flows in the established functional departments, the typical decision criteria employed, and the existing

delays. A fundamental systems management study would not limit itself to existing organizational structures. It would seek out the flows necessary to accomplish the objectives established in step one above.

3. Flow diagrams and complete mathematical formulation of the total model are completed which describe the organization and the business environment in which it operates.
4. The model equations are converted by programmers to the necessary digital computer symbology for computer simulation. Skillful programming at this stage can help systematize the examination of changes in significant constants, time delays, and decision functions.
5. A series of computer runs are made over the range of parameter variations desired by the research team and those interested in the general management of the organization. Different concepts of the customer and competitor evaluations of the organization's behavior can be formulated. Different strategies of counter action by the organization to those assumed concepts can be evaluated under conditions approaching realism. This included runs under varying assumptions of business climates. The use of probalistic functions and prediction methods can be possible and could indicate better control methods for improving the system performance.

Conclusions

The conclusions of a limited study in such a broad management research field fall into two main categories - those concerning the research method itself and those concerning the particular model studied.

With regard to the research method of Industrial Dynamics, it can be concluded that using this method, systems management research is possible on a quantitative basis for the examination of policy interactions in military product development organizations. While the model developed in this thesis is fairly simple and does not include many aspects of the organization's functions, it can easily be expanded. In addition the research studies underway in the Industrial Dynamics Group supplement this study and include aspects of research and development management and project evolution not covered here.

A small staff group could become quite useful to the management of military product development firms by employing the methods discussed in this study. In particular, the interactions of major divisions and corporate staff policy decisions on division and corporate profit levels could be examined prior to changes in policies. The staff group would need to do extensive investigation into existing policies and decision making criteria. They would be required to develop realistic models of the existing system as well as to examine the true nature of the business and its objectives. Such studies combined with concurrent staff studies when employed with model simulation efforts may, for example, indicate more accurately the true results of automating reporting and accounting procedures by electronic data processing means.

For the particular model studied, the computer runs made show that the system response is quite sensitive to delays in proposal evaluation and recruiting engineering personnel. The averaging time used to establish normal backlogs for planning purposes and the time period over which it is desired to adjust to the changing business levels effect the system stability. The effect of engineering efficiency decrease due to the efforts necessary to recruit personnel also has a strong effect on organization growth and reaction to changes in customer solicitation of new business. The decisions concerning priority of engineering manpower utilization for the alternate efforts of proposals, contracts or research work is shown to effect not only the resultant profit level but also the response time of the system.

CHAPTER II

THE MILITARY PRODUCT DEVELOPMENT ORGANIZATION

Nature of the Product and Customer

In any business, the nature of the end products, those for which the customer supplies funds upon delivery, usually has a dominant influence upon the structure of the organization supplying these products. This is particularly true for an organization engaged in study, design, development and manufacturing for the military customer. The end products are often only study reports or a few models of a new device for experimental use. Equipments which are delivered are essentially specially custom engineered products - tailored to meet specified objectives for a given task in some system framework. The obsolescense rate is fairly high, not only for the equipments but for the conclusions of the study reports also.

The usual problems encountered in high volume consumer products of marketing, distribution, and service are not present. In these latter areas, the field of weapon system support and logistics is becoming increasingly important. This is in fact a fertile area for management studies using Industrial Dynamics techniques.

In view of the high technical content, the analytical studies necessary, and the speciality design aspects of the end products, an organization working for the military tends to emphasize the engineering function. This may not prove to be the most advantageous in the long run if other functions are slighted in building the organizational structure.

The trend in military usage of weapons, from black box equipments with installation at areas near the end use location, tosophisticated systems requiring centralized management as well as technical integration during the complete life of the weapon development has become increasingly accelerated. This has been reflected in the changing nature of the organizations which supply the weapons.

Recent changes of the so called "defense market" will also have their effect on the organizations' structures. Thus it is becoming more and more difficult to distinguish "defense markets" from other government markets. At the present time it is uncertain whether "space" activities are essentially a military function or a scientific program under the National Aeronautics and Space Administration. Similarly in the area of warning or detection systems and air traffic control, it is becoming increasingly difficult to distinguish the jurisdiction of Defense Agencies from that of the Federal Aviation Agency.

An additional characteristic of the current defense market is the gradual disappearance of the distinction between Research, Design, Development, Production and Support. The government agencies have historically drawn sharp distinctions between these. Since Korea however, the tendency has been to compress the historical sequential pattern and to accelerate the actual employment of equipments. The corollary characteristics of emphasis on the use of the overall system and earliest availability of operational weaponry explain the increasing consideration given to the support, logistic, and training aspects of the total system.

The emphasis upon the project management type of organization reflects the changes mentioned above and becomes another factor in the line versus staff and function versus project discussions concerning the "best" organization structure of research, development and production for the defense market. This thesis research study does not attempt to include this aspect of the problem but rather uses a representative organizational structure. The structure used has departments within the organization which are functionally oriented - marketing, engineering, manufacturing, financial and both engineering and factory personnel. Various degrees of interdependence are assumed between functions. For example, recruiting for engineers is assumed to be done by the engineering staff and decrease their efficiency in accomplishing other work. The functional departments are discussed in the next section and the additional inter-department dependences.

Studies of the levels of expenditures[10] for the defense market have indicated that there will be no appreciable decrease in the next decade, assuming the world political situation does not change greatly. An increase in spending, reflecting the increasing gross national product and increasing costs of the more sophisticated systems of the future is predicted. Thus for the purpose of the model to be constructed, a continuing flow of requests for proposals with a number of different time variation can be assumed. The request could suddenly increase due to release of appropriation funds or show a steady increasing rate as predicted in the referenced study.[10]

Organizational Structure and Business Flows

The organization under study is assumed to consist of a number of separate departments, each distinguished mainly by the commodity flow over which they exercise dominate functional control. General discussions of these departments and the business flows through them follow. Chapter III discusses in detail the factors determining the levels and rates of flow of the quantities in each department.

The departments in the military product development organization studied in this thesis include the following:

<u>Marketing</u> - this function is the entry for incoming <u>orders</u> or requests for proposals and <u>money</u> from the customer. It establishes, based on <u>information</u> concerning the customer, its evaluation process, and the general market conditions the allocation of engineering resources to various types of work <u>efforts</u>.

<u>Engineering</u> -this function accomplishes the main work, using <u>personnel</u> obtained with the help of the personnel department. The work <u>orders</u> from Marketing are converted to proposals, contract study reports or equipment specifications, or

research investigations. Thus four flows of engineering efforts exists.

Factory - this function takes engineering effort in the form of equipment specifications and produces the equipment which are delivered to the customer.

Personnel - this function regulates the flow of personnel to and from Engineering and the Factory. It uses information from these departments to modify recruiting efforts.

Operation Control - this function is concerned with the management of the money and capital of the organization. It determines total expense and incomes and establishes money flows for the business activities in the organization.

The flows of business through the organization is shown in Figure 1.

1. Requests for proposals go from the Customer to Marketing. The rate of flow of these can be modified by Marketing and is dependent to a certain extent upon the level of activity in the organization.
2. Marketing forwards the requests for proposals to Engineering.
3. After completion of the proposals in Engineering, the Customer receives them for evaluation.
4. The Customer evaluates the proposals and, depending upon the proposals' worth, awards contracts to the organization.
5. Marketing acts upon the awarded contracts and initiates work orders to Engineering. These orders are dependent upon the availability of engineering manpower.
6. Engineering works upon the contracts and either submits study reports to the Customer (6a) or engineering

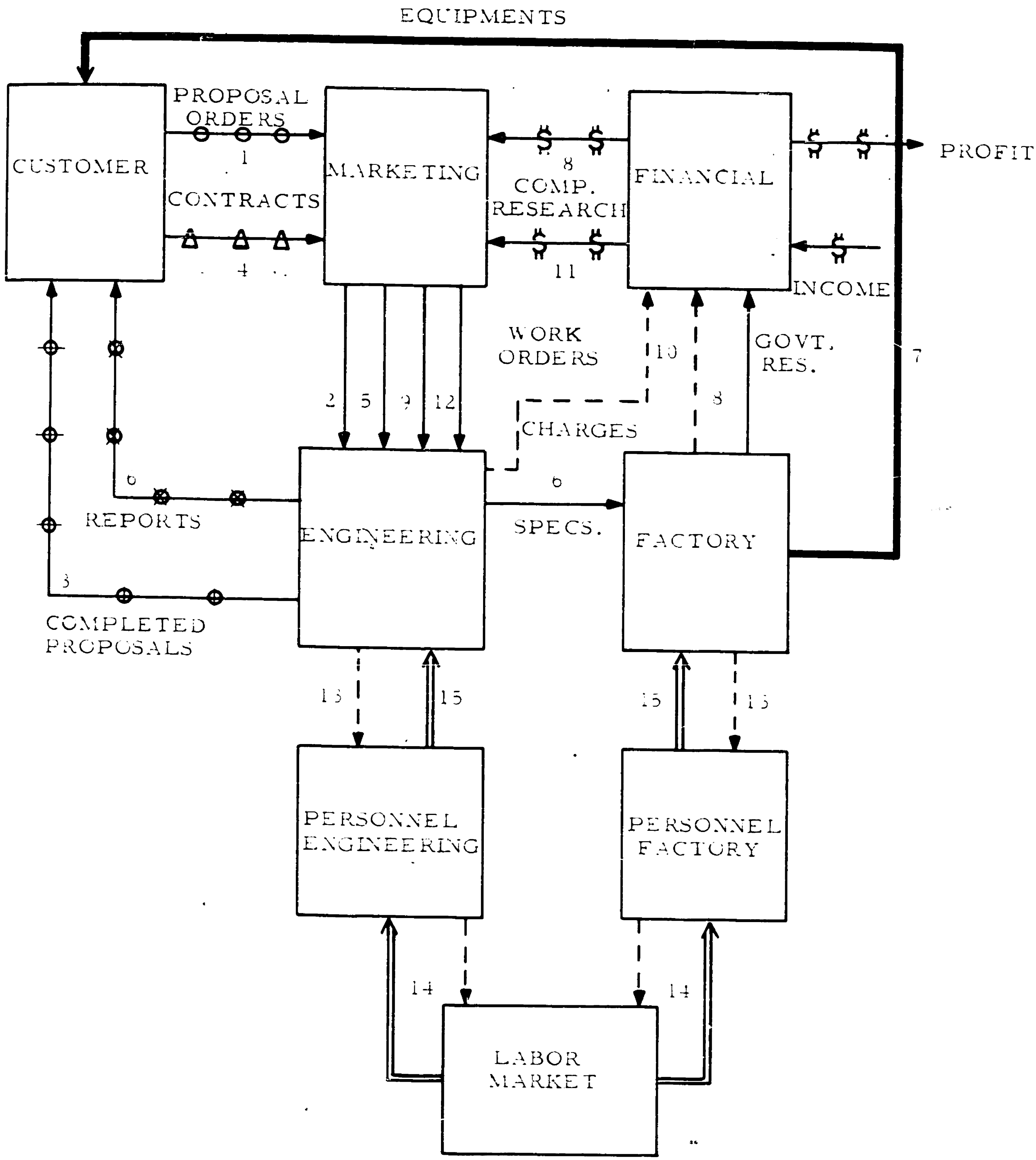

FIGURE 1. FLOW OF BUSINESS THROUGH MILITARY PRODUCT ORGANIZATION

specifications (6b) to the Factory for construction of models, prototypes or production equipment.

7. The equipments are constructed in the Factory and shipped to the customer.

8. A percentage of the Factory dollar volume (8a) is made available by Operations Control to Marketing (8b) for release for government sponsored general research work. The percentage is negotiated with the government agencies responsible for the contracts by Marketing.

9. Marketing forwards requests for this general research to Engineering which works on research and builds up competence and skill by this effort. Again the work requests forwarded depend upon availability of engineering manpower.

10. Based on information from Engineering (10a) and the Factory (10b), Operations Control establishes the rates of income and expenses and the gross profit. The money flows to the various departments are not shown. The money made available to Marketing to disburse for special research is shown (11). This money represents risk taking in that it is a percentage of net profits and is used for long range research efforts.

11. The money flow is used by Marketing which, based on availability of manpower, authorizesEngineering to do special research.

12. Engineering works on the special research. The total of all four work authorizations, proposals (2), contracts (5), general research (9), and special research (12) constitutes the work load. The last three types of work build up technical competence. The cost of proposal efforts is included in a general administrative burden rate and is thus paid for by the government as is the contract work.

13. Information on the present manpower, desired backlogs, completed work, and unfilled work requests is used by Personnel to initiate recruiting efforts. This is done for both Engineering Personnel (13a) and Factory Personnel (13b).

14. Personnel goes to the labor market. After delays for recruiting and decision making, personnel are obtained by Personnel for Engineering (14a) and the Factory (14b).

15. The personnel who join Engineering (15a) and the Factory (15b) enable these departments to complete the work request orders forwarded to these departments. The levels and flows of work are maintained consistent with assumed policy decisions. The personnel may also leave these departments depending on decreases in work requirements.

16. As a result of these various flows a net profit rate, calculated by Operations Control (16), can be considered as the system output.

Interdependence of Function

The flow of the various commodities discussed above are interdependent. Thus the number of proposal requests referred to the organization is a function of the marketing effort, backlogs, and engineering technical competence. The last is included since as an organization acquires competence in specified fields, this becomes known to contracting agencies and the organization receives more opportunities to bid.

Marketing effort would increase as backlogs in Engineering fall below levels desired for advanced planning purposes necessary for manpower allocation. The backlogs in turn depend upon the usual delays in completing the various categories of work, the orders forwarded to Engineering and the Factory, and completed work flow rates.

Technical competence is a function of work done in Engineering on efforts other than proposals. Proposal worth in turn is a function of this technical competence, price considerations, and backlogs. The latter enters in that with many years work already available, the shortage of able people to man proposal efforts and to be made available for future work will decrease the value of the proposal in the evaluation by the Customer. If there are more personnel in Engineering than there are work orders for the four type of efforts, the organization efficiency is lowered and the price of proposed work would lose competetive advantage.

The manner in which the Marketing Department decides to allocate the existing engineering manpower among the four types of engineering work in reacting to changes in proposal requests or funds available for research is quite important. If the total requests for engineering effort exceed existing manpower levels recruiting will swell the manpower total, but this takes time. In addition, engineering effort is required to recruit additional personnel and this lowers the efficiency of the Engineering Department. Thus management must establish priorities as well as the degree of risk taking using part of the profit.

The general or overall management of an organization such as that under study must be aware of this interdependence of department decisions. Each department manager may try to optimize his department's activities in the manner which he believes to be optimum. The effect of this sub-optimization on other departments or the total organization is not necessarily known to the individual department manager. He may have under his control certain delays in accomplishing work or providing information for other decisions and act upon these to the detriment of the total organization. The role of the general management must be to combine all departmental policy decisions in a manner to optimize the total system performance.

The form of optimization to be used is the responsibility of the general manager - be it net profit rate, return on assets, engineering utilization or any other criteria. The value of dynamic studies using models based on Industrial Dynamic techniques is that a research tool is provided for the systematic exploration of the interdependence and overall system effect of various department or functional policies and behavior. The following section describes the manner in which the model for the present study was constructed. It is again emphasized that each department model or organization sector can be built to any degree of detail and/or sophistication desired. An attempt has been made, in the limited time available, to include a number of the major characteristics with close attention to a realistic development of a typical military development organization.

CHAPTER III

MODEL FORMULATION

Model Formulation

The formulation of the models for the customer and the various departments of the organization studied is discussed in this chapter. Each department model is termed a sector of the total organizational model. The method proceeds as discussed in general in the preceding chapters. The important thing for the model maker to keep in mind in constructing each sector is that the actions in each department should be represented by equations which represent as close as possible what is in fact done, rather than what the model makers would like to happen. This latter change can be made later to note the actual effect of possible changes, but must of course be tested with as realistic a total model as possible.

In addition, the representation of the customer sector should adhere to the best approximation of how it may act under assumed conditions. To complete the study within the time limits of this thesis research period, always revealed to be too short as the work develops, certain limitations are imposed and assumptions made with which many could take issue. As stated previously, the attempt has been to complete a total system model. With time, each of the limitations and/or assumptions could be modified and the results of computer runs made using the modified model compared to the alleged more restrictive model.

In each discussion, which follows, the general flow of business is first discussed, and then the main equations concerning flows, levels, and functional relations are presented, with the detailed equations given in Appendix I. Thus the reader can go into as much detail as desired. The actual techniques of constructing the equations is not repeated here, the references are numerous and very well written.[8,9]

Customer Sector

The military products development organization secures business by responding to requests for proposals submitted to it by the customer. After delays in preparing the requested proposals, they are submitted to the customer and undergo further delays for evaluation. A percentage of the submitted proposals will become contract awards depending upon the customer evaluation of proposal worth. The formulation of the decisions concerning the flows of proposal requests and contract awards follows.

On an aggregate basis, it is assumed that there is a flow of total requests for proposals from the military and government agencies. It is further assumed that about ten percent of the total Department of Defense budget is applicable to the type of military research and development effort for which this model may be valid. This is in the general area of electronics and control systems and equipments. This system input may have a number of time variations such as would result from increasing budget expenditures, yearly budget variations, etc., these are discussed in Chapter IV.

Only a certain percentage of the total applicable requests for proposals are received by the organization. This percentage varies above a fixed normal value due to the customer evaluation of the firm's capability, both competence and load-wise, and the marketing activity of the organization. The latter factor can expose the Organization to more proposal opportunities, but it can not directly increase the business level.

The decision to forward a given proposal request to Engineering is made by Marketing on the basis of manpower availability as discussed in the Marketing Sector discourse. The percentage of completed and submitted proposals which the customer evaluates as acceptable is shown in Figure 2. The engineering

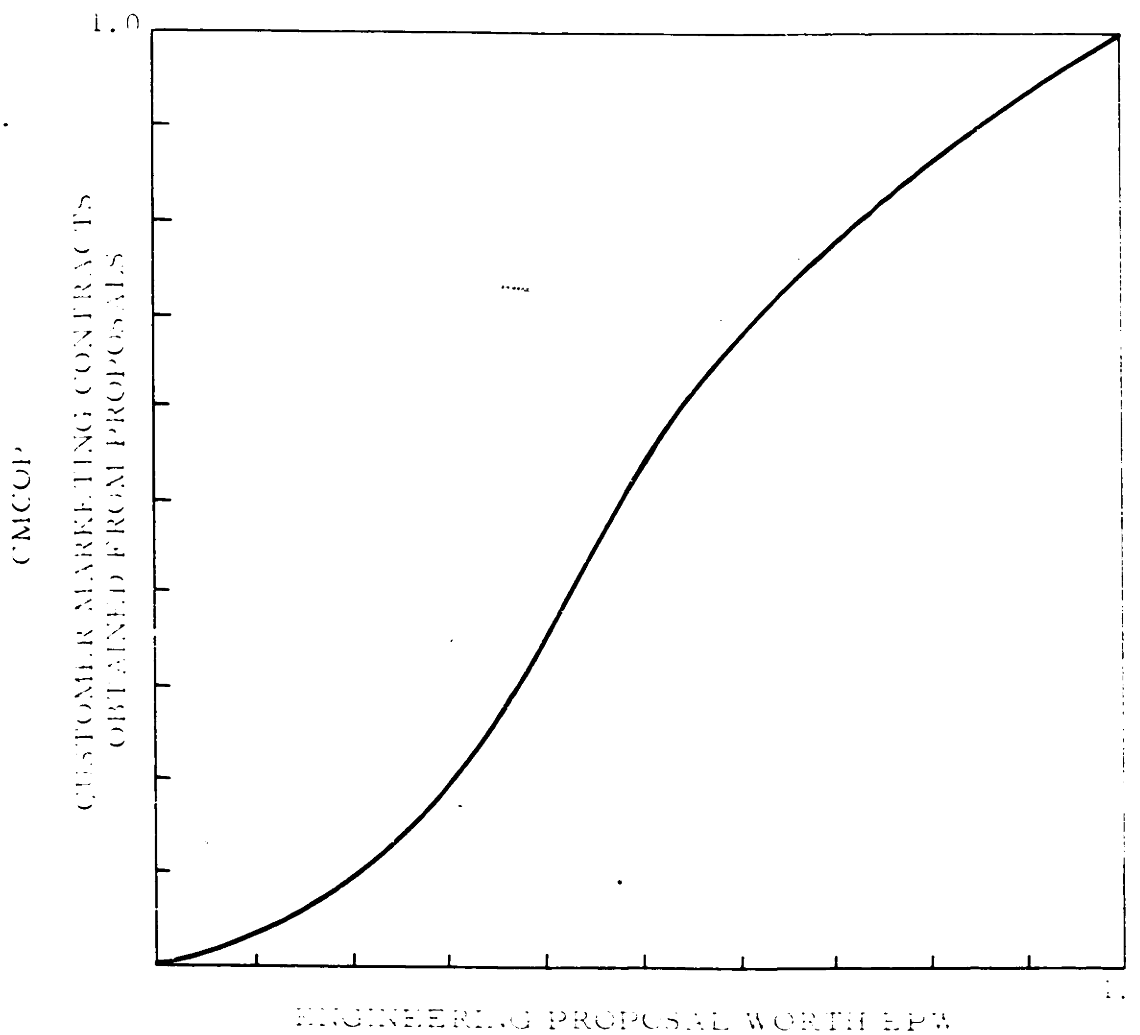

FIGURE 2. FUNCTIONAL RELATION BETWEEN [illegible]
AND COMPLETED PROPOSALS

proposal worth depends upon engineering technical competence, work load, and efficiency of manpower utilization, a price consideration.

The main sector equations follow, with the symbol R denoting a rate, L a level, and A an auxiliary equation.[7] Figure 3 gives the computer flow diagram for the Customer Sector.

The rates of proposal requests sent out by the government are given by:

CRFPO.KL = (CPPO.K) (CICM.JK) 1R

CRFPC.KL = (CPPC.K) (CICM.JK) 2R

where

CRFPO = Customer Requests For Proposals to Organization dollars/month

CRFPC = Customer Requests For Proposals to Competition dollars/month

CICM = Customer Income Capital for Military dollars/month

CPPO = Customer Percentage Proposals to Organization \$ per mo./\$ per mo.

CPPC = Customer Percentage Proposals to Competition \$ per mo./\$ per mo.

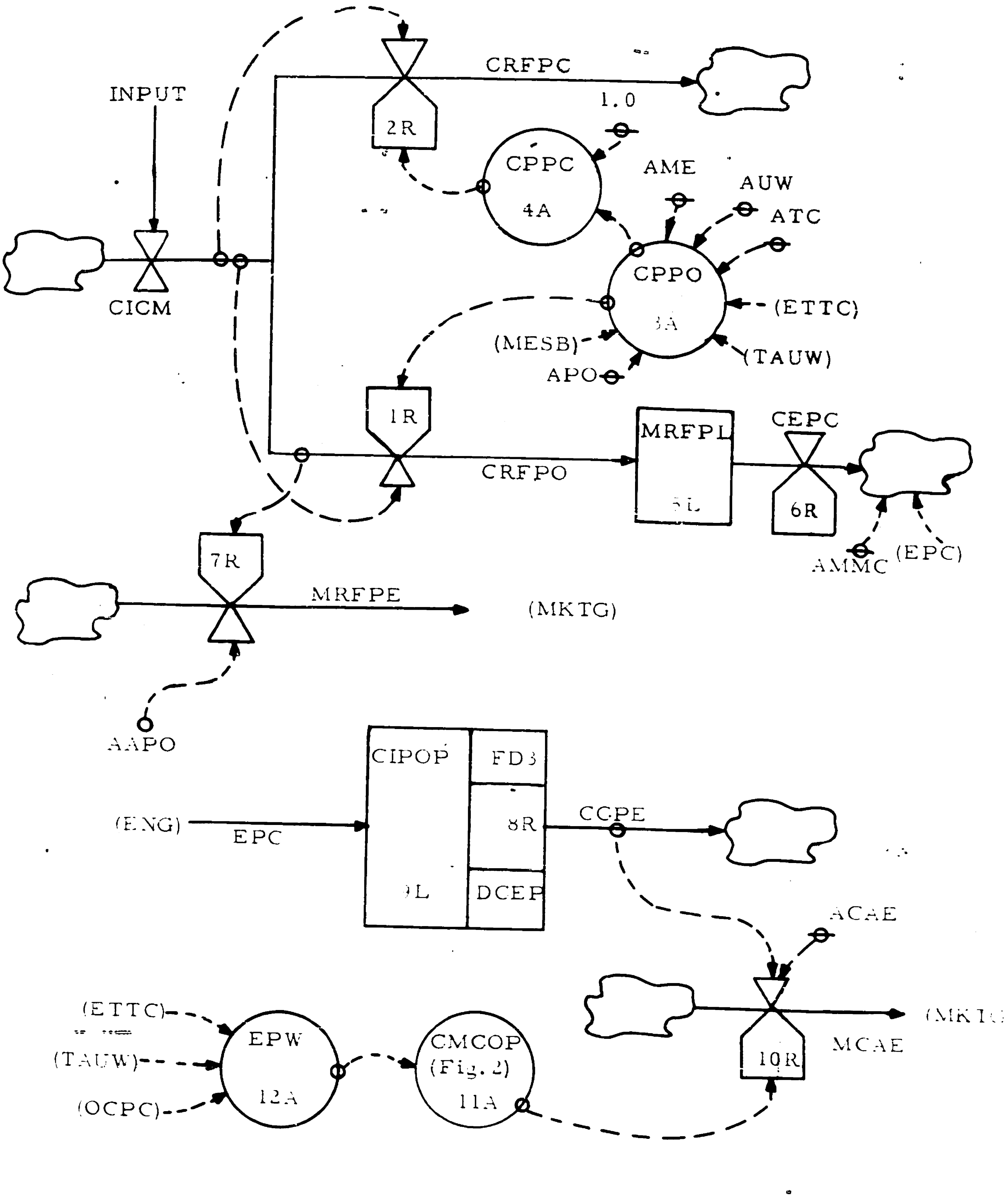

FIGURE 3. FLOW DIAGRAM OF CUSTOMER SECTOR

The percentage of proposals forwarded to the organization is given by:

$$CPPO.K = APO + (AME)(MESB.K) + (AUW)(TAUW.K) + (ATC)(ETTC.K) \quad 3A$$

$$CPPC.K = 1 - CPPO.K \quad 4A$$

where

MESB.K = Marketing Effort in Soliciting Business
dimensionless units of marketing effort

TAUW.K = Total Ability to Undertake Work
dimensionless units of functional ability to undertake work

ETTC.K = Engineering Total Technical Competence
dimensionless units of technical competence

APO = Constant, Percentage proposals to Organization
\$ per mo./\$ per mo.

AME = Constant, Marketing Effort
\$ per mo./units of mktg.effort

AUW = Constant, Ability to Undertake Work
\$ per mo./units of ability to undertake work

ATC = Constant, Technical Competence
\$ per mo./ units of tech. competence

This equation states that a certain percentage of requests for proposals issued by the government comes to the organization plus an increase above this value. The term MESB concerns the effort exerted by Marketing as the backlog of orders declines. Marketing will always seek work of course, but the second term in equation 3A reflects the increased efforts which would occur as backlogs decline. The next two terms reflect the reaction of the customer to the organization's ability to undertake work and its technical competence. As the work available to the organization gets quite large, not only are fewer people available to solicit new work, in spite of marketing efforts, but the depth of managerial personnel is less. As technical competence increases, however, more agencies will recognize that the organization might be able to supply their needs also and will forward requests to the organization.

MESB, TAUW, and ETTC are given by equations 34A, 80A, and 63A respectively.

A backlog of requests for proposals not acted upon may build up as follows:

MRFPL.K = MRFPL.J + (DT)(CRFPO.JK - CEPC.JK) 5L

where

MRFPL = Marketing Requests For Proposal Level
dollars

CRPC = Customer received Engineering Proposals Completed
dollars/month

DT = Difference Time used in calculation
months.

The rate of engineering proposals received by the customer is given by:

CEPC.KL = (AMMC)(EPC.JK) 6R

where

EPC.JK = Engineering Proposals Completed
total man months/month

AMMC = constant converting Man Month to Cash
dollars per month/man months per month.

The customer requests for proposals become an input to the marketing department in the form of man months effort per month requested:

MRFPE.KL = (AAPO)(CRFPO.JK) 7R

where

MRFPE = Marketing Requests For Proposals Entered
man months/month

AAPO = constant Allocating Proposals to Organization
man months per month/dollars per month.

At this point the model maker must take into account the implications of assigning a single numerical value for the constant AAPO. In actual practice, different proposal requests would require different man months of effort to prepare.

In addition, competing organizations would use different numbers of engineers for different lengths of time on the same requests for proposal. However, in an aggregate sense, the ratio of the dollar value of proposal request rates to the rates of effort applied to them would tend to a uniform value over a long period of time for many organizations and types of work. This conversion factor AAPO could be made variable and a function of external as well as internal factors, but this refinement does not seem necessary to detect the significant behavior of the system. A numerical value corresponding to a typical allocation of engineering personnel in a representative organization will be used.

Proposal requests are submitted to Engineering by Marketing depending on manpower as discussed in the Marketing Sector section of this chapter. Completed proposals are sent to the customer where they undergo a delay for evaluation and where a certain number are accepted based upon proposal worth. This is formulated as:

CCPE.KL = (DELAY 3)(EPC.JK, DCEP) 8R

CIPOP.K = CIPOP.J + (DT)(EPC.JK - CCPE.JK) 9L

where

CCPE = Customer Completed Proposals Evaluated
man months/month

DELAY 3 = third order delay

DCEP = Delay, Customer Evaluations Proposals
month

CIPOP = Customer Internal Processing of Organization Proposals
man months

The third order delay is used for the first time here as a representation of the aggregate functional relation of the delays occuring in the evaluation process. Some proposals are quickly evaluated and some take quite some time. The sensitivity of the system to the value of the time delay DCEP can always be tested once a complete model is available.

The percentage of evaluated proposals which become contracts and hence become requirements for engineering work is given by:

MCAE.KL = (ACAE)(CMCOP.K)(CCPE.JK) 10R

CMCOP.K = FUNCTION (EPW.K) 11A

where

MCAE = Marketing Contract Awards Entering man months/month

ACAE = constant, Contract Awards Entering man months/man months

CMCOP = Customer Marketing Contracts Obtained Percentage

EPW = Engineering Proposal Worth dimensionless units of proposal worth.

The functional relationship of equation 11A is given in Figure 2. The conversion factor ACAE, relating man months of contract awards to man months of proposal effort, requires the same type of consideration as AAPO. If these two factors are increased, more business would result in the model from the basic construction of the model. Thus the variation of these conversion factors as functions of internal and external parameters might seem necessary for complete realism. However, constant values are used. Thus ACAE is made constant and its variation as a function of changes in skill in the level of organization engineering or management can be studied after a basic model is constructed.

The engineering proposal worth is given as:

EPW.K = (AETC)(ETTC.K) + (AAUW)(TAUW.K) + (APP) (OCPC.K) 12A

where

OCPC = Operations Control Price Constant dimensionless units

AETC = constant, Engineering Technical Competition dimensionless units

AAUW = constant, Ability to Undertake Work dimensionless units

APP = constant, Price Provision dimensionless units

The factors contributing to engineering proposal worth are discussed in the Engineering Sector. These three quantities in equation 12A are used to indicate the major items the customer might use in establishing proposal worth. Again additional factors could be included. In addition the weighting of the three assumed items assumed to enter into engineering proposal worth can be modified. This can easily be done in model computer runs in an extensive study and illustrates the use that the general management could make of a model study. The equation for ETTC, TAUW, and OCPC are given by equations 63A, 80A, and 100A respectively.

Marketing Sector

The marketing function serves as the main contact between the customer and the rest of the organization. The major areas in which marketing decisions enter into the determination of the system behavior concern the allocation of manpower. Marketing also of course establishes the profit rates through negotiation with the customer.

As noted in the preceding sector discussion, two types of requests or orders for engineering effort result directly from customer actions. These are requests for proposals and contract awards. In addition to these, two types of research may be undertaken, general research, sponsored by the government, and special research, sponsored by the organization.

The amount of general research which can be undertaken is a function of the amount of manufacturing work in process. The funds for this research are established in negotiations between Marketing and the Customer. A small fixed percentage of the value of manufacturing contracts is made available for general research studies. This is done to permit continued advances in the state of the art knowledge and increase the ability of the organization to serve the nation's defense needs.

The organization may desire to invest its own money in special research areas for which the prospect of future profits may be quite promising. A percentage of the profit rate can be made available to initiate special research studies, usually long range or fundamental investigations.

Thus four types of engineering efforts must be requested by Marketing and some basis for establishing priorities must be set. This is necessary since there will only be a fixed engineering personnel staff available. If a sudden increase in work requirements occurs, personnel can not be added immediately, so a decision must be made concerning which jobs will be of lowest priority and thus wait for manpower to become available.

The policy decisions concerning work priorities are essentially the means the organization management uses strategy to react to their evaluation of the market and the customer decision means for requesting proposals and awarding contracts. It is first assumed that technical competence is established by working on special research, general research, and contracts in approximately decreasing amounts. Then if Marketing decides to always have the research work done even if a sudden increase in proposal requests occurs, they are deciding that the long term build up of competence will be "better" than stopping such work to bid on proposals. Such a decision must be made since the increase in staff can not occur quickly. The following Order Rules for utilization of engineering manpower on work requests can be considered and can be implemented in the model.

Order Rule Alpha

1. All contract work is forwarded to Engineering up to the limit of available manpower.
2. Proposal requests are forwarded to Engineering with the personnel not required on contract work.
3. General research work is done next.
4. Special research work occupies the lowest priority.

5. As these work requests persist, Personnel is requested to accelerate recruiting and the added personnel are used on work in the priority stated.

If there is still an excess of engineering personnel after the four work requests are filled in the order stated, the efficiency of the total organization falls, and its expenses increase. The argument may be made that surely the organization would use any available personnel on one of the four areas but the following limitations occur. Research is usually done on a fixed budget basis and people can not be suddenly thrown on research and the results still be expected to remain as described. The contract work usually has limiting items such that the addition of more personnel may not increase output. In addition, training and skill levels enter into the problem of integrating more people in any given program. Thus in the model the excess of personnel over work request inputs is made to react as a decrease in competitive price acceptability. The corollary penalty of having too few personnel is the sacrifice of research work and less buildup of technical competence.

Marketing may pursue a different policy concerning priority of the four work request orders. Thus a different Order Rule may be to establish the priority as given below.

Order Rule Beta

1. All general research work is given first priority, and manpower in excess of this requirement is used for other categories of work.
2. Work on contracts is done with the remaining manpower up to the level of existing engineers.
3. Proposals are requested from Engineering with remaining engineers.
4. The special research is given the lowest priority. Manpower left after the above three categories of work requests are forwarded is used on special research.

Another priority ordering of manpower can be expressed as Order Rule Gamma. In this, special research, proposal, general research, and contract work orders are forwarded to engineering in that order. Any combination of priorities can be chosen and build into the model formulation. The resultant decisions concerning the rates of work request flows serve as inputs to Engineering.

Marketing would intensify its efforts to solicit new business as the backlog of total requests remaining unfilled decreased. Also as the level of unfilled requests for proposals increases, it can be expected that a certain percentage of this becomesworthless because of fixed due dates. As the level of available personnel exceeds the four work requests, such that personnel would not be engaged in any of the four for a period of time, the voluntary terminations of engineers would be expected to increase.

The formulation of the Marketing Sector equations follows. Figure 4 gives the flow of business in Marketing.

The rates of proposal and contract work requests have been given as:

MRFPE.KL = (AAPO)(CRFPO.JK) 7R

MCAE.KL = (ACAE)(CMCOP.K)(CCPE.JK). 10R

The rate of government sponsored research is given by:

MGGRE.KL = (OCIGR.JK)/(ARE) 13R

where

MGGRE = Marketing Government General Research Entered
man months/month

OCIGR = Operations Control Income for General Research
dollars/month

ARE = constant, Rate of Engineers
dollars/man month.

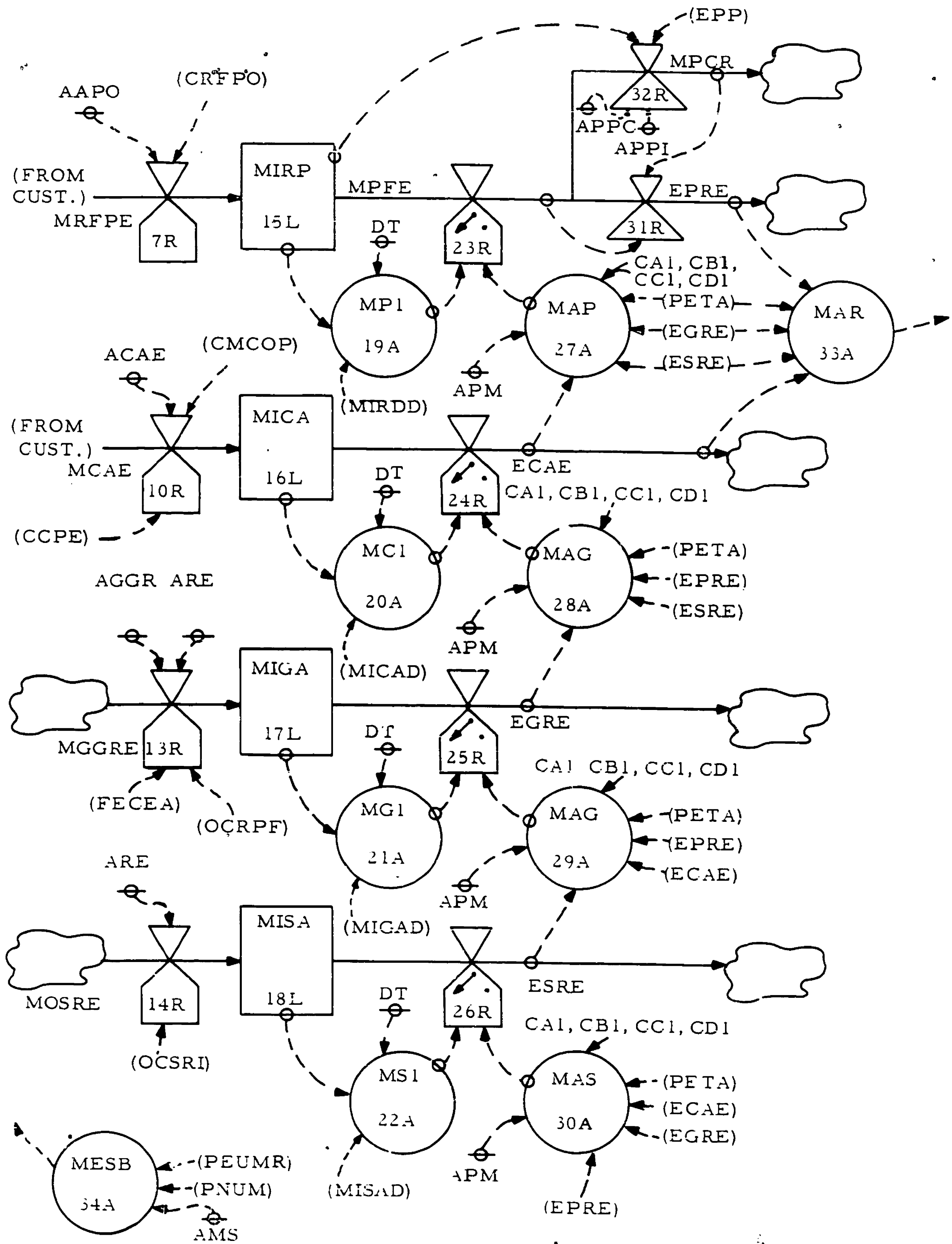

FIGURE 4. FLOW DIAGRAM OF MARKETING SECTOR

OCIGR is given by equation 103A.

The rate of special research work is determined by the amount of money the organization is willing to invest in research. The rate is given by:

MOSRE.KL = (OCSRI.JK)/(ARE) 14R

where

MOSRE = Marketing Organization Special Research Entered
man months/month

OCSRI = Operations Control Special Research Income
dollars/month.

The rates of work requests actually forwarded to Engineering are given as follows for the four types of work:

EPRE = Engineering Proposal Requests Entered
man months/month

ECAE = Engineering Contract Authorizations Entered
man months/month

EGGRE = Engineering Government General Research Entered
man months/month

ESRE = Engineering Special Research Entered
man months/month.

For each of these rates of flow, an increasing level of work requests which have not been forwarded, due to unavailability of manpower, may exist. This level will depend on which Order Rule is used. These levels are given by:

MIRP.K = MIRP.J + (DT)(MRFPE.JK - MPFE.JK) 15L

MICA.K = MICA.J + (DT)(MCAE.JK - ECAE.JK) 16L

MIGR.K = MIGR.J + (DT)(MGGRE.JK - EGRE.JK) 17L

MISR.K = MISR.J + (DT)(MOSRE.JK - ESRE.JK) 18L

where

MIRP = Marketing Inventory of Requests for Proposals
man months

MICA = Marketing Inventory of Contract Authorizations
man months

MIGR = Marketing Inventory of General Research
man months

MISR = Marketing Inventory of Special Research
man months

MPFE = Marketing Proposals Forwarded to Engineering*
man months/month.

Each time interval, these inventories of work requests are increased above desired backlogs by the input rates as follows where the -D denotes desired backlogs (see page 59)

MP1.K = (MIRP.K - MIRPD.K)/(DT) increment in proposal requests 19A
man months/month

MC1.K = (MICA.K - MICAD.K)/(DT) increment in contract authorization 20A
man months/month

MG1.K = (MIGR.K -MIGRD.K)/(DT) increment in general research work 21A
man months/month

MS1.K = (MISR.K - MISRD.K)/(DT) increment in special research work 22A
man months/month.

The decisions to foreward either the work request which has just been received, to continue the rate under steady state conditions, or to order Engineering to use only the available manpower (when the input request is greater than the available manpower as established by the priority rule) are given by the following general equations:

MPFE.KL = CLIP(MP1.k, MAP.K, MAP.K, MP1.K) 23R

ECAE.KL = CLIP(MC1.K, MAC.K, MAC.K, MC1.K) 24R

EGGRE.KL = CLIP(MG1.K, MAG.K, MAG.K, MG1.K) 25R

ESRE.KL = CLIP(MS1.K, MAS.K, MAS.K, MS1.K) 26R

where

W = CLIP (X,Y,Y,X) denotes that W is set equal to X if Y is equal to or greater than X, and is set equal to Y if Y is less than X.

* A distinction is made between the proposals requests actually entered into Engineering EPRE and the requests forwarded from Marketing MPFE in that the letter can be reduced due to the lack of manpower as explained by equations 31 and 32.

Also,

MAP = Manpower Available for Proposals man months/month

MAC = Manpower Available for Contracts man months/month

MAG = Manpower Available for General Research man months/month

MAS = Manpower Available for Special Research man months/month.

Thus MP1, MC1, MG1, and MS1 can be considered to be the work rates which if maintained, would deplete each work inventory to the desired backlog level in DT months in the absence of new incoming orders, assuming sufficient manpower. The inventories would then decrease as the backlogs decayed.

Equations are written for MAP, MAC, and MAS to establish the available manpower according to the Order Rule desired. Thus for Order Rule Alpha in which the order of priority is contracts, proposals, general research and special research:

MAP.K	= PETA.K - ECAE.JK	man months/month	27A
MAC.K	= PETA.K	man months/month	28A
MAG.K	= PETA.K - ECAE.JK - EPRE.JK	man months/month	29A
MAS.K	= PETA.K - ECAE.JK - EPRE.JK - EGGRE.JK	man months/month	30A

where

PETA.K = Personnel Engineers Total Available man = man months/month.

Note that the actual proposed requests entered into engineering EPRE is used to determine manpower availability.

For other order rules the order of C, P, G, and S would change.

As mentioned on page 31, if the proposals which can actually be entered into Engineering (EPRE) become less than the requests for proposals received from the customer (MREPE, equation 7R) due to lack of manpower, it can be expected that a certain number of the requests for proposals in the marketing inventory (MIRP) would not be answered. This could be due to cancellations by the customer, delays beyond the time for submittal, or decisions by Marketing and Engineering not to bid. The formulation of an all-inclusive decision function for the decrease in inventory has not been attempted. Instead the assumption has been made that if the increased level of the inventory of proposal requests exceeds a fraction of the requests actually in process in engineering, a certain percentage of the increased inventory is not entered into engineering. This modified decision function is now formulated.

The rate of proposal requests actually forwarded to engineering is reduced from the ones received by marketing by the rate of invalid proposals. Thus:

$$\text{EPRE.KL} = \text{MPFE.JK} - \text{MPRC.JK} \qquad \text{31R}$$

where

EPRE = Engineering Proposal Requests Entered actual man months/month

MPFE = Marketing Proposals Forwarded to Engineering man months/month

MPRC = Marketing Proposal Requests Cancelled man months/month.

The rate of marketing proposal requests cancelled is given by:

$$\text{MPRC.KL} = \begin{cases} (\text{APCC})(\text{MIRP.K} - \text{MIRPI}) & \text{if } \text{MIRP.K} - \text{MIRPI} \geq (\text{APPI})(\text{EPP.K}) \\ 0 & \text{if } \text{MIRP.K} - \text{MIRPI} < (\text{APPI})(\text{EPP.K}) \end{cases} \qquad \text{32R}^{*}$$

where

MPCC = Marketing Proposals Cancelled by Customer man months/month

* The actual formulation of MPRC was finally modified as shown in Appendix Two to make a fraction of the excess level of the preceding month become invalid, using a boxcar, level and auxiliary equations.

MIRPI = Marketing Inventory Requests for Proposals Initial
man months

APPI = constant, Proposal Percentage in Inventory

APCC = constant, Proposals Cancelled by Customer
percent/month

EPP = Engineering Proposals in Process (equation 41L)
man months.

If at any time the input requests for work of a given type are at a level which exceeds the available manpower for that type of effort, only the available manpower can be ordered to carry out that request. The requests forwarded for all lower priority categories of work are zero. The model is constructed to insure that the equations do not order negative work rates.

Conditions can occur in which the total available engineering force exceeds the four categories of work. When this happens the level of unassigned manpower is given by:

MAR.K = PETA.K - EPRE.JK - ECAE.JK - EGGRE.JK - ESRE.JK   33A
man months/month

where

MAR = Manpower Available for Reassignment
man months/month.

This level is used in establishing the competitive price decrement due to inefficiency and also the rate of voluntary terminations of engineering personnel.

The marketing department will intensify its efforts to solicit new business as the backlog of unfilled total requests for engineering effort decreases below a normal planning level. This would vary from a three to a twelve month backlog. The marketing effort is given by:

MESB.K = 1 - (AMS)(PEUMR.K)/(PNUM.K)   34A

where

PEUMR = Personnel Engineering Unfilled Manpower Requests man·months/month

PNUM = Personnel Normal Unfilled Manpower man months/month

AMS = constant, Marketing Solicitation man months/month.

This completes the Marketing Sector.

Engineering Sector

Engineering provides the proposals, contract work and research studies which constitute the main flow of business of the organization. The contract work may provide not only the equipment specifications which serve as the input to the Factory, but also study reports to the Customer. The basis for proceeding on the four types of efforts has been discussed in the preceding Marketing Sector section.

Each of the four types of work efforts would in general require a different average time for completion. On an aggregate basis, the length of time for proceeding from work authorization to work completion would increase successively for proposals, contracts, general research, and special research. This is reflected in the model by using increasing time delay constants in the third delay representations for the work processes.

As mentioned before, the available staff of engineering manpower imposes a limit upon the amount of work requests from marketing which can be initiated in engineering. The Order Rule priority establishes which type of work effort must await the hiring of additional personnel. In engineering organizations this recruiting requires the use of engineering personnel due to the technical requirements and skills required of the staff. This recruiting effort will lower the efficiency of the engineering staff. Thus in the growth of an organization responding to a sudden or growing rate of government requests for proposals, the engineers could not work at full efficiency and recruit simultaneously. This would effectively slow the growth and reduce profits.

As Engineering works on contracts and the research activities, the level of technical competence will increase. An organization which has spent much effort in a given area would in general be expected to have a greater knowledge of the best solutions and would enjoy a competitive advantage. This is reflected in the model by the establishment of a level of engineering total technical competence.

This technical competence is a function of work done on contracts, general research, and special research. At any given time, the total technical competence depends upon efforts expended in the past years on these three types of work. Work done on special research the immediate preceding year will probably not have contributed yet to technical competence. Special research is usually done on those projects for which the payoff is several years in the future. The experience gained from actual contracts, which probably not as significant an overall contribution to total technical competence, is most effective in the period immediately following its accomplishment. The effect of general research would have an effect lying between these two time characteristics.

Figure 5 shows the relative contribution of effort to technical competence in these three areas. In the equation formulation the average year's work in each area over the last eight years is weighted according to the value of Figure 5 and the total competence expressed as a sum of the three contributions. A ratio of 1 :2 :4 is given for the relative contribution of work in contracts, general research and special research. Each contribution is normalized to the maximum value expected for each type of work, since the contract work in absolute total of man months would greatly exceed research works.

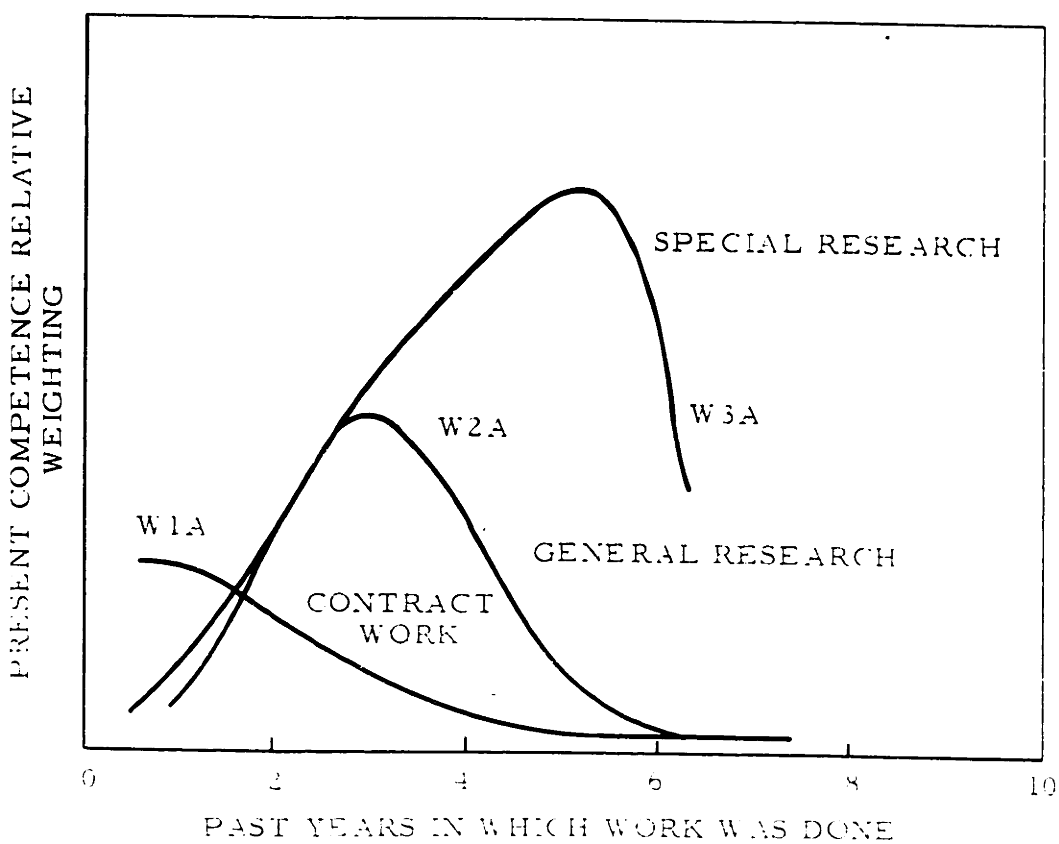

FIGURE 5. EFFECT OF VARIOUS WORK EFFORTS ON ENGINEERING TECHNICAL COMPETENCE

Another way of expressing the weighting of past effort implied in Figure 5 is shown in Figure 6. This represents an optimum curve of expenditures per year over the years before the market date of a given project or equipment. If all the money were spent immediately, by the market date the effectiveness of the expenditures would be dissipated due to changed market conditions, obsolescence, etc. The money can not be spent immediately prior to the market date either, since any improvement could not be implemented in a short time before marketing. Some money should be spent after market date since product improvement would insure continued product acceptance and recorders before the entry of competitor reorders the innovator's advantage.

The actual formulation of the technical competence has a definite influence on the model's system behavior. Changes in the form of the equations can be made if it is felt that a given method may not be as realistic as desired. This is done easily by changing the weighting values and normalizing constants.

The contract work completed serves as the input to the Factory in the form of equipment specifications. The number of man months engineering effort equivalent to one equipment can be changed and represents the ratio of equipment to study type of contract work.

The ability of Engineering to undertake additional work is a function of its work load at any given time. If the backlog of work not yet finished is many times a normal years work backlog, the organization will be less able to undertake additional work. This is shown in Figure 7 where as the time to exhaust the given backlog increases the ability to undertake additional work decreases.

The equations used in the Engineering Sector follow. Figure 8 gives the flows in the Engineering Sector.

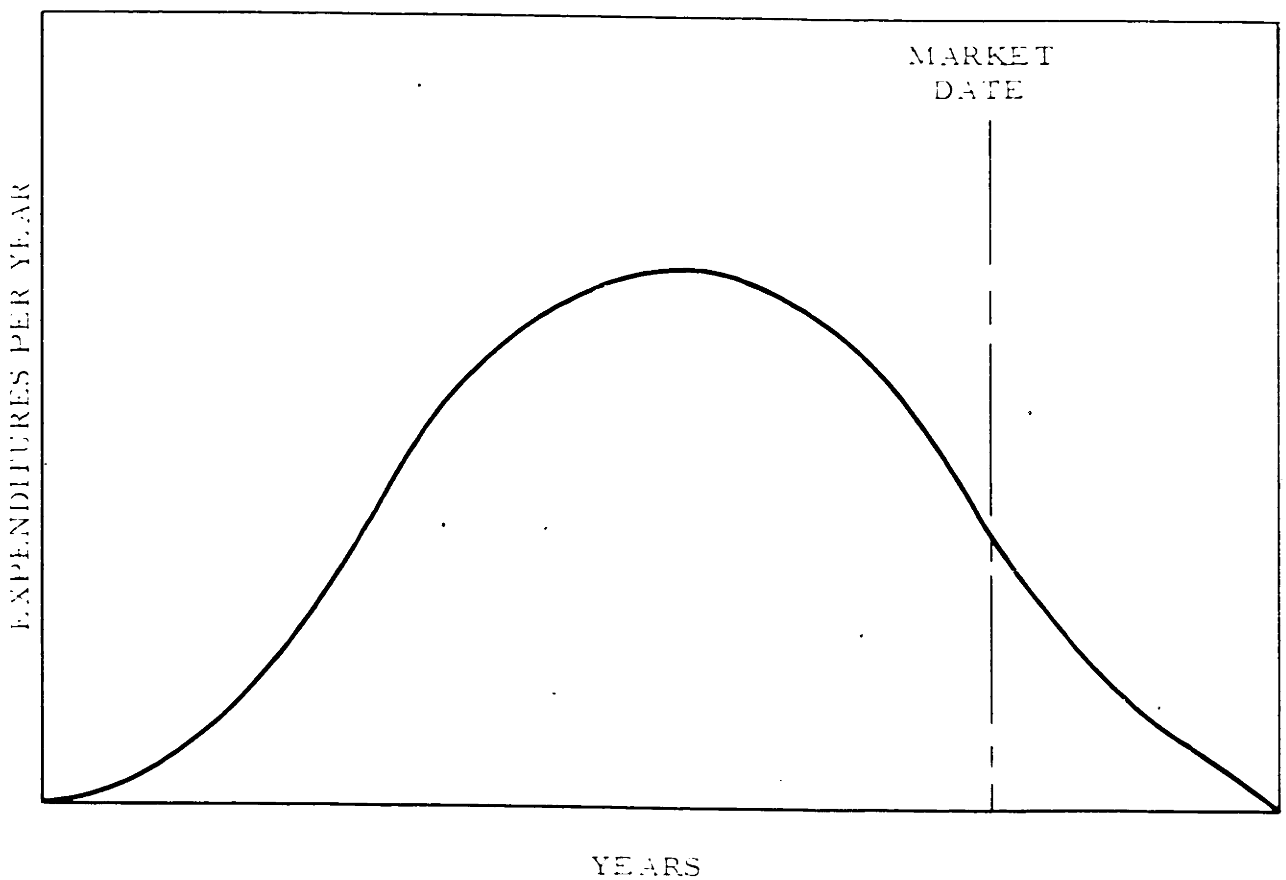

FIGURE 6. EXPENDITURE OF RESEARCH AND DEVELOPMENT FUNDS PRIOR TO MARKETING DATE

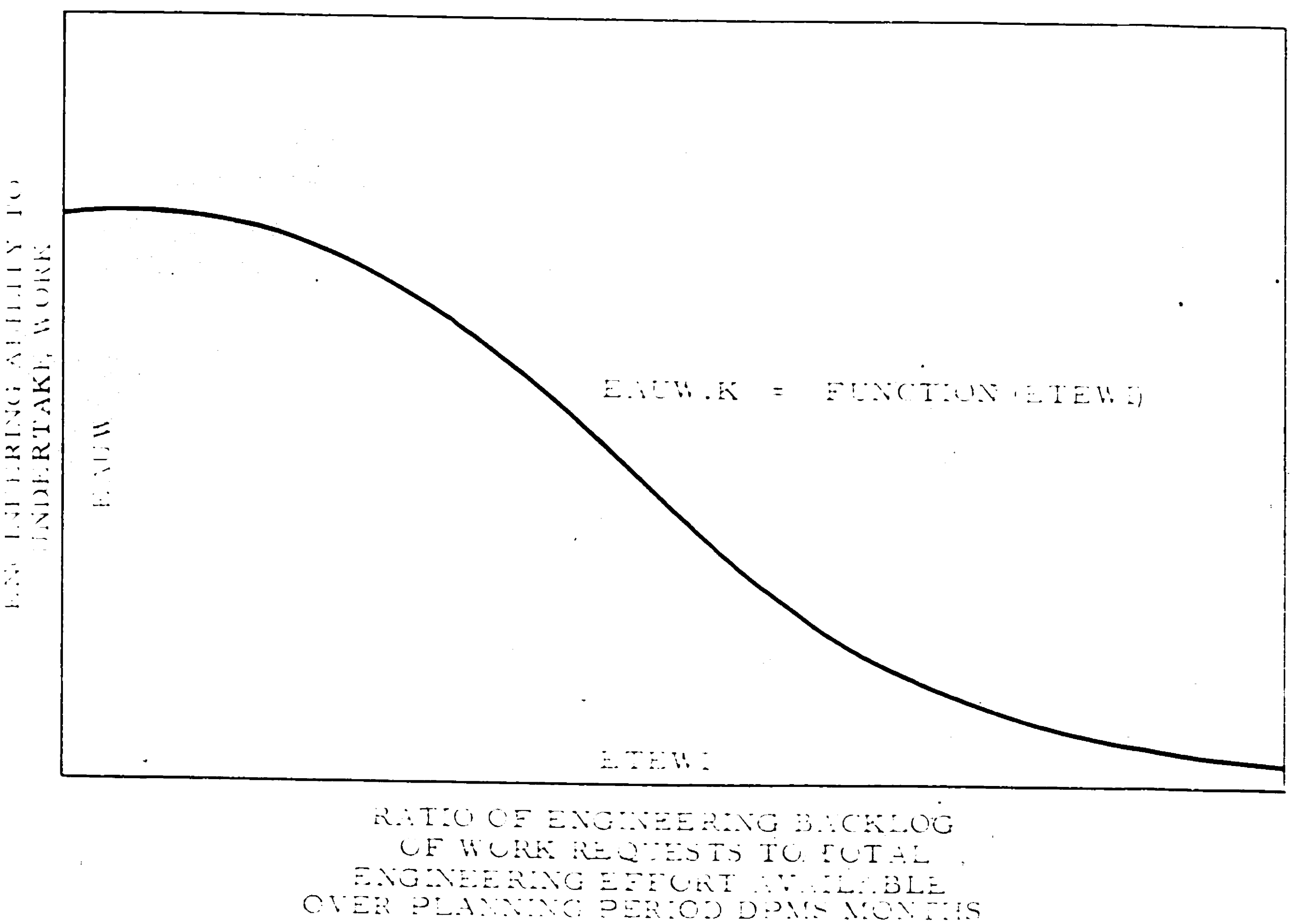

FIGURE 7. ENGINEERING ABILITY TO UNDERTAKE WORK AS FUNCTION OF BACKLOG

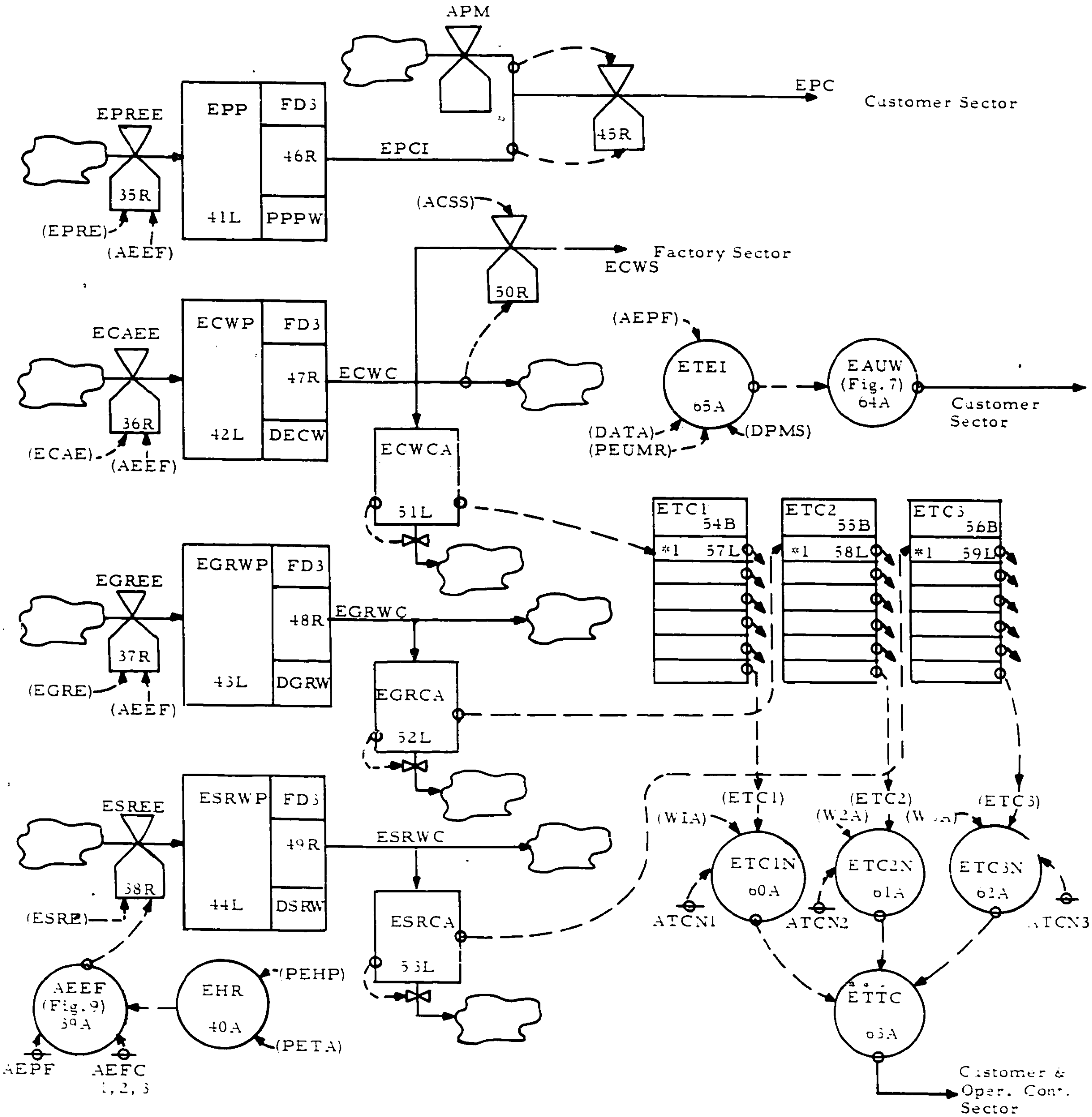

FIGURE 8. FLOW DIAGRAM OF ENGINEERING SECTOR

As discussed previously there are four types of work requests forwarded to Engineering from Marketing, depending upon the availability of manpower and the Order Rule of work priority. These are:

EPRE = Engineering Proposal Requests Entered man months/month

ECAE = Engineering Contract Authorization Entered man months/month

EGGRE = Engineering Government General Research man months/month

ESRE = Engineering Special Research Entered man months/month.

The rates of work actually initiated in Engineering is a function of engineering efficiency, which in turn depends on the involvement of engineers in recruiting to decrease the buildup of unfilled work requests in Marketing. The effective rates of work initiated in Engineering are given by:

$$\text{EPREE.KL} = (\text{AEEF.K})(\text{EPRE.JK}) \qquad 35R$$

$$\text{ECAEE.KL} = (\text{AEEF.K})(\text{ECAE.JK}) \qquad 36R$$

$$\text{EGREE.KL} = (\text{AEEF.K})(\text{EGGRE.JK}) \qquad 37R$$

$$\text{ESREE.KL} = (\text{AEEF.K})(\text{ESRE.JK}) \qquad 38R$$

$$\text{AEEF.K} = \begin{cases} \text{AEPF} & \text{if EHR.K} < \text{AEFC2} \\ \text{AEPF} - (\text{AEFC3})(\text{EHR.K}) & \text{if AEFC2} \leq \text{EHR.K} \leq \text{AEFC1} \\ \text{AEFC1} & \text{if EHR.K} > \text{AEFC1} \end{cases} \qquad 39A$$

$$\text{EHR.K} = (\text{PEHP.JK})/(\text{PETA.K}) \qquad 40A$$

where

EPREE = Engineering Proposal Requests Entered Effective man months/month

ECAEE = Engineering Contract Authorizations Entered Effective man months/month

EGREE = Engineering General Research Entered Effective man months/month

ESREE = Engineering Special Research Entered Effective
man months/month

AEEF.K = Attrition in Engineering Efficiency Factor

EHR.K = Engineering Hiring Ratio
man months per month/man

AEPF = constant, Engineering Productivity Factor
man months/man months

AEFC1 = constant, Effeciency Factor Constant

AEFC2 = constant, Efficiency Factor Constant

AEFC3 = constant, Efficiency Factor Constant.

Figure 9 illustrates the variation of this efficiency.

The effect of a decrease in engineering efficiency is twofold. The work completed is less than originally ordered so the money income rate is less. In addition, more manpower will be recruited to equate work requested with work output. The income rate goes up as more work is done but expenses increase as manpower increases.

In the engineering department certain delays would occur in processing the work authorizations received from Marketing. These delays are included in the actual work-in-process delays ato simplify the model consturction. Each flow of orders becomes an input to the engineering work processes which are expressed as third order aggregate delays. The work in process levels of work are given by:

EPP.K = EPP.J + (DT)(EPREE.JK - EPC1.JK) 41L

ECWP.K = ECWP.J + (DT)(ECAEE.JK - ECWC.JK) 42L

EGRWP.K = EGRWP.J + (DT)(EGREE.JK - EGRWC.JK) 43L

ESRWP.K = ESRWP.J + (DT)(ESREE.JK - ESRWC.JK) 44L

where

EPP = Engineering Proposals in Process
man months

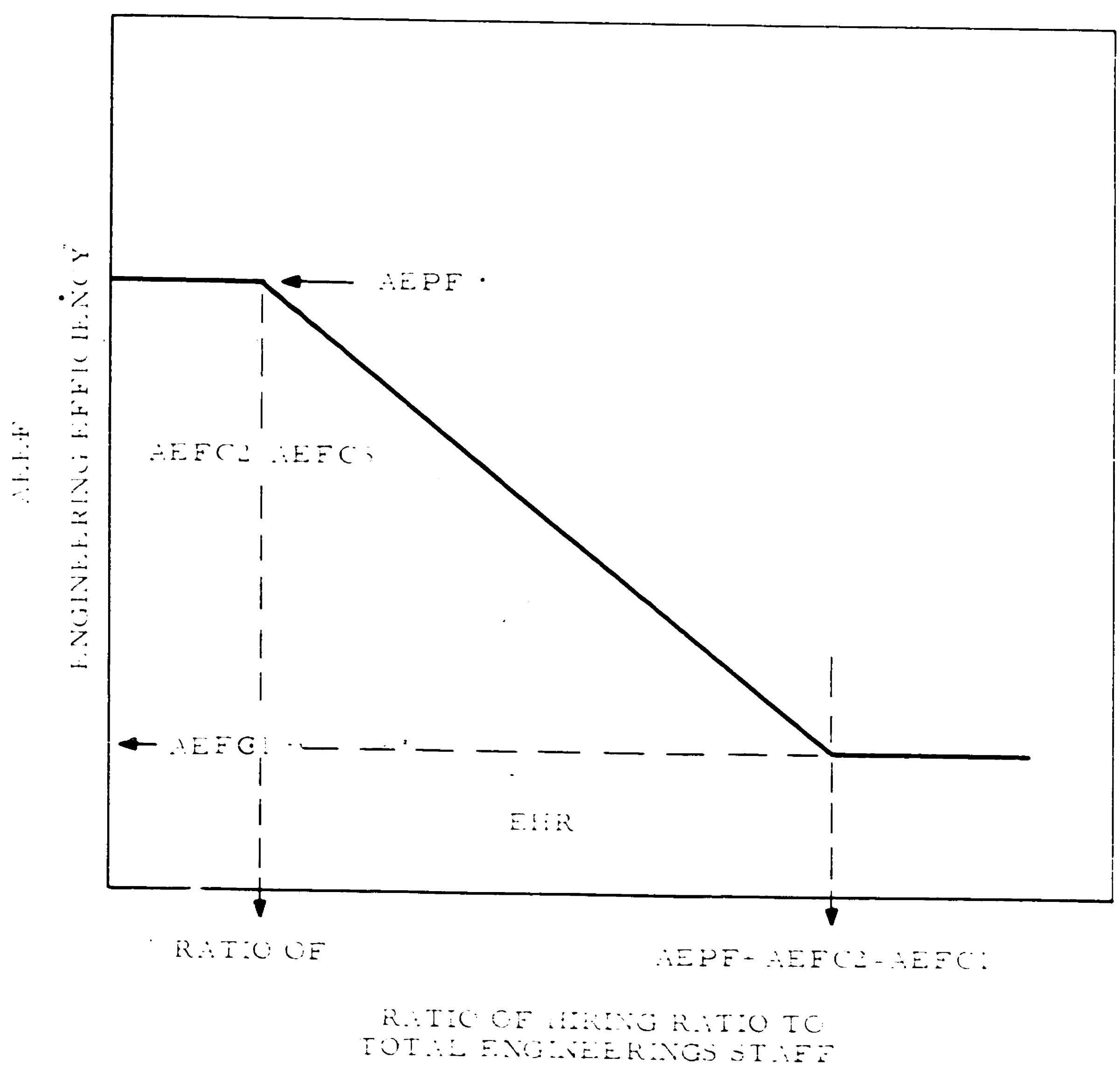

FIGURE 9. ENGINEERING EFFICIENCY AS FUNCTION OF RECRUITING EFFORT

ECWP = Engineering Contract Work in Process
man months

EGRWP = Engineering General Research Work in Process
man months

ESRWP = Engineering Special Research Work in Process
man months

EPC1 = Engineering Proposals Completed due to Marketing Requests
man months/month

ECWC = Engineering Contract Work Completed
man months/month

EGRWC = Engineering General Research Work Completed
man months/month

ESRWC = Engineering Special Research Work Completed
man months/month.

In equation 41L,

EPC.KL = EPC1.JK + APM 45R

where

EPC = Engineering Proposals Completed total
man months/month

EPC1 = Engineering Proposals Completed due to marketing requests
man months/month

APM = Proposal Effort Maintained
man months/month.

The constant APM is introduced to indicate the unsolicited proposals which an organization might decide to present to the government. If APM is used to represent a constant number of personnel who are at all times working on proposals, APM would be subtracted from each of the manpower levels in equations 27A through 30A and 33A. This is done for any order rule used in establishing work priority.

The output rates of work are given by third order delays as:

EPC1.KL = DELAY 3(EPREE.JK, DPPW) 46R

ECWC.KL = DELAY 3(ECAEE.JK, DECW) 47R

EGRWC.KL = DELAY 3(EGREE.JK,DGRW) 48R

ESRWC.KL = DELAY 3(ESREE.JK,DSRW) 49R

where

DPPW = Delay, Proposal Process Work months

DECW = Delay, Engineering Contract Work months

DGRW = Delay, General Research Work months

DSRW = Delay, Special Research Work months

It is seen that no control is exerted over the engineering work once the order rates are decided on the basis of input orders, priority, efficiency and availability of manpower. This is not completely realistic. The time delays would also change in actual practice. The delays could be made variable, but for this study this additional feature is not included.

The completed proposals go to the customer as discussed in the Customer Sector. It is assumed that the contract work completed becomes in part an input to the Factory as specifications for equipments.

The input to the Factory is given by:

ECWS.KL = (ACSS)(ECWC.JK) 50R

where

ECWS = Engineering Contract Work Specifications equipment/month

ACSS = constant, Converting Specification to equipment Shipments equipments per month/man months per month.

The constant ACSS is like AAPO and ACAE, an inter-sector transfer constant. An organization which can work on contracts in which the engineering content is low, or which has a more efficient work force, such that a given number of man months of engineering effort gives more equipments would show a greater volume of business and hence greater profits for a given input. Thus the use of a constant value of ACSS does represent a limitation of the present model. Methods of making it a variable could be devised.

The formulation for engineering technical competence is based on the preceding sector. The average work completed over a year's period is calculated for contracts and the two types of research work. These averages are remembered by using a computer mechanism called a "linear boxcar" which stores the value entered into the first boxcar level and retains successive values for as many time intervals as desired by shifting values to memory cells. The average work levels to be stored are given by:

ECWCA.K	=	ECWCA.J + (DT)(1/TCWC)(ECWC.JK - ECWCA.J)	51L
EGRCA.K	=	EGRCA.J + (DT)(1/TGRE)(EGRWC.JK - EGRCA.J)	52L
ESRCA.K	=	ESRCA.J + (DT)(1/TSRC)(ESRWC.JK - ESRCA.J)	53L

where

ECWCA	=	Engineering Contract Work Average level	man months
EGRCA	=	Engineering General Research Work Average level	man months
ESRCA	=	Engineering Special Research Work Average level	man months
TCWC	=	Time Constant for Contract Work Completion average	months
TGRC	=	Time Constant for General Research Completion Average	months
TSRC	=	Time Constant for Special Research Completion average	months.

The memory of past work is given by:

ETC1	=	BOXLIN (8,12)	54B
ETC2	=	BOXLIN (8,12)	55B

ETC3 = BOXLIN (8,12) 56B

ETC1*1.K = ETC1*1.J + (DT)(ECWCA.J) (input to boxcar memory) 57L

ETC2*1.K = ETC2*1.J + (DT)(EGRCA.J) " 58L

ETC3*1.K = ETC3*1.J + (DT)(ESRCA.J) " 59L

where ETC1, ETC2, and ETC3 denote the linear boxcar device which keeps available the average value of contract, general and special research work completed for eight successive values, shifted every twelve months. The beginning or entry value is the average work completed in each case.

The weighting for the work done each of the previous years is given in Figure 5 which shows the weighting factors for the three types of work. The technical competence contributed by each work effort is given by:

ETC1N.K = (1/ATCN1)(SUM 2(8,W1A,ETC1) 60A

ETC2N.K = (1/ATCM2)(SUM 2(8,W2a,ETC2) 61A

ETC3N.K = (1/ATCN3) (SUM 2(8,W2A,ETC2) 62A

ETTC.K = ETC1N.K + ETC2N.K + ETC3N.K 63A

where ETC1N, ETC2N, and ETC3N are the normalized contributions to technical competence of contract, general research and special research respectively. Each is found by summing for eight years the product of the average work effort each year times the weighting factor assigned to that year's work. The normalizing factors ATCN1, ATCN2, and ATCN3 are direct functions of the maximum possible work levels for each type of effort and as such are related to the input and intersector transfer constants. For a model in which the input value increases the constants must be made functions of the input. The instrumentation for this is shown in Appendix I.

The total technical competence is ETTC.

The engineering department's ability to undertake more work is a function of the inventory of unfilled work request and the available manpower at that time. If the ratio of unfilled requests in man months to the number of available engineers times a normal planning time, say thru to twelve months, becomes very large, the ability to start new work decreases.

The equations are:

EAUW.K = FUNCTION (ETEI.K) 64A

ETEI.K = (PEUMR.K)/(PETA.K)(DPMS)(AEPF) 65A

where

EAUW = Engineering Ability to Undertake Work

ETEI = Engineering Times to Exhaust Inventory
man months/man months

PEUMR = Personnel Engineering Unfilled Manpower Requested
man months

PETA = Personnel Engineering Total Available
men

DPMS = Delay, Personnel Manpower Available
months

Figure 7 gives the functional variation for equation 64A. The total ability to undertake work is given in equation 80A.

Factory Sector

The construction of the equipment produced by the military product development organization is done in the Factory. The input orders to the Factory Sector consist of orders from Engineering in the form of specifications for particular equipments. The specifications are completed in Engineering but may require additional work for drawings, methods engineering, etc. and hence undergo a work process delay before actual construction is initiated. The rate of factory orders ready for actual construction is used by the factory management in their decision concerning production rates initiated. Inventories of orders for equipments received but not yet ordered and received but not yet completed will occur in the normal flow of business.

Since military equipment is similar to custom equipment for which no standard inventories can be maintained, the prime factors controlling production rate include the incoming order, available manpower, facilities , and the desire to maintain backlog at levels permiting maximum utilization of manpower. Equipment totals ordered by engineering will include allowances for testing and tooling studies.

Work will be initiated on those equipments for which factory specifications have been completed. The rate of production will be determined by the available labor force and its productivity. The rate will be equal to the incoming rate as long as the available labor force does not limit the amount of work which can be done. If the labor force is insufficient then an inventory of work ordered but not initiated will build up. This inventory can be reduced by the addition of workers to the factory labor force. This is described in the Personnel-Factory Sector discussion. Until the additional manpower becomes available, the production rate is limited to the number of equipments per month obtainable at the actual factory manpower level.

The equipments are produced using an aggregate time delay and then shipped to the customer. Income is derived on the basis of equipments shipped (including those for testing and tooling studies).

Expenses are incurred for material and labor.

The factor Sector equations follow. Figure 10 presents the flow diagram for the Factory.

The orders from Engineering, ECWS, enter a work process in the Factory for drawing, product engineering, and methods engineering. The level of specification under study and the output rates of factory orders are given by:

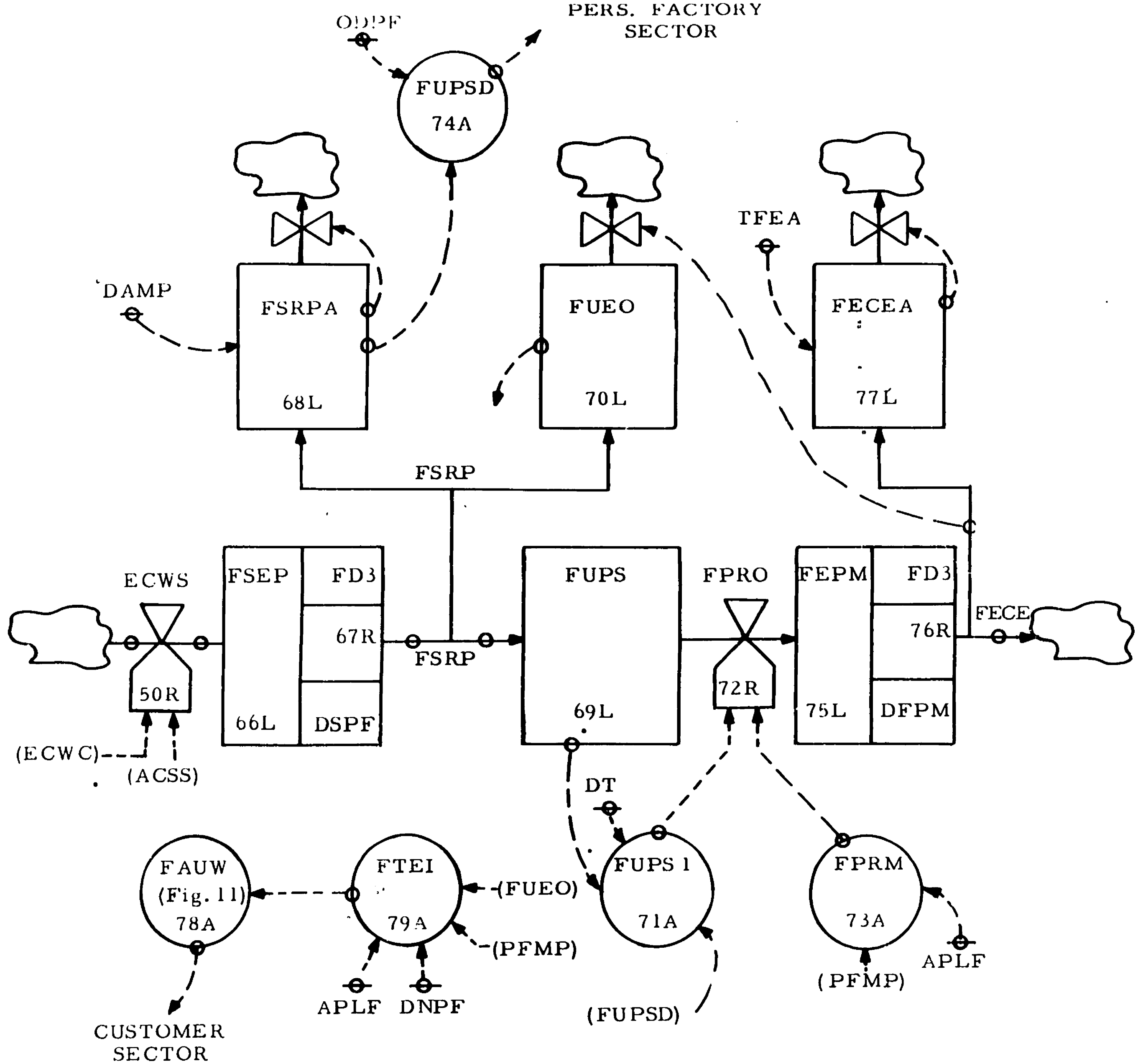

FIGURE 10. FLOW DIAGRAM OF FACTORY SECTOR

FSEP.K = FSEP.J + (DT)(ECWS.JK - FSRP.JK) 66L

FSRP.KL = DELAY 3(ECWS.JK,DSPF) 67R

where

FSEP = Factory Specifications from Engineering in Process
equipments

FSRP = Factory Specifications Ready for Production
equipments/month

DSPF = Delay in Specifications Process at Factory
months.

The average rate of factory specifications is given by:

FSRPA.K = FSRPA.J + (DT)(1/TSPA)(FSRP.JK - FSRPA.J) 68L

where

FSRPA = Factory Specification Ready for Production, Average
equipments/month

TSPA = Time constant for Specification Production Average
months.

The factory specifications ready for initiating production become the input to an unordered production order backlog given by:

FUPS.K = FUPS.J + (DT)(FSRP.JK - EFRD.JK) 69L

where

FUPS = Factory Unordered Production Specifications
equipments

FPRD = Factory Production Rate Decision
equipments/month.

This backlog is the reservoir of accumulated new orders for equipment which have not yet been ordered from the actual factory line. There may also be a reservoir of accumulated new orders not yet completed and shipped which is given by:

FUEO.K = FUEO.J + (DT)(FSRP.JK - FECE.JK) 70L

where

FUEO = Factory Unfilled Equipment Orders
equipment

FECE = Factory Equipments Completed and Exited
equipments/month

FSRP = Factory Specification Ready for Production
equipments/month.

The factory production rate decision, FPRD, is established on the basis of orders, manpower, and desired backlogs as discussed below.

The inventory, FUPS, is increased each DT period by the input rate, FSRP, and this is the rate which should be ordered as long as sufficient manpower is available. The increment in the inventory above a desired backlog FUPSD is given by:

FUPS1.K = (FUPS.K - FUPSD.K)/DT 71A

where

FUPS1 = increment in equipment order per month.

The production rate decision is given by:

FPRD.KL = CLIP(FUPS1.K, FPRM.K, FPRM.K, FUPS1.K) 72R

where

FPRD = Factory Production Rate Decision
equipment/month

FPRM = Factory Production Rate Maximum
equipment/month.

The factory production rate maximum is given by:

FPRM.K = (PFMP.K)(APLF) 73A

where

PFMP = Personnel Factory Manpower total
men

APLF = constant, Productivity Labor Factor
equipments/men month.

Equations 71A, 72R, and 73A state that the production rate is limited by either the incoming rate of orders or the size of the labor force. The production rate FUPS1 is that which would deplete the inventory FUPS to the desired backlog in DT months in the absence of new incoming specifications, assuming adequate manpower.

A desired backlog of equipments is used to establish the size of the factory work force. This desired backlog is given by:

FUPSD.K = (FSRPA.K)(DNPF) 74A

where

FUPSD = Factory Unfilled Production Specification Desired
equipments

FUSRA = Factory Specification Ready for Production
equipments/month

DNPF = Delay for Normal Planning in the Factory
months.

Once the decision to produce equipment at a given rate is made, the manufacturing process is initiated. At any time there will be a certain number of equipments in the manufacturing process. The time delay to completion will be a function of the actual processes and methods as well as the delay in materials and supplies. The equations for the equipments in process and output rate are:

FEPM.K = FEPM.J + (DT)(FPRD.JK - FECE.JK) 75L

FECE.KL = DELAY 3(FPRD.JK,DFPM) 76R

where

FEPM = Factory Equipment in Process of Manufacturing
equipments

DFPM = Delay in Factory Process of Manufacturing
months

The equipments which are completed are tested and shipped to the customer. An average rate of equipment shipments is required in the Operation Control Sector to establish the general research funds. The average is given by:

FECEA.K = FECEA.J + (DT)(1/TFEA)(FECE.JK - FECEA.J) 77L

where

FECEA = Factory Equipment Completed Average
equipments/month

TFEA = Time constant for Factory Equipment Average
month.

The factory ability to undertake work is a function of the ratio of unfilled equipment orders to the available manpower. As this ratio increases the factory becomes less able to undertake work. This is given by:

FAUW.K = FUNCTION (FTEI.K) 78A

FTEI.K = (FUEO.K)/(DNPF)(PFMP.K)(APLF) 79A

where

FAUW = Factory Ability to Undertake Work

FUEO = Factory Unfilled Equipment Orders
equipments.

FTEI = Factory Times to Exhaust Inventory.

Figure 11 gives the function of equation 78A.

The total ability to undertake work, TAUW, is the sum of the Engineering and Factory, abilities to undertake work, EAUW and FAUW given by:

TAUW.K = EAUW.K + FAUW.K 80A

Personnel-Engineering Sector

The personnel department is responsible for recruiting additional personnel required for the business of the organization. For the purposes of this model, it is assumed that recruiting is done for Engineering and the Factory and that the other sections are adequately manned. Their sizes will vary of course, but the manpower variations for these sectors are assumed to be included in the two department manpower variations presented.

The total available manpower in Engineering varies as the engineers enter due to hiring decisions or leave. The size of the staff desired is that necessary to accomplish the work requests forwarded by Marketing. It is not reasonable to

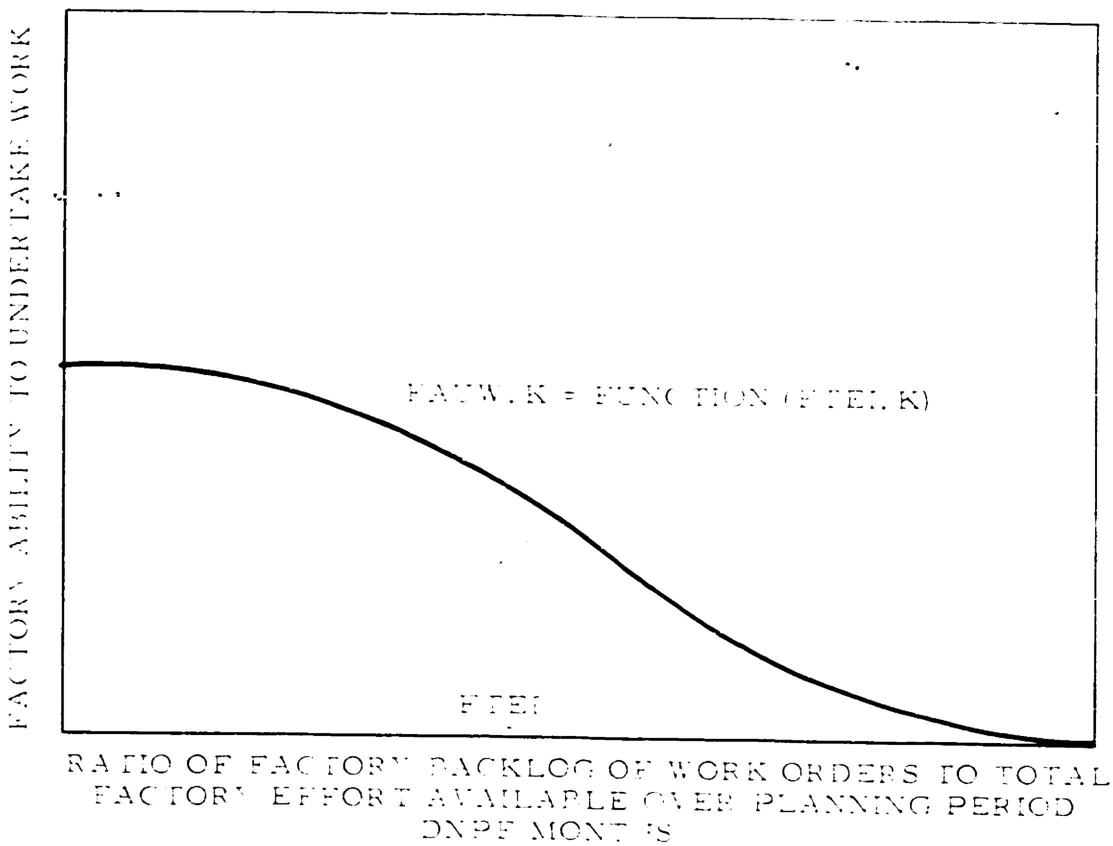

FIGURE 11. FACTORY ABILITY TO UNDERTAKE WORK AS FUNCTION OF BACKLOG

keep adding manpower to reduce the level of requests to zero. Thus a normal backlog of work requests would be maintained and manpower added as the income work requests exceed this normal value. The hiring ratio also would not be expected to follow every fluctuation in input requests. Thus the hiring is done to handle increases in average work requests and to adjust to the desired backlog over a given time period.

If the work requests decrease, in today's market engineers are not usually fired. However if there is a number of engineers not engaged in one of the four types of work, a certain percentage would leave voluntarily, especially if this number is substantial.

There will be an appreciable delay in hiring engineers also, so the decision as to the desirable work backlog and time period to attempt to reduce unbalances in manpower levels is an important determinant of system behavior.

The system equations are formulated below. Figure 12 gives the flow diagram for the Personnel-Engineering Sector.

The total available engineering force is given by:

PETA.K = PETA.J + (DT)(PELE.JK - PELT.JK) 81L

where

PETA = Personnel Engineers Total Available
man

PELE = Personnel Engineering Labor Entering
man/month

PELT = Personnel Engineering Labor Terminations
man/month.

The total engineering work requests received at Marketing, are given by:

PEMRT.KL = MRFPE.JK + MCAE.JK + MGGRE.JK + MOSRE.JK 82R

where

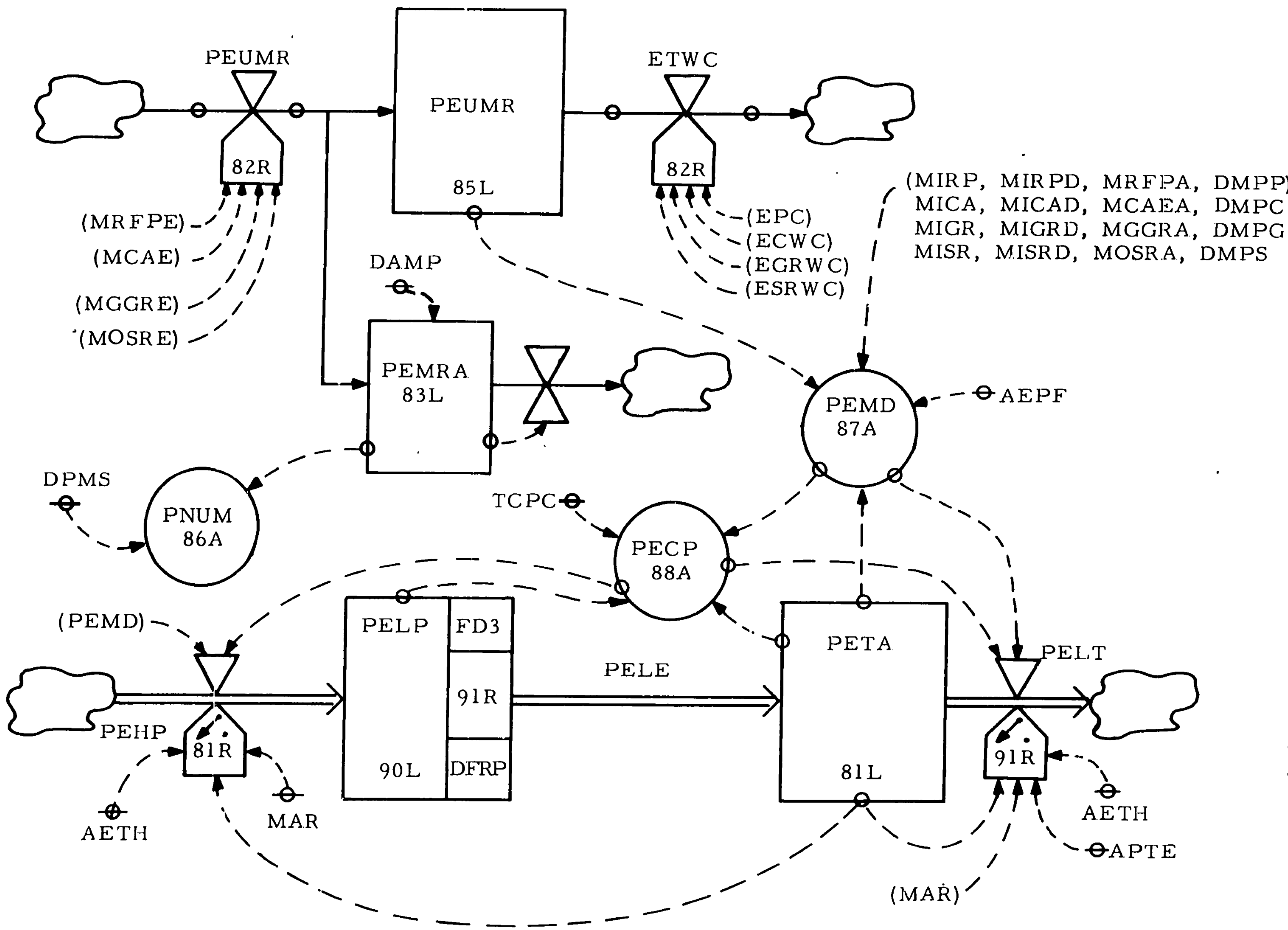

FIGURE 12. FLOW DIAGRAM OF PERSONNEL-ENGINEERING SECTOR

PEMRT = Personnel Engineering Manpower Requests Total
man months/month.

The average value of PEMRA is PEMRA and is given by:

PEMRA.K = PEMRA.J + (DT)(1/DAMP)(PEMRT.JK - PEMRA.J) 83L

where

DAMP = Delay for Averaging Man Power requests
month.

The order rates MRFPE, MCAE and MOSRE are given by equations 7R, 10R, 13R, and 14R respectively.

The total rate of work completion is given by:

ETWC.K = EPC.JK + ECWC.JK + EGRWC.JK + ESRWC.JK 84R

where

ETWC = Engineering Total Work Completed rate
man months/month.

The expressions for EPC, ECWC, EGRWC, and ESRWC are given by equations 46R, 47R, 48R and 49R respectively.

The total level of work requested but not completed work is given by:

PEUMR.K = PEUMR.J + (DT)(PEMRT.JK - ETWC.JK) 85L

where

PEUMR = Personnel Engineering Unfilled Manpower Requests
men.

Normal backlogs of work exist as discussed on page 31. These desired backlogs are given by MIRPD, MICAD, MIGRD and MISRD for proposals, contracts, general research and special research respectively. Each is found by multiplying the average input rates MRFPA, MCAEA, MGGRA, and MOSRA by DMPP, DMPC, DMPG and DMPS respectively as shown in Appendix Two, page 112.

An overall normal backlog is given by:

DNUM.K = (DPMS+DT)(PEMRA.K)+(DPPW)(MRFPA.K)+(DECW)(MCAEA.K)+(DGRW)(MGGRA.K)+(DSRW)(MOSRA.K) 86A

when DPMS is a single normal planning delay if the individual planning delays are assumed equal. Varying values of average backlogs delays could also be used.

If the unfilled inventory exceeds the normal value, more manpower is needed to avoid missing due dates for work completion. As the backlog gets less, marketing effort is intensified as discussed earlier.

The total desired manpower PEMD is given by:

PEMD.K = PEPWD.K + PECWD.K + PEGWD.K + PESWD.K   87A

The four terms on the right hand side of equation 87A are shown in detail on page 113. Each includes a desired level for average orders and a backlog adjustment.

The second terms in the desired manpower levels on page 113 represent the fractions of the excess of the actual backlogs over the desired backlogs that are added to each averaged level of orders. These backlog adjustments are positive for increases in input orders if the averaging time constants for computing average orders exceed the time constants used to establish the normal number of months backlog. Each adjustment time could be made different.

The policy concerning the change in the size of the engineering staff is given by:

PECP.K = (1/TPCP)(PEMD.K - PETA.K - PELP.K)   88A

where

PECP = Personnel Engineering Change Policy
man/month

TPCP = Time constant for Personnel Change Policy
month.

The actual hiring rate, PEHP, is set by:

PEHP.KL = PECP.K when PEMD.K - PETA.K ≥ AETH.   89R load changes the manpower necessary to implement the production rate desired will vary. The productivity of the labor force and the desired normal backlog establishes the necessary level of employees. The labor market is entered when the production rate decision is limited by availability of manpower.

Thus if the input rate of equipment specification increases the following occurs. The inventories of equipments ordered but not yet started and ordered but not completed will increase directly. The average input rate starts to increase as does the excess of orders over the desired backlog if TSPA is greater than DNPF. Thus the rate of production should increase both because of the average increase and the backlog adjustment and if personnel are available it will. If not, all personnel will be used at the maximum rate and the personnel department will start recruiting.

The equations follow. Figure 13 shows the flow of diagram for the Personnel Factory Sector.

The level of manpower in the factor at any time is given by:

PFMP.K = PFMP.J + (DT)(PFLE.JK - PFLT.JK) 93L

where

PFMP = Personnel Factory Man Power — men

PFLE = Personnel Factory Labor Entering — men/month

PFLT = Personnel Factory Labor Terminations — men/month

The production rate decision PPRD was formulated in equation 72R to correspond to theinput order rate if the factory manpower level is adequate. The labor force desired for the various work orders would vary from job to job. Thus for complete realism a labor productivity factor should be formulated which varies with work content. For this aggregate model however a constant

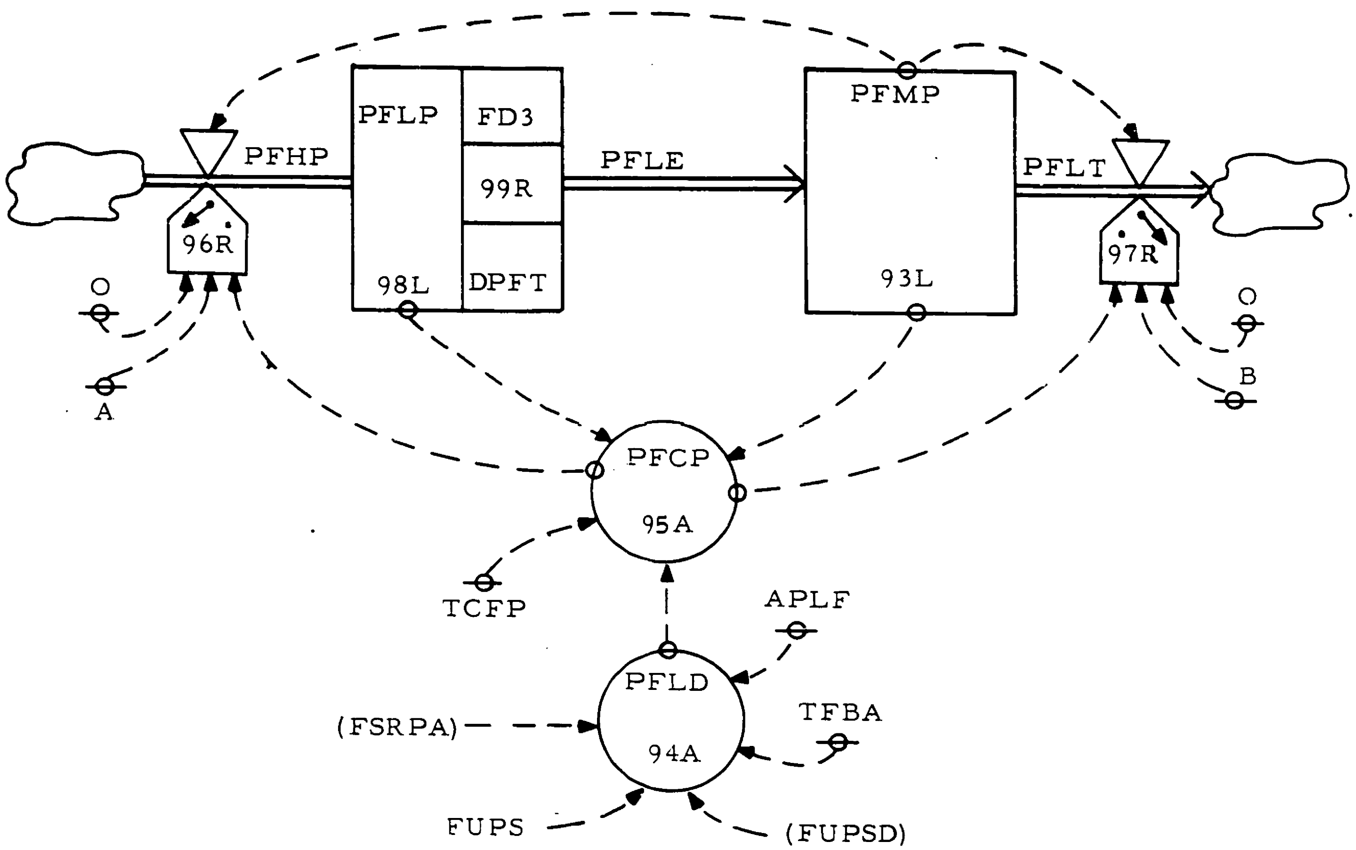

FIGURE 13. FLOW DIAGRAM OF PERSONNEL-FACTORY SECTOR

productivity is assumed and the desired work force is given by:

PFLD.E = FSRDA.K/APLF + (1/TFBA)(FUPS.K - FUPSD.K)/APLF 94A

where

PFLD = Personnel Factory Labor Desired — men

TFBA = Time constant Factory Backlog Adjustment — months

APLF = constant, Productivity of Labor Force — equipments per month/man.

This equation states that the desired size of the labor force is equal to the average for equipments plus a backlog equipment adjust, both divided by the labor productivity factor. This adjustment is a fraction of the excess of the actual backlog over the desired backlog. The adjustment is positive if TSPA is greater than DNDF.

When this desired labor force varies from the actual, a factory personnel change policy must be established such as:

PFCP.K = (1/TCFP)(PFLD.K - PFMP.K -PFLP.K). 95A

where

PFCP = Personnel Factory Change Policy — men/month

TCFP = Time constant Change Factory Policy — month.

The factory management probably will have threshold values of numbers of factory personnel such that when the number of personnel which they should hire or fire exceed these thresholds, action will be taken. The model is so formulated as noted in Appendix I.

The hiring and firing rates are given by:

PFHP.KL = PFCP.K if PFLD.K - PFMP.K $\geq$ A
PFHP.KL = 0 if PFLD.K - PFMP.K $<$ A 96R

and

PFLT.KL = -PFCD.K if PFLD.K - PFCP $\leq$ B
PFLT.KL = 0 if PFLD.K - PFCP $>$ B 97R

where

PFHP = Personnel Factory Hiring Policy

PFLT = Personnel Factory Labor Termination policy,

and A and B are the thresholds for hiring and firing respectively.

When a decision to hire results, it takes time to find acceptable personnel, the level of personnel in the process of joining the organization are given by:

PFLP.K = PFLP.J + (DT)(PFHP.JK - PFLE.JK) 98L

PFLE.KL = DELAY 3(PFHP.JK,DPFT) 99R

where

PFLD = Personnel Factory Labor in Process men

PFLE = Personnel Factory Labor in Entering men/month

DPFT = Delay, Personnel Factory Training and recruiting month.

Operations Control Sector

The responsibility for the financial flows in the organization rest with Operations Control. This department gathers information from other departments to establish expense and income rates. The department would also participate in the negotiations concerning profit rates, for which Marketing would have prime responsibility. The problems of capital budgeting, cash management, dividend dispursements, etc. are notincluded in this model study. Instead, the net income will be ascertained from the actual work on contracts in the engineering and factory departments. Since the expenses incurred in proposal preparation are usually charged to a general administrative expense with a negotiated rate for this used in establishing allowable costs, the work in proposals is included as an income item. The rates to be used for men months labor and equipment changes are such as to cover the other department expenses.

The total income is thus found from the work on proposals and contracts, the equipments completed, and the income for general research. This last is a percentage of the income from equipment shipments. Each income rate uses the appropriate profit rate. It is assumed that the profit rate for equipments shipped from the factory can be increased above a fixed value as the technical competence increases. This in effect provides a reward for a product which represents the innovator's more favorable competitive advantage. This is the direct monetary reward for effort expended in previous years on research activities. The money for special research is not included since it is derived from the organization's profits.

The total expenses are calculated using the rates for manpower and equipment material. These are charged at the present levels of manpower in the engineering and factory departments and equipment deliveries respectively.

The profit rate before taxes is calculated as the difference of the two total rates above. The organization may decide to invest a certain percentage of this profit if the ratio of the profit to total income is above a value established by an overall organization policy. The net profit rate is found by subcontracting taxes (one half the profit before taxes) and the income diverted to special research from the profit before taxes.

The effect of decisions to do more proposal work as this opportunity occurs, or to do more research work, which is implicit in the Order Rules for establishing work priorities in Marketing, can be noted as follows. The use of available personnel to work on proposals in place of on research work will increase the opportunity for receiving fairly early more contracts, as more proposals will be submitted for evaluation. The long term effect may be to decrease future proposal acceptability, and hence business, since technical competence will not be built up. The policy to let research work go until more manpower is recruited has another effect also. The profit rate on equipments will decrease since the technical competence will not reflect the increase which would result from work done on research. If research is done, and proposals left waiting for the acquisition from recruiting, then the fact that the backlog of proposals not yet initiated builds up will result in a certain percentage becoming invalid.

The final aspect of manpower utilization is the effect on competitive price acceptability of the organization's proposals. To avoid a complicated formulation, the assumption is made that the presence of personnel unassigned to the four types of usual work effort in Engineering represents an inefficient management. Thus a decrease in price acceptability occurs as the percentage of the total staff unassigned increases. This may not always be the main effect of such unassigned personnel however. If a sudden increase of customer requests for proposals occurs, the presence of unassigned personnel may permit the organization to react more optionally, depending upon the Order Rule of Priority used in Marketing.

The equations used in the Operation Control Sectory follow. Figure 14 presents the flows in this sector.

The price acceptability of proposals, OCPC, used in equation 12A is given by:

OCPC.K = 1 - (AEC)(MAR.K)/(PETA.K) 100A

where

MAR = Manpower Available for Reassignment — men

PETA = Personnel Engineering Total Available — men

AEC = constant, Engineering Cost variation — dimensionless.

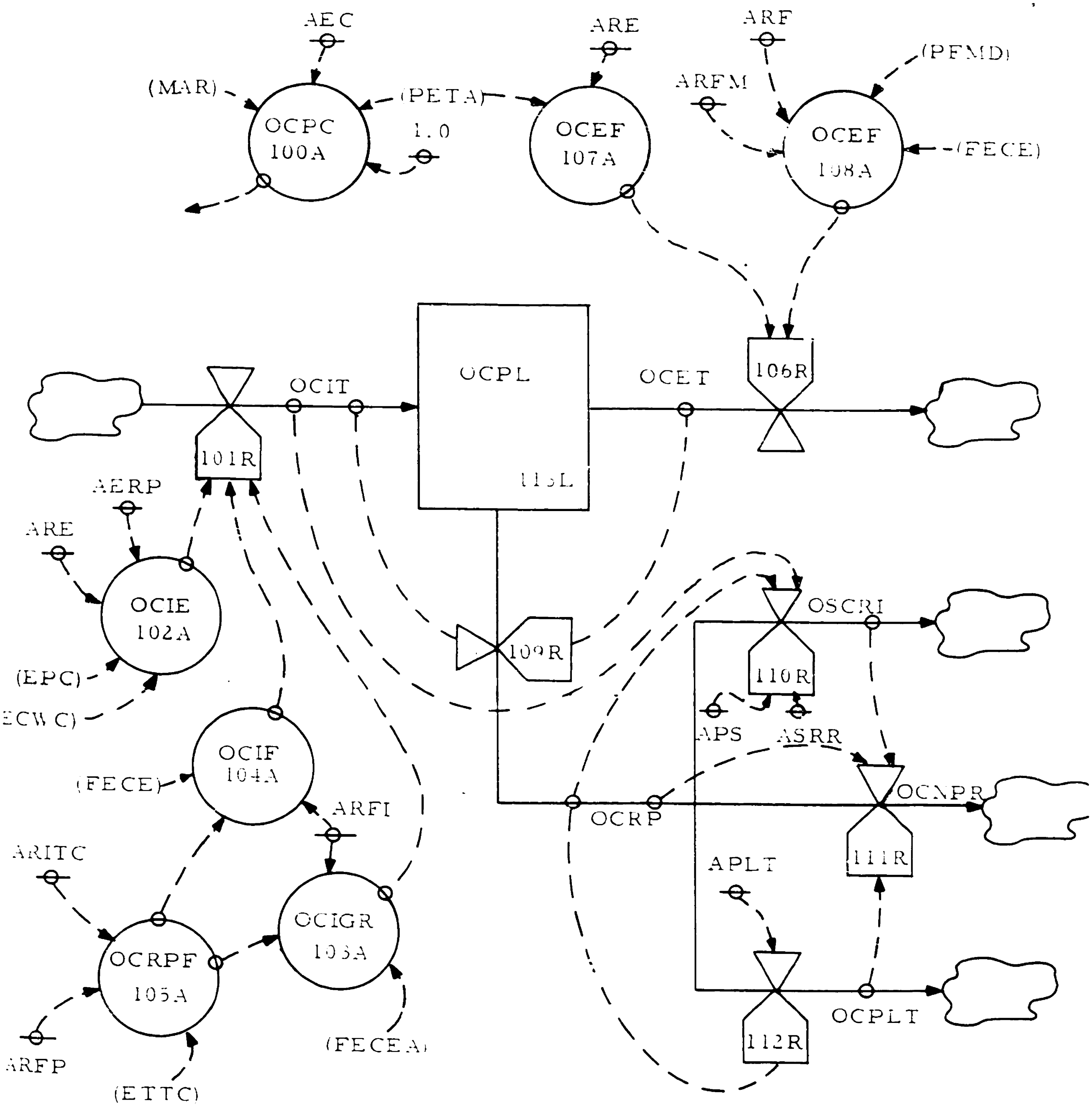

FIGURE 14. FLOW DIAGRAM OF OPERATIONS CONTROL SECTOR

The total rate of income to the organization is:

OCIT.KL = OCIE.K + OCIGR.K + OCIF.K   101R

where

OCIT = Operations Control Income Total   dollars/month

OCIE = Operations Control Income Engineering   dollars/month

OCIGR = Operations Control Income General Research   dollars/month

OCIF = Operations Control Income Factory   dollars/month.

The incomes in equation 101A are given by:

OCIE.K = (ARE)(AERP)(EPC.JK + ECWC.JK)   102A

OCIGR.K = (ARGR)(ARFI)(FECEA.K) (OCRPF.K)   103A

OCIF.K = (ARFI)(OCRPF.K)(FECE.JK)   104A

where

ARE = constant, Rate for Engineers   dollars/man month

AERP = constant, Engineering Rate of Profit

EDC + ECWC = Engineering Proposals Completed + Contract Work Completed   man month/month

ARGR = constant, percentage Rate for General Research

ARFI = constant, Rate for Factory Income   dollars/equipment

OCRPF = Operations Control Rate of Profit for Factory $ per mo/$ per mo.

FECE = Factory Equipment Completed   equipment/month.

The rate of profit for the factory is given by:

OCRPF.K = ARFP + (ARITC)(ETTC.K)   105A

where

ARFP = Constant, fixed Rate of Factory Profit

ARITC = Constant, Rate Increase for Technical Competence

The total rate of expenses of the organization are given by:

OCET.KL = OCEE.K + OCEF.K 106R

where

OCET = Operations Control Expenses Total dollars/month

OCEE = Operations Control Engineering Expenses dollars/month

OCEF = Operations Control Expenses of Factory dollars/month.

The two expense rates are given by:

OCEE.K = (ARE)(PETA.K) 107A

OCEF.K = (ARF)(PFMP.K) + (ARFM)(FECE.JK) 108A

where

ARF = Constant, Rate for Factory personnel dollars/month

ARFM = Constant, Rate for Factory Material dollars/equipment.

The profit rate before taxes, OCRP, is given by:

OCRP.KL = OCIT.K - OCET.K 109R

A certain percentage of this profit rate may be reinvested for special research, if the ratio of OCRP to OCIT is above a minimum value. This is given by:

OCSRI.KL = (ASRR)(OCRP.JK) 110R

if (OCRP.JK)/(OCIT.K) $\geq$ APS

where

OCSRI = Operations Control Special Research Income dollars/month

ASRR = constant, Special Research Rate

APS = constant, Profit minimum for Special research.

The net profit rate is given by:

OCNPR.KL = OCRP.JK - OCSRI.JK - OCPLT.JK 111R

where

OCNPR = Operations Control Net Profit Rate dollars/month

OCPLT = Operations Control Profit Loss to Taxes dollars/month

OCPLT.KL = (ALPT)(OCRP.JK) 112R

and

APLT = constant, Profit Loss to Taxes.

The profit level, OCPL, is given by:

OCPL.K = OCPL.J + (DT)(OCNPR.JK) 113L

Either the net profit rate or profit level may be considered as an indication of the organization's success.

CHAPTER IV

SIMULATION OF SYSTEM BEHAVIOR

The preceding chapter has discussed the formulation of the major defining equations which represent the flows and decisions involving the significant commodities in the system. Before proceeding to a discussion of the actual computer runs, the general problems in preparing for these runs are discussed here. These include establishing the intersector transfer functions and constants, setting steady state and initial conditions, determining transient behavior modes, and preparing equations suitable for programming.

Inter-Sector Transfers Functions and Constants

The flow of business through the organization was discussed in a general manner in Chapter II as represented in Figure 1. The major equations were formulated in Chapter III and each sector flow shown in a separate symbolic flow diagram. Figure 15 presents a diagram of the total business flow. It is noticed that in addition to the sequential flow from proposals requests into the organization to final equipments shipped, a number of decisions concerning flows in one sector are functions of quantities which are established in other sectors. In addition, the relation between the flow of one type of commodity to the resultant sequential but different commodity flow in another sector requires a determination of the transfer ratio or function between the flows.

These two general types of inter-sector quantities are listed below.

The inter-sector functional dependences used in the rate decision expressions are:

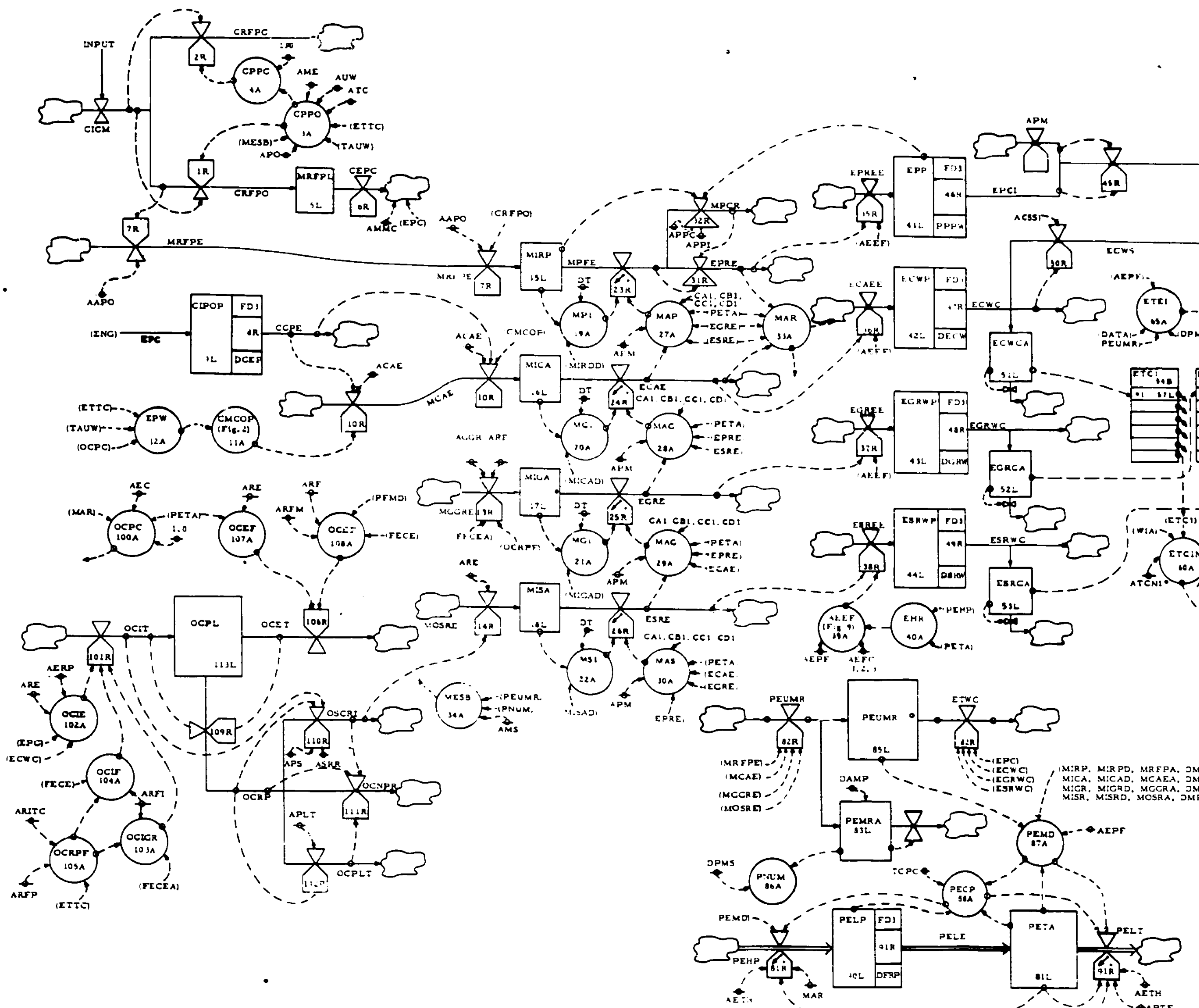

FIGURE 15. FLOW DIAGRAM OF OVERALL ORGANIZA

CPPO	=	Customer Proposal Percentage to Organization	Eq. 3A
CMCOP	=	Customer Marketing Contracts Obtained Percentage	Eq. 11A
MESB	=	Marketing Effort to Solicit Business	Eq. 34A
ETTC	=	Engineering Total Technical Competence	Eq. 63A
EPW	=	Engineering Proposal Worth	Eq. 12A
EAUW	=	Engineering Ability to Undertake Work	Eq. 64A
AEEF	=	Engineering Efficiency Factor	Eq. 39A
FAUW	=	Factory Ability to Undertake Work	Eq. 78A
OCPC	=	Operation Control Price Capability	Eq. 100A
OCRPF	=	Operation Control Rate of Profit in Factory	Eq. 105A

CPPO depends on MESB, EAUW, FAUW, and ETTC and determines the flow of proposals presented to the organization. CMCOP depends on EPW and establishes the percentage of contract awards from completed proposals. MESB depends on the total engineering work load requests and completions and influences the proposals received by Marketing. ETTC depends on the work done in past years on contracts, and general and special research. EPW is a function of ETTC, EAUW, FAUW and OCPC. EAUW and FAUW depend on backlogs of work and the size of work forces. AEEF depends on the engineering recruiting effort. OCPC depends on the unassigned manpower. OCRPF depends on ETTC and establishes income from the factory.

These inter-sector functional relations have been formulated in a relatively simple manner using background knowledge of typical organizations. The weighting of the various system parameters entering into these ten basic inter-sector functional relationships is given in each equation listed.

The weighting on CPPO of marketing effort, backlog load, and technical competence above the minimum value of APO is determined by AME, AUW, and ATC. The sensitivity of marketing effort to backlogs of work is a function of AMS. The backlogs depend on normal delay planning times DPMS and DNPF for Engineering and the Factory. The technical competence depends on past contract, general research and special research efforts weighted by: W1A, ATCN1, W2A, ATCN2, and W3A, ATCN3 respectively. The contract work received depends on the engineering proposal worth EPW which is a function of competence, backlog, and price, weighted by AETC, AAUW, and APP respectively. The general research is the fraction ARGR of the income for the factory work load. The special research is a fraction ASRR of profits above a certain ratio APS of profits to total income. Each of the work outputs depends on engineering efficiency AEEF which is a function of recruiting effort expressed as a percentage of present staff level PETA. The price factory OCPC depends on unassigned manpower MAR. The factory profit depends on technical competence.

In addition to the above inter-sector functional variations certain constant ratios between flows are assumed which affect the levels of business. These are

AAPO converts $/mo proposal requested to mm/m proposal requested

ACAE converts mm/m proposals evaluated to mm/m contract authorized

ACSS converts mm/m contract work completed to equip/mo orders initiated

AEPF converts mm/m work requests normal to mm/m effort actual

APLF converts mm/m factory effort to equip/mo

APCC converts mm unforwarded proposals to lost proposals

APTE converts m unassigned to mm/m engineering percentage terminations

These plus the charging rates and profit rates given in the Operations Control sector are all assumed constant although each actually approaches a single value in an aggregate sense only.

Steady State Considerations and Initial Conditions

The model formulated for this study is essentially a growth model in that a fixed rate of input requests will cause a steady growth of the net profit level considered as the system output or a fixed rate of net profit in the steady state. To initiate any computer run the system should be in a stable steady state value such that with the initial input value left fixed, the system variable will not change regardless of the length of run. Considerable energy was expended to arrive at a method of determining initial values of the system variables and a value of initial total technical competence ETTC1 which would meet this condition. The system depends to a large extent upon the technical competence factor ETTC, which in turn is a function of work done over the past eight years in three areas. Therefore the condition of absolute steady state is obtained only by tieing all initial values of equation variables to the input value CICMN and setting the past eight years average work at the maximum obtainable values of contract and research work values. These maximum values are determined by the constants and weighting factors discussed in the first part of this chapter and are given in Appendix I.

Thus in the absolute steady state the system settles to the maximum values of the percentage of proposals referred to the organization and contracts obtained from completed proposals as given by CPPOT = APO + AME + AUW + APP and CMCOP = 1 respectively. These maximums are MPREM = CPPOT x AAPO x CICM and MCAEM = ACAE x MPREM respectively. These values result from the limiting values of MESB = 1.0 - AMS; ETTC = 1.0;EPW = 1.0; EAUW = F(1) = 0.57; AERF = AEPF; FAUW = F(1) = 0.47; OCPC= 1.0; and OCRPF $\pm$ ARFP + ARITC. The equations from which these result are given on pages 7,8 and 9 of Appendix I where the maximum values of contract, general research, and special research, MCAEM, MGGRM, and MOSMR respectively, are determined. There are MCA11, MCA21, and MOSM1 respectively.

Thus if any computer run is initiated with the past eight years average work in the areas of contracts and research less than the maximum values above the technical competence will be less than unity. Eventually the technical competence will increase, the proposal flow will increase, people will be hired, and the system will eventually drive all values to the limits of the previous paragraph and a maximum profit rate will be obtained. The time and manner of reaching the steady state and the integrated profit obtained will vary depending upon the time constants and delays used as well as the Order Rule priority used by Marketing. This is discussed in the remainder of this chapter.

In establishing the initial conditions for the computer runs, the initial values of total availability to undertake work TAUW, price factor OCPC, marketing effort MESB had to be given numerical values in place of literal values to avoid the fallacy of simultaneous initial value equations which the computer can not solve. In addition the ratio of two identical literal expressions is not recognized as unity by the computer. The computer searches for the final numerical input which can lead to simultanity in the given literal expressions.

A value of ETTC other than unity can be used as a realistic initial starting point. This could represent the effect of a sudden change in policy concerning the reinvestment of earnings or the ability to negotiate higher profit or general research rates. In either case the work in past years need not necessarily correspond to the new maximum rates. This is done in the model by storing in the boxcars ETC1, ETC2, and ETC3 values of average levels of work in the preceding eight years at levels below the maximum values. In addition with a growing or changing input, the maximum values also change. For this reason the normalizing constants ATCN, ATCN2, and ATCN3 have been made functions of the changing maximum values MCAEM, MGGRM and MOSMR respectively as shown on page 6 of Appendix I.

The model can be used to study growth situations as well as reactions to sudden changes in market conditions. This done by setting ETTC1 as a low value and applying a sudden step or ramp of orders CICM to the system.

Transient Behavior Modes

As discussed above the final steady state to which a model with a given set of inter-sector transfer functions and constants will approach will be a direct function of the input and the constants. The manner in which the organization reaches that final condition is a function of the system delays, time constants, and most particularly the Order Rules used by Marketing to establish the priority of handling various work requests.

The choices concern the order of using manpower for proposals, contracts, general research and special research and is expressed by the equations for MAP, MAC, MAG, and MAS respectively. These are given on pages 3 and 4 of Appendix I. For any priority rule chose, the available manpower is successively assigned to the work requests in the order desired. If at any time it develops that a given type of work requests requires more people than are available, that work is requested from engineering at the available manpower level only. All lower priority work must await the acquisition of manpower. The backlogs of work request but not ordered from engineering are given by MIRP, MICA, MIGR, and MISR for proposals, contracts, general research and special research respectively. The recruiting effort is a function of the excess of these backlogs over a normal value since the recruiting effort seeks to adjust for backlogs as well as average orders. This is essentially an additional information source to Personnel-Engineering which intensifies recruiting effort. It also lowers efficiency as engineers spend time on recruiting.

The evaluation of the effect of a number of different Order Rules is discussed in Chapter IV.

Equation Programming for DYNAMO Computer Runs

The use of the IBM computer in the MIT Computation Center for running Industrial Dynamic models using the DYNAMO computer program is discussed in the references.[8,9] Considerable time was spent in writing the equations of Chapter III in a correct form for DYNAMO programming.

The actual program equations are given in Appendix I with the numerical values of all constants and time delays.

Considerable difficulty was encountered during a series of test runs with the inter-sector functional equations which couple the sectors. The variations in EAUW, FAUW, MESB, OCPC, MPRC, and AEEF from one computing interval to the next caused oscillatory changes in the variables EPRE, ECAE, EGRE, and ESRE. This is due to the quick variation in CRFPO and CMCOP. Sudden changes in the inter-sector functions cause corresponding changes in the proposals and contracts entered into Marketing.

The computer equations for the six inter-sector functions were modified as shown in Appendix Two to decrease the inter-sector coupling. For each computing period, any change in one of the function values is compared to the value for the preceding computing period and a fraction of this difference noted. This fractional difference is then added to the preceding value, giving the actual function value to be used.

If a given variable is changed suddenly to a larger value which then remains fixed, and a 10 percent fraction of the difference is used, then in one month (ten computing periods for DT = 0.1 month) the variable increases by 69 percent. The percentage increase becomes 90 and 99 percent in one month for fractions of 20 and 40 percent respectively. The actual equations are given in Appendix Two. The result is equivalent to the addition of a delay in the coupling functions. The rate of proposal cancellations MPRC which results from a build up of proposal requests when there is insufficient manpower was also modified as shown in Appendix Two.

Changes in the formulation of ETTC and the engineering hiring and terminating policies, PEHD and PELT, were also found to be necessary as a result of computer runs.

The equations for ETTC were modified in a manner similar to that discussed above for the six inter-sector coupling functions. The shifting of a new yearly average of work in the equations for ETC1, ETC2, and ETC3 caused abrupt changes in the three components of engineering technical competence. Therefore, the changes were made gradual with the use of a level equation as an auxiliary as shown in detail in Appendix Two. With a value of AFTC1, AFTC2, and AFTC3 set equal to 0.025, by the end of about 40 computing periods of four months, the variation on the respective technical competences will have been gradually changed to about 68% of their final values.

Early computer runs with large inputs indicated that the personnel-engineering sector formulation allowed continual hiring of engineers even after a level of unassigned engineers, MAR, existed. Therefore the changes shown in Appendix Two were added to indicate a different policy. Hiring is discontinued if the level of unassigned engineers exceeds the desired rate of hiring. Those engineers who had been contacted before and accepted would still join the organization and the model permits this. This change makes the model more realistic. The termination policy is treated in a similar manner. When the unassigned level of engineers exceeds a fixed number, say 5 engineers, voluntary terminations begin to occur. When these terminations were suspended until the desired manpower rate of hiring became less then a fixed number, the results were unsatisfactory. The level of unassigned engineers remained large, with resultant continuing losses.

It is important to note that the use of the fractional change discussed above adds another series of constants whose effect on system performance would require systematic investigation in a long range thorough research study. The effect of ACMEB, AEEF,ACEAW, ACFAW, ACDC, AEPCC, AFTC1, AFTC2, and AFTC3 is to add delays in the effectiveness of inter-sector couplings. Again these changes are in the nature of closer approaches to realism. The need for these modifications becomes evident as computer runs are studied to explain variations in the time histories of significant variables such as shown in the figures of actual computer runs.

CHAPTER V

DYNAMO COMPUTER RESULTS

The preceding chapters have discussed a complete mathematical model of the various organization sectors, the factors entering into the level, rate, and auxiliary equations, the inter-sector dependence, and the setting of initial values. The complete set of equations is given in Appendix I.

The model has a very large number of parameters which determine the system response. These include the weighting factors, transfer constants, rates, delays, time constants, and decision factors which determine its behavior to any given input. The total number of parameters are

Weighting Factors	14	
Sector constants	12	
Inter-sector coupling delays	9	
Rates	10	
Delays and time constants	24	
Order Rule decision factors	24	(variation of 4 items one at a time =4!)

This gives a total of 93 items to vary.* It is obvious first, that all 93 items need not be varied one at a time to study the system response and second, that some quantities will have little effect if varied over substantial ranges. The choice of which runs to make, in view of the many variables and the short total time for this study, is a

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* If different delay times for desired backlags in the four work areas of engineering are used, then four more variables are introduced.

difficult one, but it, like many of the dec

in the model itself, must be decided.

A study of the dependence of the sys

Rules used to assign manpower, and to react

first priority in the thesis research study

seem the most significant

Order Rule	α	β
Priority in Assignment		
First	C	G
Second	P	C
Third	G	P
Fourth	S	S

where P = Proposals, C = Contracts, G = G

Research.

The next decision concerns the type

existing steady state levels to use for co

defense budget of $4.08 billion per year w

and CICMN = 340,000,000 dollars per month

A ten percent step increase was imposed on

maximum input of $374,000,000 per month.

average efforts in the contract and resear

to set the initial boxcar - remembered val

initial engineering total technical compet

were selected at a fraction of the maximum

initial engineering technical competence c

average value of the input builds up, the

ATCN2, and ATCN3 increase also from the initial values corresponding t the $364,000,000 per month level to the values for the final input rat of $374,000,000 per month.

Runs were also made to simulate growth models by starting at CICM = $10,000,000 month, ETTC1 = 0 and applying a step of $364,000,00 per month to provide the same final maximum value as the first series runs. The values of ATCN1, ATCN2, and ATCN3 were initially set at values corresponding to levels of $10,000,000 per month.

To examine the basic time response of the system and hence establish a reasonable length of run, a series of pulse input runs wer used. In these an impulse input equivalent to a half month amount of proposal requests or $340,000,000/month x 1/2 month was impressed on t system initially in a steady state corresponding to CICM = $10,000,0 per month and ETTC1 = 0.

Appendix Two presents the computer equations used for the signi icant computer runs. Appendix Three presents the details of the comput results and reproductions of the IBM print-outs.

Figure III-1 shows the system growth to an impressed step of $364,000,000 per month when applied to the equivalent of a newly creat organization. The assumption of uniform policy decisions and/or functi relations remaining constant during the complete growth period is not valid of course, but the model does give a representative comparison. The effect of Order Rule priorities is seen to be important in that applying higher priorities to special research yields more profit.

Figures III-2 and III-3 show the variation of system response to the ten percent step increase of the input rate of proposal requests.

It is seen from Table III-2 that while all cases will approach the same final steady state eventually, that the decision to assign lowest priority to proposals, Order Rule Eta, as compared to other Order Rules reduces the integrated net profit rate considerably at 180 months.

Figure III-4 shows the time responses of systems with Order Rule Epsilon, the impulse input.

Figures III-5 and III-6 show the system response to ramp inputs of about six percent of the $364,000,000 per month value applied to organization originally with no technical competence.

With the limited time available, both computer time and real time, only a limited exploration of the multidimensional matrix of variables could be investigated. The problem of backlog adjustments in the various work efforts in engineering is one area for example which could be examined to establish system sensitivity. The extension to considering for quality levels of engineering talent, with the recruiting of high quality, experienced engineers increasing technical competence more quickly is also possible. The slow growth of technical competence can be considered more a first result of initial model formulation which can be modified after the system has been thoroughly "de-bugged".

CHAPTER VI

SUMMARY AND CONCLUSION

Summary

This thesis presents a dynamic model study of a typical organization engaged in designing and producing custom equipment for the nation's defense market. The method used is that of Industrial Dynamics as developed at the School of Industrial Management, Massachusetts Institute of Technology. The flow of business and the variation of the level of work and profits are studied under as realistic conditions as possible. The following elements of the business are included:

a) requests for proposals received by the organization which are influenced by competence, backlogs and marketing efforts,

b) contract awards resulting from completed proposals on the basis of proposal worth,

c) proposal worth influenced by competence, extent of work load, and price consideration,

d) competence resulting from work on contracts and government and organization sponsored research,

e) work in the organization limited by availability of manpower in engineering and the factory,

f) recruiting a function of average orders and the desire to maintain backlogs commensurate with normal work loads in engineering and the factory,

g) variation of engineering efficiency with recruiting efforts, and

h) equipment profit rates increasing, within limits, with competence.

A complete dynamic model is formulated and all the equation necessary for digital computer simulation have been programmed. Computer runs which demonstrate the flow of business in the organization under different orders of priority for utilizing manpower on proposals, contracts, and government and special research have been made.

The limited number of runs made clearly show the effect on the profit levels and the response times of the organization due to priority of manpower use. The effect on the growth of the organization of different priorities in the use of manpower is also evident from the dynamic model studied.

Conclusions

Conclusions based on the research study which this thesis report summarizes can be made in two areas - the particular studies of the organization for which the model was built and the use of Industrial Dynamics Techniques for management research.

A thorough study of the dynamics of the flow of business in the organizations serving the defense market could engage a group of staff specialists for much longer than the time which has been available to the author. However a model was developed and it was found that the interactions between the different functions in a research and development organization are quite important. Time was not adequate to systematically study the influence of different delays in the various work processes and constant values for transfer functions were used where it is known that these can and do vary. The optimization for the long term is seen to provide a substantial improvement in profits for the model studied. It is also seen that under certain priority rules the basic frequency of response of the system may be such as to require more attention to the time phasing of various reviews and accounting periods.

This research study does show the validity of the Industrial Dynamics method in examining management techniques. It would be worthwhile for organizations engaged in businesses where the interaction of the different functional departments is suspected to be important to apply these techniques for management staff studies. Different policies designed to counter customer actions or to optimize the organization's business under different criteria could be tested easily once a basic model were constructed. The necessity to examine each function to note the factors which enter into decisions influencing the business flows is also quite useful.

Each department management may seek to optimize its own department's performance. The organization's general management must consider the overall system performance. The use of mathematical models such as the one started in this report would permit general management to test various department policies.

A basic study of the actual nature of the business and the functions and flows necessary to satisfy the customer and yield the desired result would be required to apply this method thoroughly. Such a study may well show that the departmentalization of business flows introduces delays and introduces ancillary decision making processes which do not contribute to the desired objectives.

Future studies using this model as a starting point could examine the result of varying the various system parameters. In addition the removal of the simplifying assumptions concerning the non-variance of inter-sector functions could be accomplished in a systematic manner.

Using such a model as a building block, the management problem of a major corporation with separate divisions but with common policy decisions could be examined quantitatively. Here the influence of corporate objectives and the interaction of division objectives, where each division may be organized in a somewhat different manner, could be studied. A thorough research into the manner of decision making and risk taking taken by managers in each division and each division's departments could be instrumentated in a dynamic model. The influence and interactions of these lower level decisions on the corporate performance could be studied for the first time in a quantitative manner.

APPENDIX ONE

```
DYN   M1039-837-INPUTS TO MILITARY PRODUCT DEVELOPMENT MODEL-BEAUMARIAGE  DB0001
RUN   0702DB/DT=0.1/LENGTH=100/PRTPER=2.0/PLTPER=1.0                      DB0702
NOTE  DELAYED STEP INPUT TO SS ONE  ORDER RULE GAMMA TWO                  DB0370
NOTE  INTER-SECTOR CONSTANTS DETERMINED FROM OUTPUT CONDITIONS  SS ONE    DB0004
NOTE  MODIFIED ENG. HIRING AND LEAVING POLICIES                           DB8887
NOTE  ETTC COUPLING MODIFIED                                              DB8867
NOTE  EQUATIONS FOR CUSTOMER SECTOR FOLLOW                                DB1006
12R   CRFPO.KL=(CPPO.K)(CICM.JK)                                          DB0006
12R   CRFPC.KL=(CPPC.K)(CICM.JK)                                          DB0007
9A    CPPO.K=APO+CPPOM.K+CPPOB.K+CPPOC.K                                  DB0008
12A   CPPOM.K=(AME)(MESB.K)                                               DB0009
12A   CPPOB.K=(AUW)(TAUW.K)                                               DB0010
12A   CPPOC.K=(ATC)(ETTC.K)                                               DB0011
7A    CPPC.K=1.0-CPPO.K                                                   DB0023
1L    MRFPL.K=MRFPL.J+(DT)(CRFPO.JK-CEPC.JK)                              DB0026
12R   CEPC.KL=(AMMC)(EPC.JK)                                              DB0027
12R   MRFPE.KL=(AAPO)(CRFPO.JK)                                           DB0028
39R   CCPE.KL=DELAY3(EPC.JK,DCEP)                                         DB0030
1L    CIPOP.K=CIPOP.J+(DT)(EPC.JK-CCPE.JK)                                DB0029
13R   MCAE.KL=(ACAE)(CMCOP.K)(CCPE.JK)                                    DB0031
59A   CMCOP.K=TABLE(OPAP,EPW.K,0,1.0,0.05)                                DB0032
C     OPAP*=0/0.02/0.04/0.07/0.10/0.15/0.20/0.29/0.38/0.47/0.55/0.62/0.6  DB0033
X1    9/0.74/0.79/0.83/0.87/0.92/0.95/0.98/1.00                           DB0033
16A   EPW.K=(AETC)(ETTC.K)+(AAUW)(TAUW.K)+(APP)(OCPC.K)+(0.0)(0.0)        DB0110
C     APO=0.10                                                            DB0019
C     AME=0.03                                                            DB0020
C     AUW=0.03                                                            DB0021
C     ATC=0.04                                                            DB0022
20N   AMMC=1/AAPO                                                         DB0034
C     AAPO=0.000756                                                       DB0035
C     ACAE=12.4                                                           DB0036
C     AETC=0.45                                                           DB0142
C     AAUW=0.20                                                           DB0143
C     APP=0.35                                                            DB0144
C     DCEP=6                                                              DB0024
NOTE  INITIAL CONDITIONS FOR CUSTOMER SECTOR  SS ONE  FOLLOW              DB1039
12N   CRFPO=(CPPO1)(CICM)                                                 DB0040
12N   CRFPC=(CPPO2)(CICM)                                                 DB0047
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16N   CPPO1=(1)(APO)+(AME)(MESB1)+(AUW)(TAUW1)+(ATC)(ETTC1)          DB0045
7N    CPPO2=1-CPPO1                                                  DB0048
6N    MRFPL=0                                                        DB0043
12N   CEPC=(AMMC)(EPC)                                               DB0044
12N   MRFPE=(AAPO)(CRFPO)                                            DB0046
12N   CIPOP=(DCEP)(EPC)                                              DB0041
13N   MCAE=(ACAE)(CMCO1)(CCPE)                                       DB0050
59N   CMCO1=TABLE(OPAP,EPW1,0,1.0,0.05)                              DB0032
16N   EPW1=(AETC)(ETTC1)+(AAUW)(TAUW1)+(APP)(OCPC3)+(0)(0)           DB0110
6N    CICM=CICMN                                                     DB0039
NOTE  EQUATIONS FOR MARKETING SECTOR FOLLOW                          DB1051
20R   MGGRE.KL=OCIGR.K/ARE                                           DB0051
20R   MOSRE.KL=OCSRI.JK/ARE                                          DB0052
1L    MIRP.K=MIRP.J+(DT)(MRFPE.JK-MPFE.JK)                           DB0053
1L    MICA.K=MICA.J+(DT)(MCAE.JK-ECAE.JK)                            DB0056
1L    MIGR.K=MIGR.J+(DT)(MGGRE.JK-EGRE.JK)                           DB0059
1L    MISR.K=MISR.J+(DT)(MOSRE.JK-ESRE.JK)                           DB0062
21A   MP1.K=(1/DT)(MIRP.K-MIRPD.K)                                   DB0055
21A   MC1.K=(1/DT)(MICA.K-MICAD.K)                                   DB0058
21A   MG1.K=(1/DT)(MIGR.K-MIGRD.K)                                   DB0061
21A   MS1.K=(1/DT)(MISR.K-MISRD.K)                                   DB0064
12A   MIRPD.K=(DMPP)(MRFPA.K)                                        DB2000
12A   MICAD.K=(DMPC)(MCAEA.K)                                        DB1100
12A   MIGRD.K=(DMPG)(MGGRA.K)                                        DB3100
12A   MISRD.K=(DMPS)(MOSRA.K)                                        DB1200
3L    MRFPA.K=MRFPA.J+(DT)(1/TCAP)(MRFPE.JK-MRFPA.J)                 DB1230
3L    MCAEA.K=MCAEA.J+(DT)(1/TCAC)(MCAE.JK-MCAEA.J)                  DB2230
3L    MGGRA.K=MGGRA.J+(DT)(1/TCAG)(MGGRE.JK-MGGRA.J)                 DB3230
3L    MOSRA.K=MOSRA.J+(DT)(1/TCAS)(MOSRE.JK-MOSRA.J)                 DB4230
C     TCAP=6                                                         DB5230
C     TCAC=6                                                         DB6230
C     TCAG=6                                                         DB7230
C     TCAS=6                                                         DB8230
C     DMPP=3                                                         DB1000
C     DMPC=3                                                         DB7100
C     DMPG=3                                                         DB7300
C     DMPS=3                                                         DB7200
51R   MPFE.KL=CLIP(MP1.K,MAP.K,MAP.K,MP1.K)                          DB0054
51R   ESRE.KL=CLIP(MS1.K,MAS.K,MAS.K,MS1.K)                          DB0065
51R   EGRE.KL=CLIP(MG1.K,MAG.K,MAG.K,MG1.K)                          DB0060
51R   ECAE.KL=CLIP(MC1.K,MAC.K,MAC.K,MC1.K)                          DB0057
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16A   MAP.K=(CA1)(PA2.K)+(CB1)(PB3.K)+(CC1)(PC2.K)+(1)(MOPP.K)          DB7065
16A   MAC.K=(CA1)(PETA.K)+(CB1)(PB2.K)+(CC1)(PC4.K)+(1)(MOPC.K)         DB7066
16A   MAG.K=(CA1)(PA3.K)+(CB1)(PETA.K)+(CC1)(PC3.K)+(1)(MOPG.K)         DB7067
16A   MAS.K=(CA1)(PA4.K)+(CB1)(PB4.K)+(CC1)(PETA.K)+(1)(MOPS.K)         DB7068
16A   MAR.K=(CA1)(PA5.K)+(CB1)(PB5.K)+(CC1)(PC5.K)+(1)(MOPR.K)          DB7069

16A   MOPP.K=(CE1)(PE3.K)+(CF1)(PETA.K)+(CG1)(PG4.K)+(-1)(APM)          DB7447
16A   MOPC.K=(CE1)(PE2.K)+(CF1)(PF2.K)+(CG1)(PETA.K)+(-1)(APM)          DB7448
16A   MOPG.K=(CE1)(PE4.K)+(CF1)(PF4.K)+(CG1)(PG2.K)+(-1)(APM)           DB7449
16A   MOPS.K=(CE1)(PETA.K)+(CF1)(PF4.K)+(CG1)(PG3.K)+(-1)(APM)          DB7450
16A   MOPR.K=(CE1)(PE5.K)+(CF1)(PF5.K)+(CG1)(PG5.K)+(-1)(APM)           DB7451
51A   PA2.K=CLIP(PA2A.K,0,PA2A.K,0)                                     DB0070
7A    PA2A.K=PETA.K-ECAE.JK                                             DB0070
51A   PA3.K=CLIP(PA3A.K,0,PA3A.K,0)                                     DB0071
7A    PA3A.K=PA2A.K-EPRE.JK                                             DB0071
51A   PA4.K=CLIP(PA4A.K,0,PA4A.K,0)                                     DB0072
7A    PA4A.K=PA3A.K-EGRE.JK                                             DB0072
51A   PB2.K=CLIP(PB2B.K,0,PB2B.K,0)                                     DB0076
7A    PB2B.K=PETA.K-EGRE.JK                                             DB0076
51A   PB3.K=CLIP(PB3B.K,0,PB3B.K,0)                                     DB0077
7A    PB3B.K=PB2B.K-ECAE.JK                                             DB0077
51A   PB4.K=CLIP(PB4B.K,0,PB4B.K,0)                                     DB0078
7A    PB4B.K=PB3B.K-EPRE.JK                                             DB0078
51A   PC2.K=CLIP(PC2C.K,0,PC2C.K,0)                                     DB0080
7A    PC2C.K=PETA.K-ESRE.JK                                             DB0080
51A   PC3.K=CLIP(PC3C.K,0,PC3C.K,0)                                     DB0081
7A    PC3C.K=PC2C.K-EPRE.JK                                             DB0081
51A   PC4.K=CLIP(PC4C.K,0,PC4C.K,0)                                     DB0082
7A    PC4C.K=PC3C.K-EGRE.K                                              DB0082
7R    EPRE.KL=MPFE.JK-MPRC.JK                                           DB0074
51R   MPRC.KL=CLIP(MPRCV.K,MPFE.JK,MPFE.JK,MPRCV.K)                     DB0075
1L    MPRCV.K=MPRCV.J+(DT)(MPRCF.J+0)                                   DB1075
18A   MPRCF.K=(AEPCC)(MPRCT.K-MPRCV.K)                                  DB2075
51A   MPRCT.K=CLIP(MIRP1.K,0,MIRP2.K,EPP1.K)                            DB3075
12A   MIRP1.K=(APCC)(MPBL*2.K)                                          DB4075
37B   MPBL=BOXLIN(2,1)                                                  DB5075
1L    MPBL*1.K=MPBL*1.J+(DT)(MIRP2.J+0)                                 DB6075
7A    MIRP2.K=MIRP.K-MIRPD.K                                            DB7075
12A   EPP1.K=(APP1)(EPP.K)                                              DB9075
51A   PA5.K=CLIP(PA5A.K,0,PA5A.K,0)                                     DB0073
7A    PA5A.K=PA4A.K-ESRE.JK                                             DB0073
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51A   PB5.K=CLIP(PB5B.K,0,PE5B.K,0)                    DB0079
7A    PB5B.K=PB4B.K-ESRE.JK                            DB0079
51A   PC5.K=CLIP(PC5C.K,0,PC5C.K,0)                    DB0085
7A    PC5C.K=PC4C.K-ECAE.JK                            DB0083
51A   PE2.K=CLIP(PE2E.K,0,PE2E.K,0)                    DB7452
7A    PE2E.K=PETA.K-ESRE.JK                            DB7453
51A   PE3.K=CLIP(PE3E.K,0,PE3E.K,0)                    DB7454
7A    PE3E.K=PE2E.K-ECAE.JK                            DB7455
51A   PE4.K=CLIP(PE4E.K,0,PE4E.K,0)                    DB7456
7A    PE4E.K=PE5E.K-EPRE.JK                            DB7457
51A   PE5.K=CLIP(PE5E.K,0,PE5E.K,0)                    DB7458
7A    PE5E.K=PE4E.K-EGRE.JK                            DB7459
51A   PF2.K=CLIP(PF2F.K,0,PF2F.K,0)                    DB7460
7A    PF2F.K=PE" .K-EPRE.JK                            DB7461
51A   PF3.K=CLIP(PF3F.K,0,PF3F.K,0)                    DB7462
7A    PF3F.K=PF2F.K -ECAE.JK                           DB7463
51A   PF4.K=CLIP(PF4F.K,0,PF4F.K,0)                    DB7464
7A    PF4F.K=PF3F.K-EGRE.JK                            DB7465
51A   PF5.K=CLIP(PF5F.K,0,PF5F.K,0)                    DB7466
7A    PF5F.K=PF4F.K-ESRE.JK                            DB7467
51A   PG2.K=CLIP(PG2G.K,0,PG2G.K,0)                    DB7468
7A    PG2G.K=PETA.K-ECAE.JK                            DB7469
51A   PG3.K=CLIP(PG3G.K,0,PG3G.K,0)                    DB7470
7A    PG3G.K=PG2G.K-EGRE.JK                            DB7471
51A   PG4.K=CLIP(PG4G.K,0,PG4G.K,0)                    DB7472
7A    PG4G.K=PG5G.K-ESRE.JK                            DB7473
7A    PG5G.K=PG4G.K-EPRE.JK                            DB7475
51A   PG5.K=CLIP(PG5G.K,0,PG5G.K,0)                    DB7474
1L    MESB.K=MESB.J+(DT)(MESBF.J+0)                    DB0084
18A   MESBF.K=(ACMEB)(MESBT.K-MESB.K)                  DB2084
51A   MESBT.K=CLIP(MF1.K,0,1.0,MF2.K)                  DB1084
7A    MF1.K=1.0-MF2.K                                  DB0085
44A   MF2.K=(AMS)(PEUMR.K)/PNUM.K                      DB0086
C     ACMEB=0.05                                       DB3084
6N    MESB=MESB1                                       DB4084
C     APCC=0                                           DB0099
C     AEPCC=0.04                                       DB4975
C     APP1=0.25                                        DB5075
C     AMS=0.25                                         DB0100
NOTE  INITIAL CONDITIONS FOR MARKETUNG SECTOR FOLLOEW  SS ONE   DB1087
20N   MGGRE=OCIG1/ARE                                  DB0087
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20N   MOSRE=OCSRI/ARE                                          DB0088
15N   MIRP=(DMPP)(MRFPA)+(DT)(MRFPE)                           DB4001
15N   MICA=(DMPC)(MCAEA)+(DT)(MCAE)                            DB4002
15N   MIGR=(DMPG)(MGGRA)+(DT)(MGGRE)                           DB4003
15N   MISR=(DMPS)(MOSRA)+(DT)(MOSRE)                           DB4004
6N    MRFPA=MRFPE                                              DB1250
6N    MCAEA=MCAE                                               DB2250
6N    MGGRA=MGGRE                                              DB3250
6N    MOSRA=MOSRE                                              DB4250
6N    MPFE=MRFPE                                               DB0098
6N    ECAE=MCAE                                                DB0092
6N    EGRE=MGGRE                                               DB0094
6N    ESRE=MOSRE                                               DB0096
7N    EPRE=MPFE-MPRC                                           DB0090
6N    MPRC=0                                                   DB0975
6N    MPRCV=MPRC                                               DB1975
C     MPBL*=0/0                                                DB6975
C     MESB1=0.75                                               DB0262
NOTE  EQUATIONS FOR ENGINEERING SECTOR FOLLOW                  DB1101
12R   EPREE.KL=(AEEF.K)(EPRE.JK)                               DB0210
12R   ECAEE.KL=(AEEF.K)(ECAE.JK)                               DB0211
12R   EGREE.KL=(AEEF.K)(EGRE.JK)                               DB0212
12R   ESREE.KL=(AEEF.K)(ESRE.JK)                               DB0213
1L    AEEF.K=AEEF.J+(DT)(AEEFF.J+0)                            DB0220
51A   AEEFT.K=CLIP(AEEF1.K,AEFC1,AEEF1.K,AEFC1)                DB1220
7A    AEEF1.K=AEPF-AEEF2.K                                     DB0219
51A   AEEF2.K=CLIP(AEEF3.K,0,AEEF3.K,0)                        DB0220
7A    AEEF3.K=AEEF4.K-AEFC2                                    DB0221
44A   AEEF4.K=(AEFC3)(PEHP.JK)/PETA.K                          DB0222
18A   AEEFF.K=(AEFCC)(AEEFT.K-AEEF.K)                          DB2220
C     AEFCC=0.10                                               DB3220
6N    AEEF=AEPF                                                DB4220
1L    EPP.K=EPP.J+(DT)(EPREE.JK-EPC1.JK)                       DB0101
1L    ECWP.K=ECWP.J+(DT)(ECAEE.JK-ECWC.JK)                     DB0103
1L    EGRWP.K=EGRWP.J+(DT)(EGREE.JK-EGRWC.JK)                  DB0106
1L    ESRWP.K=ESRWP.J+(DT)(ESREE.JK-ESRWC.JK)                  DB0108
7R    EPC.KL=EPC1.JK+APM                                       DB0159
39R   EPC1.KL=DELAY3(EPREE.JK,DPPW)                            DB0102
39R   ECWC.KL=DELAY3(ECAEE.JK,DECW)                            DB0104
39R   EGRWC.KL=DELAY3(EGREE.JK,DGRW)                           DB0107
39R   ESRWC.KL=DELAY3(ESREE.JK,DSRW)                           DB0109
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12R   ECWS.KL=(ACSS)(ECWC.JK)                                          DB0105
3L    ECWCA.K=ECWCA.J+(DT)(1/TCWC)(ECWC.JK-ECWCA.J)                    DB0111
3L    EGRCA.K=EGRCA.J+(DT)(1/TGRC)(EGRWC.JK-EGRCA.J)                   DB0112
3L    ESRCA.K=ESRCA.J+(DT)(1/TSRC)(ESRWC.JK-ESRCA.J)                   DB0113
37B   ETC1=BOXLIN(8,12)                                                DB0114
37B   ETC2=BOXLIN(8,12)                                                DB0116
37B   ETC3=BOXLIN(8,12)                                                DB0118
1L    ETC1*1.K=ETC1*1.J+(DT)(ECWCA.J+0)                                DB0115
1L    ETC2*1.K=ETC2*1.J+(DT)(EGRCA.J+0)                                DB0117
1L    ETC3*1.K=ETC3*1.J+(DT)(ESRCA.J+0)                                DB0119
1L    ETC1E.K=ETC1E.J+(DT)(ETC1F.J+0)                                  DB1126
18A   ETC1F.K=(AFTC1)(ETC1N.K-ETC1E.K)                                 DB2126
20A   ETC1N.K=ETC1W.K/ATCN1.K                                          DB0126
1L    ETC2E.K=ETC2E.J+(DT)(ETC2F.J+0)                                  DB1127
18A   ETC2F.K=(AFTC2)(ETC2N.K-ETC2E.K)                                 DB2127
20A   ETC2N.K=ETC2W.K/ATCN2.K                                          DB0127
1L    ETC3E.K=ETC3E.J+(DT)(ETC3F.J+0)                                  DB1128
18A   ETC3F.K=(AFTC3)(ETC3N.K-ETC3E.K)                                 DB2128
20A   ETC3N.K=ETC3W.K/ATCN3.K                                          DB0128
55A   ETC1W.K=SUM2(8,W1A,ETC1)                                         DB0123
55A   ETC2W.K=SUM2(8,W2A,ETC2)                                         DB0124
55A   ETC3W.K=SUM2(8,W3A,ETC3)                                         DB0125
C     W1A*=0/10.0/7.0/4.0/2.0/1.0/1.0/0                                DB0120
C     W2A*=0/3.0/12.0/13.0/12.0/3.0/1.0/1.0                            DB0121
C     W3A*=0/5.0/12.0/20.0/25.0/30.0/6.0/2.0                           DB0122
12A   ATCN1.K=(MCAEM.K)(AN1TC)                                         DB0145
12A   ATCN2.K=(MGGRM.K)(AN2TC)                                         DB0146
12A   ATCN3.K=(MOSMP.K)(AN3TC)                                         DB0147
12A   MCAEM.K=(ACMCA)(CIC1A.K)                                         DB0269
12A   MGGRM.K=(ACMGR)(MCA2M.K)                                         DB0291
12A   MCA2M.K=(ACMCA)(CIC2A.K)                                         DB0270
13A   MOSMR.K=(ASRR1)(ACMSR)(MCA3M.K)                                  DB0426
12A   MCA3M.K=(ACMCA)(CIC3A.K)                                         DB0271
3L    CIC1A.K=CIC1A.J+(DT)(1/TCC11)(CICM.JK-CIC1A.J)                   DB0264
3L    CIC2A.K=CIC2A.J+(DT)(1/TCC12)(CICM.JK-CIC2A.J)                   DB0265
3L    CIC3A.K=CIC3A.J+(DT)(1/TCC13)(CICM.JK-CIC3A.J)                   DB0266
8A    ETTC.K=ETC1E.K+ETC2E.K+ETC3E.K                                   DB0129
1L    EAUW.K=EAUW.J+(DT)(EAUWF.J+0)                                    DB0134
59A   EAUWT.K=TABLE(EWA,ETETT.K,0,1/,0.5)                              DB1134
C     EWA*=0.60/0.59/0.57/0.52/0.45/0.32/0.21/0.14/0.09/0.05/0.03/.02/.0 DB0132
X1    2/.02/.02/.01/.01/.01/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0            DB0132
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51A    ETE11.K=CLIP(ETET.K,1,1,ETET.K)                                          DB0150
42A    ETET.K=MTBL.K/((PETA.K)(DPMS))                                           DB0150
9A     MTBL.K=MERPD.K+MICAD.K+MIGRD.K+MISRD.K                                   DB1136
18A    EAUWF.K=(ACEAW)(EAUWI.K-EAUW.K)                                          DB2134
C      ACEAW=0.05                                                               DB3134
C      AFTC1=0.02                                                               DB4126
C      AFTC2=0.02                                                               DB4127
C      AFTC3=0.02                                                               DB4128
6N     EAUW=0.57                                                                DB4134
C      AEPF=1.0                                                                 DB0243
C      APM=0                                                                    DB0156
C      ACSS=0.0211                                                              DB0141
C      AEFC1=0.50                                                               DB0223
C      AEFC2=0.10                                                               DB0224
C      AEFC3=1.0                                                                DB0225
C      AN1TC=175                                                                DB0272
C      AN2TC=175                                                                DB0295
C      AN3TC=175                                                                DB0455
15N    ACMCA=(CPPOI)(AAPO)(ACAE)                                                DB0267
16N    CPPOI=(1)(APO)+(AME)(MESDI)+(AOW)(TAOWI)+(AIC)(1)      MAX VALUE         DB0266
13N    ACMGR=(ACMGI)(ORPFM)(ACSS)                                               DB0292
44N    ACMGI=(ARGR)(ARFI)/ARE                                                   DB0293
7N     ORPFM=ARFP+ARITC                                                         DB0294
20N    ASRR1=ASRR/ASRR2                                                         DB0346
7N     ASRR2=1+ASRR                                                             DB0347
7N     ACMSR=ACRP1+ACFCE                                                        DB0434
12N    ACRP1=(AERP1)(ACAEI)                                                     DB0430
7N     AERP1=AERP-1                                                             DB0427
7N     ACAE1=ACAEI+1                                                            DB0429
20N    ACAEI=1/ACAE                                                             DB0428
19N    ACFCE=(ARCRS)(ORPFM+AROFM-1+0)                                           DB0433
44N    ARCRS=(ARFI,(ACSS)/ARE                                                   DB0431
12N    AROFM=(ARGR)(ORPFM)                                                      DB0432
C      DPPW=6                                                                   DB0151
C      DECW=12                                                                  DB0152
C      DGRW=18                                                                  DB0153
C      DSRW=24                                                                  DB0154
C      TSRC=12                                                                  DB0155
C      TCWC=12                                                                  DB0157
C      TGRC=12                                                                  DB0158
C      TCCI1=12                                                                 DB0273
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C       TCCI2=18                                                        DB0296
C       TCCI3=24                                                        DB0436
NOTE    INITIAL CONDITIONS FOR ENGINEERING SECTOR  SS ONE  FOLLOW       DB1160
12N     EPREE=(AEPF)(EPRE)                                              DB0214
12N     ECAEE=(AEPF)(ECAE)                                              DB0215
12N     EGREE=(AEPF)(EGRE)                                              DB0216
12N     ESREE=(AEPF)(ESRE)                                              DB0217
12N     EPP=(DPPW)(EPREE)                                               DB0161
12N     ECWP=(DECW)(ECAEE)                                              DB0162
12N     EGRWP=(DGRW)(EGREE)                                             DB0163
12N     ESRWP=(DSRW)(ESREE)                                             DB0164
7N      EPC=EPCI+APM                                                    DB0168
12N     ECWS=(ACSS)(ECWC)                                               DB0171
6N      ECWCA=ECWC                                                      DB0165
6N      EGRCA=EGRWC                                                     DB0166
6N      ESRCA=ESRWC                                                     DB0167
6N      ETC1E=ETC11                                                     DB3126
6N      ETC2E=ETC21                                                     DB3127
6N      ETC3E=ETC31                                                     DB3128
20N     ETC11=ETC12/ATC1                                                DB0126
20N     ETC21=ETC22/ATC2                                                DB0127
20N     ETC31=ETC32/ATC3                                                DB0128
55N     ETC12=SUM2(8,W1A,ETC1)                                          DB0123
55N     ETC22=SUM2(8,W2A,ETC2)                                          DB0124
55N     ETC32=SUM2(8,W3A,ETC3)                                          DB0125
12N     ATC1=(MCA11)(AN1TC)                                             DB0443
12N     MCA11=(ACMCA)(CIC1A)                                            DB0440
6N      CIC1A=CICM                                                      DB0437
13N     ATC2=(ACMGR)(MCA21)(AN2TC)                                      DB0444
12N     MCA21=(ACMCA)(CIC2A)                                            DB0441
6N      CIC2A=CICM                                                      DB0438
12N     ATC3=(MOSM1)(AN3TC)                                             DB0445
13N     MOSM1=(ASRR1)(ACMSR)(MCA31)                                     DB0446
12N     MCA31=(ACMCA)(CIC3A)                                            DB0442
6N      CIC3A=CICM                                                      DB0439
8N      ETTC1=ETC11+ETC21+ETC31                                         DB0129
NOTE    EQUATIONS FOR FACTORY SECTOR FOLLOW                             DB1176
1L      FSEP.K=FSEP.J+(DT)(ECWS.JK-FSRP.JK)                             DB0176
39R     FSRP.KL=DELAY3(ECWS.JK,DSPF)                                    DB0177
3L      FSRPA.K=FSRPA.J+(DT)(1/TSPA)(FSRP.JK-FSRPA.J)                   DB0178
1L      FUPS.K=FUPS.J+(DT)(FSRP.JK-FPRD.JK)                             DB0179
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1L    FUEO.K=FUEO.J+(DT)(FSRP.JK-FECE.JK)                          DB0130
51R   FPRD.KL=CLIP(FUP1.K,FPRM.K,FPRM.K,FUP1.K)                     DB0134
21A   FUP1.K=(1/DT)(FUPS.K-FUPSD.K)                                 DB0182
12A   FPRM.K=(PFMP.K)(APLF)                                         DB0182
12A   FUPSD.K=(FSRPA.K)(DNPF)                                       DB0181
1L    FEPM.K=FEPM.J+(DT)(FPRD.JK-FECE.JK)                           DB0188
39R   FECE.KL=DELAY3(FPRD.JK,DFPM)                                  DB0189
3L    FECEA.K=FECEA.J+(DT)(1/TFEA)(FECE.JK-FECEA.J)                 DB0190
1L    FAUW.K=FAUW.J+(DT)(FAUWF.J+0)                                 DB0135
59A   FAUWT.K=TABLE(FWA,FTEI1.K,0,1,0.5)                            DB1135
C     FWA*=0.40/0.39/0.37/0.30/0.21/0.14/0.08/0.06/0.04/0.03/0.02/.02/.0 DB0135
X1    2/.02/.02/.01/.01/.01/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0           DB0135
51A   FTEI1.K=CLIP(FTEI.K,1,1,FTEI.K)                               DB0131
46A   FTEI.K=(1)(1)(FUPSD.K)/((DNPF)(PFMP.K)(APLF))                 DB0131
18A   FAUWF.K=(ACFAW)(FAUWT.K-FAUW.K)                               DB2135
C     ACFAW=0.05                                                    DB3135
6N    FAUW=0.37                                                     DB4135
7A    TAUW.K=EAUW.K+FAUW.K                                          DB0136
C     APLF=0.01                                                     DB0266
C     DSPF=1                                                        DB0194
C     TSPA=6                                                        DB0195
C     DNPF=3                                                        DB0192
C     DFPM=10                                                       DB0196
C     TFEA=12                                                       DB0199
NOTE  INITIAL CONDITIONS FOR FACTORY SECTOR STEADY STATE ONE FOLLOW DB1202
12N   FSEP=(DSPF)(ECWS)                                             DB0204
6N    FSRPA=FSRP                                                    DB0207
15N   FUEO=(1)(FUPS)+(DFPM)(FSRPA)                                  DB0203
15N   FUPS=(DNPF)(FSRPA)+(DT)(FSRP)                                 DB0201
6N    FPRD=FSRP                                                     DB0202
12N   FEPM=(DFPM)(FPRD)                                             DB0205
6N    FECEA=FECE                                                    DB0206
C     TAUW1=0.94                                                    DB0191
NOTE  EQUATIONS FOR PERSONNEL-ENGINEERING SECTOR FOLLOW             DB1226
1L    PETA.K=PETA.J+(DT)(PELE.JK-PELT.JK)                           DB0226
10R   PEMRT.KL=MRFPE.JK+MCAE.JK+MGGRE.JK+MOSRE.JK+APM+0             DB0227
3L    PEMRA.K=PEMRA.J+(DT)(1/DAMP)(PEMRT.JK-PEMRA.J)                DB0230
9A    ETWC.K=EPC.JK+ECWC.JK+EGRWC.JK+ESRWC.JK                       DB0228
1L    PEUMR.K=PEUMR.J+(DT)(PEMRT.JK-ETWC.J)                         DB0229
14A   PNUM.K=PNUMP.K+(DPMST)(PEMRA.K)                               DB0231
7N    DPMST=DPMS+DT                                                 DB2231
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16A   PNUMP.K=(DPPW)(MRFPA.K)+(DECW)(MCAEA.K)+(DGRW)(MGGRA.K)+(DSRW)(MOS   DB1231
X1    RA.K)                                                                DB1231
21R   PECP.KL=(1/TPCP)(PEMD.K-PETAT.K)                                     DB0235
7A    PETAT.K=PETA.K+PELP.K                                                DB1235
9A    PEMD.K=PEPWD.K+PECWD.K+PESWD.K+PEGWD.K                               DB6565
7A    PEPWD.K=PEPW1.K+PEPW2.K                                              DB6000
20A   PEPW1.K=MRFPA.K/AEPF                                                 DB7000
20A   PEPW2.K=PEPW3.K/AEPF                                                 DB8045
21A   PEPW3.K=(1/DAPB)(MIRP.K-MIRPD.K)                                     DB9000
7A    PECWD.K=PECW1.K+PECW2.K                                              DB5100
20A   PECW2.K=PECW3.K/AEPF                                                 DB5100
20A   PECW1.K=MCAEA.K/AEPF                                                 DB4100
21A   PECW3.K=(1/DAPC)(MICA.K-MICAD.K)                                     DB6100
7A    PEGWD.K=PEGW1.K+PEGW2.K                                              DB5300
20A   PEGW1.K=MGGRA.K/AEPF                                                 DB4300
20A   PEGW2.K=PEGW3.K/AEPF                                                 DB5300
21A   PEGW3.K=(1/DAPG)(MIGR.K-MIGRD.K)                                     DB6300
7A    PESWD.K=PESW1.K+PESW2.K                                              DB3200
20A   PESW1.K=MOSRA.K/AEPF                                                 DB4200
20A   PESW2.K=PESW3.K/AEPF                                                 DB5200
21A   PESW3.K=(1/DAPS)(MISR.K-MISRD.K)                                     DB7106
51R   PEHP.KL=CLIP(PECP.JK,0,PECP1.K,MAR1.K)                               DB0236
7A    PECP1.K=PEMD.K-PETAT.K                                               DB0237
1L    PELP.K=PELP.J+(DT)(PEHP.JK-PELE.JK)                                  DB0240
39R   PELE.KL=DELAY3(PEHP.JK,DFRP)                                         DB0241
51R   PELT.KL=CLIP(PELT1.K,0,MAR.K,AETH)                                   DB0238
17A   PELT1.K=(0.5)(APTE)(MARC*1.K)+(1)(APTE)(MARC*2.K)+(2)(APTE)(MARC*3   DB9876
X1    .K)                                                                  DB9876
37B   MARC=BOXLIN(3,1)                                                     DB1239
1L    MARC*1.K=MARC*2.J+(DT)+(MARF.J+0)                                    DB2239
18A   MARF.K=(ACMAR)(MAR.K-MARC*1.K)                                       DB3239
C     ACMAR=0.50                                                           DB5239
C     MARC*=0/0/0                                                          DB4239
51A   MAR1.K=CLIP(MAR.K,AETH1,MAR.K,AETH1)                                 DB1236
C     DAPB=3                                                               DB3000
C     DAPC=3                                                               DB8100
C     DAPG=3                                                               DB8300
C     DAPS=3                                                               DB8200
C     AETH=5                                                               DB0242
C     AETH1=1.0                                                            DB0242
C     APTE=0.10                                                            DB0249
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C     DAMP=6                                                         DB0244
C     DPMS=3                                                         DB0245
C     TPCP=3                                                         DB0247
C     DFRP=6                                                         DB0248
NOTE  INITIAL CONDITIONS FOR PERS-ENG SECTOR SS ONE FOLLOW           DB1251
6N    FETA=PETAKT                                                    DB0250
10N   PEMPI=MKPPE+PCAL+POGRE+POSRE+APRM+0                            DB0256
6N    PEMRA=PEMRT                                                    DB0255
10N   PEDMR=HIRP+MICAR+TOR+TISR+PNWPI+0                              DB0254
16N   PNWPI=(DPRW)(SKRPA)+(DECW)(SCALA)+(DCRW)(MOSRA)+(DSRW)(MOSRA)  DB1254
6N    PECP=0                                                         DB0257
6N    PEHP=PECP                                                      DB0251
6N    PELT=0                                                         DB0252
12N   PFLP=(DFRP)(PEHP)                                              DB0253
NOTE  EQUATIONS FOR PERSONNEL-FACTORY SECTOR FOLLOW                  DB1276
1L    PFMP.K=PFMP.J+(DT)(PFLE.JK-PFLT.JK)                            DB0276
7A    PFLD.K=PFLD1.K+PFLD2.K                                         DB0277
20A   PFLD1.K=FSRPA.K/APLF                                           DB1277
20A   PFLD2.K=PFLD3.K/APLF                                           DB2277
21A   PFLD3.K=(1/DFBA)(FUPS.K-FUPSD.K)                               DB3277
21A   PFCP.K=(1/TPFR)(PFLD.K-PFMPT.K)                                DB0278
7A    PFMPT.K=PFMP.K+PFLP.K                                          DB1278
51R   PFHP.KL=CLIP(PFCP.K,0,PFCP1.K,AFTH1)                           DB0279
7A    PFCP1.K=PFLD.K-PFMPT.K                                         DB1278
51R   PFLT.KL=CLIP(0,-PFCP.K,PFCP1.K,-AFTH)                          DB0280
1L    PFLP.K=PFLP.J+(DT)(PFHP.JK-PFLE.JK)                            DB0281
39R   PFLE.KL=DELAY3(PFHP.JK,DPFT)                                   DB0282
C     AFTH=50                                                        DB1257
C     AFTH1=5                                                        DB0287
C     DPFT=3                                                         DB0289
C     TPFR=3                                                         DB0288
C     DFBA=3                                                         DB1288
NOTE  INITIAL CONDITIONS FOR PERS-FAC SECTOR STEADY STATE ONE FOLLOW DB1283
20N   PFMP=FSRPA/APLF                                                DB0283
6N    PFHP=0                                                         DB0285
6N    PFLT=0                                                         DB0284
12N   PFLP=(DPFT)(PFHP)                                              DB0290
NOTE  EQUATIONS FOR OPERATIONS CONTROL SECTOR FOLLOW                 DB1301
1L    OCPC.K=OCPC.J+(DT)(OCPCF.J+0)                                  DB0137
51A   OCPCT.K=CLIP(OCP1.K,0,1.0,OCP2.K)                              DB1137
7A    OCP1.K=1.0-OCP2.K                                              DB0138
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44A   OCP2.K=(AEC)(CAR.K)/PETA.K                                  DB0139
18A   OCPCF.K=(ACPC)(OCPCI.K-OCPC.K)                              DB2137
C     ACPC=0.05                                                   DB3137
6N    OCPC=OCPC3                                                  DB4137
8R    OCIT.KL=OCIE.K+OCIGR.K+OCIF.K                               DB0308
13A   OCIE.K=(ECT.K)(ARE)(AERP)                                   DB0303
7A    ECT.K=ECWC.JK+EPC.JK                                        DB0304
13A   OCIGR.K=(ARGFI)(FECEA.K)(OCRPF.K)                           DB0305
13A   OCIF.K=(FECE.K)(OCRPF.K)(ARFI)                              DB0306
14A   OCRPF.K=ARFP+(ARITC)(ETTC.K)                                DB0307
7R    OCET.KL=OCEF.K+OCEE.K                                       DB0309
12A   OCEE.K=(PETA.K)(ARE)                                        DB0302
15A   OCEF.K=(PFMP.K)(ARF)+(FECE.JK)(ARFM)                        DB0301
7R    OCRP.KL=OCIT.JK-OCET.JK                                     DB0310
3L    OCRPA.K=OCRPA.J+(DT)(1/TOCPA)(OCRP.JK-OCRPA.J)              DB1310
C     TOCPA=3                                                     DB2310
6N    OCRPA=OCRP                                                  DB1330
51R   OCSRI.KL=CLIP(OCS1.K,0,OCRPS.K,APS)                         DB0313
12A   OCS1.K=(OCRPA.K)(ASRR)                                      DB0314
20A   OCRPS.K=OCRPA.K/OCIT.JK                                     DB0312
8R    OCNPR.KL=OCRP.JK-OCSRI.JK-OCPLT.JK                          DB0317
51R   OCPLT.KL=CLIP(OCPT1.K,0,OCRP.JK,0)                          DB0318
12A   OCPT1.K=(APLT)(OCRP.JK)                                     DB0316
1L    OCPL.K=OCPL.J+(DT)(OCRP.JK-OCS2.J)                          DB0311
7A    OCS2.K=OCSRI.JK+OCPLT.JK                                    DB0315
C     AEC=3.2                                                     DB0140
C     ARE=3                                                       DB0328
C     AERP=1.070                                                  DB0319
12N   ARGFI=(ARGR)(ARFI)                                          DB1350
C     ARGR=0.020                                                  DB0320
C     ARFI=330                                                    DB0321
C     ARFP=1.070                                                  DB0322
C     ARITC=0.070                                                 DB0325
C     ARF=1.100                                                   DB0326
C     ARFM=220                                                    DB0327
C     APS=0.025                                                   DB0323
C     ASRR=0.100                                                  DB0324
C     APLT=0.500                                                  DB0329
NOTE  INITIAL CONDITIONS FOR OPS-CONT FOLLOW                      DB1330
C     OCPC3=1.00                                                  DB0140
8N    OCIT=OCIE1+OCIG1+OCIF1                                      DB0334
```

```
13N    OCIE1=(ARE)(AERP)(ECT1)                                                        DB0336
7N     ECT1=ECWC+EPC                                                                  DB0337
12N    OCIG1=(ARGR)(OCIF1)                                                            DB0338
13N    OCIF1=(ARFI)(ORPF1)(FECE)                                                      DB0339
14N    ORPF1=ARFP+(ARITC)(ETTC1)                                                      DB0340
16N    OCET=(ARE)(PETA)+(ARF)(PFMP)+(ARFM)(FECE)+(0)(0)                               DB0335
7N     OCRP=OCIT-OCET                                                                 DB0330
12N    OCSRI=(ASRR1)(OCRI1)                                                           DB0332
7N     OCRI1=OCRI2+OCRI3                                                              DB0348
16N    OCRI2=(1)(OCIT)+(-ARF)(PFMP)+(-ARFM)(FECE)+(0)(0)                              DB0349
16N    OCRI3=(-ARE)(MRFPE)+(-ARE)(MCAE)+(-ARE)(MGGRE)+(-ARE)(APM)                     DB0350
12N    OCPLT=(APLT)(OCRP)                                                             DB0333
6N     OCPL=0                                                                         DB0331
16R    CICM.KL=(C1)(INP1.K)+(C2)(INP2.K)+(C3)(INP3.K)+(C4)(INP4.K)                    DB0012
7A     INP1.K=CICMN+INSTP.K                                                           DB0025
45A    INSTP.K=STEP(STEP,TAU1)                                                        DB0013
7A     INP2.K=CICMN+INRMP.K                                                           DB0037
47A    INRMP.K=RAMP(RAMP,TAU2)                                                        DB0015
7A     INP3.K=CICMN+INIMP.K                                                           DB9038
41A    INIMP.K=PULSE(3400000,0.2,120)                                                 DB8017
7A     INP4.K=CICMN+RNDM.K                                                            DB0341
7A     RNDM.K=BIAS+RNDOM.K                                                            DB0342
33A    RNDOM.K=(CVAR)NOISE                                                            DB0343
C      RAMP=20400/TAU2=1                                                              DB0016
C      BIAS=0                                                                         DB0344
C      CVAR=85000                                                                     DB0345
C      STEP=34000/TAU1=0.50                                                           DB7014
C      CICMN=340000                                                                   DB8003
C      CA1=0/CB1=0/CC1=1/CE1=0/CF1=0/CG1=0                                            DB4444
C      C1=1/C2=0/C3=0/C4=0                                                            DB0351
C      ETC1*=300/300/300/300/300/300/300/300                                          DB8148
C      ETC2*=3/3/3/3/3/3/3/3                                                          DB8149
C      ETC3*=3/3/3/3/3/3/3/3                                                          DB8150
NOTE   ORDER RULE GAMMA                                                               DB9997
PRINT  1)CICM,CRFPO,MRFPL,CIPOP,CCPE/2)CPPO,EPW,CMCOP,MESB,TAUW/3)MRFFE,M             DB0353
X1     CAE,MGGRE,MOSRE,EPP/4)EPRE,ECAE,EGRE,ESRE,MAR/5)EPC,ECWC,EGRWC,ESR             DB0353
X2     WC,ECWS/6)ETC1N,ETC2N,ETC3N,ETTC,EAUW/7)PEMRT,PEUMR,ETWC,PNUM,PEMD             DB0353
X3     /8)PECP,PEHP,PELE,PETA,PELT/9)FSEP,FSRP,FUPS,FPRD,FEPM/10)FECE,FUE             DB0353
X4     O,FUPSD,MPRC,PFLD/11)PFCP,PFHP,PFLE,PFMP,PFLT/12)OCEE,OCEF,OCET/13             DB0353
X5     )OCIE,OCIF,OCIGR,OCSRI,OCIT/14)OCPC,OCRP,OCNPR,OCPL,MPFE                       DB0353
PLOT   EPRE=P/MCAE=A,ECAE=C/EGRE=G,ESRE=S/PETA=E/PFMP=T/OCPL=M/OCNPR=O/OC             DB1354
```

```
X1      IT=I                                                        DB1354
RUN     0703DB/DT=0.1/LENGTH=100/PRTPER=2.0/PLTPER=1.0              DB0703
NOTE    DELAYED STEP INPUT TO  SS ONE ORDER RULE ALPHA TWO          DB0005
C       CC1=0                                                       DB7005
C       CA1=1                                                       DB7002
RUN     0712DB/DT=0.1/LENGTH=100/PRTPER=2.0/PLTPER=1.0              DB0712
NOTE    ORDER RULE EPSILON                                          DB9995
C       CC1=0                                                       DB7005
C       CF1=1                                                       DB7010
RUN     0709DB/DT=0.10/LENGTH=100/PRTPER=2.0/PLTPER=1.0             DB0709
NOTE    TEST RUN WITH ZERO BACKLOG IN ENGINEERING
C       DMPC=0                                                      DB7100
C       DMPP=0                                                      DB1000
C       DMPG=0                                                      DB7300
C       DMPS=0                                                      DB7200
```

APPENDIX

LIST OF SYMBOLS AND DEFINITIONS

		Equation #*
AAPO =	constant Allocating Proposals to Organization	7R
AAUW =	constant, Ability to Undertake Work	12A
ACAE =	constant, Contract Awards Entering	10R
ACSS =	constant, Converting Specification to Equipment Shipments	50R
AEC =	constant, Engineering Cost variation	100A
AEEF =	Attrition in Engineering Efficiency Factor	39A/35R-38R
AEFC1 =	constant, Efficiency Factor Constant	39A
AEFC2 =	constant, Efficiency Factor Constant	39A
AEFC3 =	constant, Efficiency Factor Constant	39A
AETC =	constant, Engineering Technical Competition	12A
AEPF =	constant, Engineering Productivity Factor	39A,87A
AERP =	constant, Engineering Rate of Profit	102A
AMMC =	constant, converting Man Month to Cash	6R
AME =	constant, Marketing Effort	3A
AMS =	constant, Marketing Solicitation	34A
APCC =	constant, Proposals Cancelled by Customer	32R
APLF =	constant, Productivity Labor Factor	73A,79A,94A
APLT =	constant, Profit Loss to Taxes	112R
APM =	constant, Proposal Effort Maintained	45R
APO =	constant, Percentage proposals to Organization	3A
APP =	constant, Price Provision	12A

* For constants, delays and time constants, equation numbers are where symbol is used. For others, first equation gives definition, other equation numbers indicate where symbol is used on right hand side.

APS =	constant, Profit minimum for Special Research	110R
APTE =	constant, Personnel Terminating from Engineering	92R
ARE =	constant Rate of Engineers	13R,14R,107A

here

ARF =	constant Rate for Factory personnel	108A
ARFI =	constant, Rate for Factory Income	104A
ARFM =	constant Rate for Factory Material	108A
ARFP =	constant, fixed Rate of Factory Profit	105A
ARGR =	constant, percentage Rate for General Research	103A
ARITC =	constant, Rate Increase for Technical Competence	105A
ASRR =	constant, Special Research Rate	110R
ATC =	constant, Technical Competence	3A
AUW =	constant, Ability to Undertake Work	3A
CCPE =	Customer Completed Proposals Evaluated	8R/9L,10R
CEPC =	Customer received Engineering Proposals Completed	6R/5L
CICM =	Customer Income Capital for Military	1R,2R
CIPOP =	Customer Internal Processing of Organization Proposals	9L
CMCOP =	Customer Marketing Contracts Obtained Percentage	11A/10R
CPPC =	Customer Percentage Proposals to Competition	4A/2R
CPPO =	Customer Percentage Proposals to Organization	3A/1R,4A
CRFPC =	Customer Requests for Proposals to Competition	2R
CRFPO =	Customer Requests for Proposals to Organization	1R/5L,7R
DAMP =	Delay for Averaging Man Power requests	83L
DCEP =	Delay Customer Evaluation Proposals	8R
DECW =	Delay, Engineering Contract Work	47R
DELAY 3 =	third order delay	

DERP =	Delay, Engineering Recruiting Process	91R
DFBA =	Delay Factory Backlog Adjustment	94A
DFPM =	Delay in Factory Process of Manufacturing	76R
DGRW =	Delay, General Research Work	48R
DNPF =	Delay, Normal Planning at Factory	74A, 79A
DPFT =	Delay, Personnel Factory Training and recruiting	99R
DPMS =	Delay for Planning Manpower Size	86A
DPPW =	Delay, Proposal Process Work	46R
DSPF =	Delay in Specifications Process at Factory	67R
DSRW =	Delay, Special Research Work	49R
DT =	Difference Time used in calculation	
EAUW =	Engineering Ability to Undertake Work	64A/80A
ECAE =	Engineering Contract Authorization Entered	24R/16L,27A 29A,30A,36R
ECAEE =	Engineering Contract Authorizations Entered Effective	36R/42L,47R
ECWC =	Engineering Contract Work Completed	47R/42L,50R, 51L,102A
ECWCA =	Engineering Contract Work Average level	51L/57L,84R
ECWP =	Engineering Contract Work in Process	42L
ECWS =	Engineering Contract Work Specifications	50R/66L,67R
EGRCA =	Engineering General Research Work Average level	52L/58L
EGRE =	Engineering General Research	25R/30A,37R, 17L
EGREE =	Engineering General Research Entered Effective	35R/43L,48R
EGRWC =	Engineering General Research Work Completed	48R/43L,52L 84R
EGRWP =	Engineering General Research Work in Process	43L
EHR =	Engineering Hiring Ratio	40A/39A

EPC	=	Engineering Proposals Completed total	45R/6R,8R,9R, 84R,102A
EPC1	=	Engineering Proposals Completed due to Marketing requests	46R/45R,41L
EPP	=	Engineering Proposals in Process	41L
EPRE	=	Engineering Proposal Requests Entered	31R/29A,30A
EPREE	=	Engineering Proposal Requests Entered Effective	35R/41L,46R
EPW	=	Engineering Proposal Worth	12A/11A
ESRCA	=	Engineering Special Research Work Average level	53L/57L
ESRE	=	Engineering Special Research Entered	26R/18L/38R
ESREE	=	Engineering Special Research Entered Effective	38R/44L,49R
ESRWC	=	Engineering Special Research Work Completed	49R/44L,53L, 84R
ESRWP	=	Engineering Special Research Work in Process	44L
ETC1	=	Engineering Technical Competence, past contract work	54B/60A
ETC2	=	Engineering Technical Competence,past general research work	55B/61A
ETC3	=	Engineering Technical Competence,past special research work	56B/62A
ETC1*1	=	Engineering Technical Competence,first level contract work	57L
ETC2*1	=	Engineering Technical Competence,first level general research work	58L
ETC3*1	=	Engineering Technical Competence, first level special work	59L
ETC1N	=	Engineering Technical Competence 1, normalized	60A/63A
ETC2N	=	Engineering Technical Competence 2, normalized	61A/63A
ETC3N	=	Engineering Technical Competence 3, normalized	62A/63A
ETEI	=	Engineering Times to Exhaust Work Inventory	65A/64A
ETTC.K	=	Engineering Total Technical Competence	63A/3A,12A,105A
ETWC	=	Engineering Total Work Completion rate	84R/85L

FAUW =	Factory Ability to Undertake Work	78A/80A
FECE =	Factory Equipments Completed and shipped	76R/70L,77L, 109A
FECEA =	Factory Equipment Completed Average	77L/103A
FEPM =	Factory Equipment in Process of Manufacturing	75L
FPRD =	Factory Production Rate Decision	72R/69L,75L,76R
FPRM =	Factory Production Rate Maximum	73A/72R
FSEP =	Factory Specifications from Engineering in Process	66L
FSRP =	Factory Specification Ready for Production	67R/66L,68L, 69L,70L
FSRPA =	Factory Specification Ready for Production, Average	68L/74A,94A
FTEI =	Factory Times to Exhaust Inventory	79A/78A
FUEO =	Factory Unfilled Equipment Orders	70L/94A
FUPS =	Factory Unordered Production Specifications	69L/71A,79A
FUPS1 =	Factory Unordered equipment increment	71A/72R
FUPSD =	Factory Unordered Production Specification Desired	74A/94A
MAC =	Manpower Available for Contracts	28A/24R
MAG =	Manpower Available for General Research	29A/25R
MAP =	Manpower Available for Proposals	27A/23R
MAR =	Manpower Available for Reassignment	33A/92R,100A
MAS =	Manpower Available for Special Research	30A/26R
MC1 =	Marketing Contract Increments	20A/24R
MCAE =	Marketing Contract Awards Entering	10R/16L,82R
MESB =	Marketing Effort in Soliciting Business	34A/3A
MG1 =	Marketing Government Research increment	21A/25R
MGGRE =	Marketing Government General Research Entered	13R/17L,82R
MICA =	Marketing Inventory of Contract Authrcization	16L/20A

MIGR =	Marketing Inventory of General Research	17L/21A
MIRP =	Marketing Inventory of Requests for Proposals	15L/19A,32A
MISR =	Marketing Inventory of Special Research	18L/22A
MOSRE =	Marketing Organization Special Research Entered	14R/18L,82R
MP1 =	Marketing Proposal increment	19A/23R
MPFE =	Marketing Proposals Forwarded to Engineering	23R/15L,31R
MPCC =	Marketing Proposals Cancelled by Customer	32R/31R
MRFPE =	Marketing Requests For Proposals Entered	7R/15L,82R
MRFPL =	Marketing Requests For Proposal Level	5L
MS1 =	Marketing Special Research increment	22A/26R
OCEE =	Operations Control Engineering Expenses	107A/106A
OCEF =	Operations Control Expenses of Factory	108A/106A
OCET =	Operations Control Expenses Total	106A/109R
OCIE =	Operations Control Income Engineering	102A/101A
OCIF =	Operations Control Income Factory	104A/101A
OCIGR =	Operations Control Income for General Research	103A/13R,101A
OCIT =	Operations Control Income Total	101A/109R,110R
OCNPR =	Operations Control Net Profit Rate	111R/113L
OCPC =	Operations Control Price Constant	100A/12A
OCPL =	Operations Control Profit Level	113L
OCPLT =	Operations Control Profit Loss to Taxes	112R/111R
OCRP =	Operations Control Rate of Profit	109R/110R,111R, 112R
OCRPF =	Operations Control Rate of Profit for Factory	105A/103A,104A
OCSRI =	Operations Control Special Research Income	110R/14R,111R
PECP =	Personnel Engineering Change Policy	88R/89R
PEHP =	Personnel Engineering Hiring Policy	89R/40A
PELE =	Personnel Engineering Labor Entering	91R/81L

PELP =	Personnel Engineering Entering Labor in Process	90L/91R
PELT =	Personnel Engineering Labor Terminations	42R/81L
PEMD =	Personnel Engineering Manpower Desired	87A/88R
PEMRT =	Personnel Engineering Manpower Requests Total	82R/83L,85L
PEMRA=	Personnel Engineering Manpower Requests Average	83L/86A,87A
PETA =	Personnel Engineering Total Available	81L/27A,28A, 29A,30A,40A, 65A,88R,100A,108A
PEUMR =	Personnel Engineering Unfilled Manpower Requests	85L/34A,64A,87A
PFCP =	Personnel Factory Change Policy	95A/96R,97R
PFHP =	Personnel Factory Hiring Policy	96R/98L,99R
PFLD =	Personnel Factory Labor Desired	94A/95A
PFLE =	Personnel Factory Labor Entering	99R/93L
PFLP =	Personnel Factory Labor in Process	98L/99R
PFLT =	Personnel Factory Labor Terminations	97R/93L
PFMP =	Personnel Factory Man Power	93L/73A,79A, 95A,108A
PNUM =	Personnel Normal Unfilled Manpower requests	86A/34A,87A
TAUW =	Total Ability to Undertake Work	80A/3A,12A
TCFP =	Time constant Change Factory Policy	95A
TCWC =	Time constant for Contract Work Completion average	51L
TDPM =	Time constant to adjust Delay in Planning Manpower	87A
TFEA =	Time constant for Factory Equipment Average	77L
TGRC =	Time constant for General Research Completion average	52L
TPCP =	Time constant for Personnel Changing Policy	88R
TSPA =	Time constant for Specification Production Average	68L
TSRC =	Time constant for Special Research Completion average	53L

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APPENDIX TWO

MODIFICATIONS TO ORIGINAL SET OF EQUATIONS

MODIFICATION OF INTERSECTOR COUPLING FUNCTIONS

FRACTION OF CHANGE ADDED PER COMPUTING PERIOD
(BY CHANGING CONSTANTS IN 18A EQUATIONS)

MESB - MARKETING EFFORT IN SOLICITING BUSINESS

```
1L    MESB.K=MESB.J+(DT)(MESBF.J+0)
18A   MESBF.K=(ACMEB)(MESBT.K-MESB.K)                DB0084
51A   MESBT.K=CLIP(MF1.K,0,1.0,MF2.K)                DB2084
C     ACMEB=0.05                                     DB1084
C     ACMEB=0.10                                     DB3034
6N    MESB=MESB1                                     DB3084
                                                     DB4084
```

AEEF - ENGINEERING EFFICIENCY FACTOR

```
1L    AEEF.K=AEEF.J+(DT)(AEEFF.J+0)
18A   AEEFF.K=(AEFCC)(AEEFT.K-AEEF.K)                DB0220
51A   AEEFT.K=CLIP(AEEF1.K,AEFC1,AEEF1.K,AEFC1)      DB2220
C     AEFCC=0.10                                     DB1220
6N    AEEF=AEPF                                      DB3220
                                                     DB4220
```

EAUW - ENGINEERING ABILITY TO UNDERTAKE WORK

```
1L    EAUW.K=EAUW.J+(DT)(EAUWF.J+0)
18A   EAUWF.K=(ACEAW)(EAUWT.K-EAUW.K)                DB0134
59A   EAUWT.K=TABLE(EWA,ETEI1.K,0,17,0.5)            DB2134
42A   ETEI.K=MTBL.K/((PETA.K)(DPMS))                 DB1134
9A    MTBL.K=MIRPD.K+MICAD.K+MIGRD.K+MISRD.K         DB0130
C     ACEAW=0.05                                     DB1130
C     ACEAW=0.10                                     DB3134
6N    EAUW=0.57                                      DB3134
                                                     DB4134
```

FAUW - FACTORY ABILITY TO UNDERTAKE WORK

```
1L    FAUW.K=FAUW.J+(DT)(FAUWF.J+0)
18A   FAUWF.K=(ACFAW)(FAUWT.K-FAUW.K)                DB0135
59A   FAUWT.K=TABLE(FWA,FTEI1.K,0,17,0.5)            DB2135
46A   FTEI.K=(1)(1)(FUPSD.K)/((DNPF)(PFMP.K)(APLF))  DB1135
C     ACFAW=0.05                                     DB0131
C     ACFAW=0.10                                     DB3135
6N    FAUW=0.37                                      DB3135
                                                     DB4135
```

OCPC - OPERATIONS CONTROL PRICE COMPETITION FACTOR

```
1L    OCPC.K=OCPC.J+(DT)(OCPCF.J+0)
18A   OCPCF.K=(ACPC)(OCPCT.K-OCPC.K)                 DB0137
51A   OCPCT.K=CLIP(OCP1.K,0,1.0,OCP2.K)              DB2137
C     ACPC=0.05                                      DB1137
C     ACPC=0.10                                      DB3137
6N    OCPC=OCPC3                                     DB3137
                                                     DB4137
```

```
        MPRC - MARKETING PROPOSAL REQUESTS CANCELLED

7R      EPRE.KL=MPFE.JK-MPRC.JK
51R     MPRC.KL=CLIP(MPRCV.K,MPFE.JK,MPFE.JK,MPRCV.K)              D80074
1L      MPRCV.K=MPRCV.J+(DT)(MPRCF.J+0)                            D80075
18A     MPRCF.K=(AEPCC)(MPRCT.K-MPRCV.K)                           D81075
51A     MPRCT.K=CLIP(MIRP1.K,0,MIRP2.K,EPP1.K)                     D82075
12A     MIRP1.K=(APCC)(MPBL*2.K)                                   D83075
37B     MPBL=BOXLIN(2,1)                                           D84075
1L      MPBL*1.K=MPBL*1.J+(DT)(MIRP2.J+0)                          D85075
7A      MIRP2.K=MIRP.K-MIRPD.K                                     D86075
12A     EPP1.K=(APP1)(EPP.K)                                       D87075
6N      MPRC=0                                                     D89075
6N      MPRCV=MPRC                                                 D80975
C       MPBL*=0/0                                                  D81975
C       AEPCC=0.04                                                 D86975
C       AEPCC=0.1                                                  D84975
                                                                   D86075

            MODIFED TECHNICAL COMPETENCE CHANGES
        ETTC - ENGINEERING TOTAL TECHNICAL COMPETENCE

8A      ETTC.K=ETC1E.K+ETC2E.K+ETC3E.K
1L      ETC1E.K=ETC1E.J+(DT)(ETC1F.J+0)                            D80129
18A     ETC1F.K=(AFTC1)(ETC1N.K-ETC1E.K)                           D81126
1L      ETC2E.K=ETC2E.J+(DT)(ETC2F.J+0)                            D82126
18A     ETC2F.K=(AFTC2)(ETC2N.K-ETC2E.K)                           D81127
1L      ETC3E.K=ETC3E.J+(DT)(ETC3F.J+0)                            D82127
18A     ETC3F.K=(AFTC3)(ETC3N.K-ETC3E.K)                           D81128
C       AFTC1=0.025                                                D82128
C       AFTC2=0.025                                                D84126
C       AFTC3=0.025                                                D84127
6N      ETC1E=ETC11                                                D84128
6N      ETC2E=ETC21                                                D83126
6N      ETC3E=ETC31                                                D83127
                                                                   D83128

            MODIFIED BACKLOG CRITERIA FOR PERSONNEL IN ENG. AND FACTORY

21A     MP1.K=(1/DT)(MIRP.K-MIRPD.K)
21A     MC1.K=(1/DT)(MICA.K-MICAD.K)                               D80055
21A     MG1.K=(1/DT)(MIGR.K-MIGRD.K)                               D80056
21A     MS1.K=(1/DT)(MISR.K-MISRD.K)                               D80061
12A     MIRPD.K=(DMPP)(MRFPA.K)                                    D80064
12A     MICAD.K=(DMPC)(MCAEA.K)                                    D82000
12A     MIGRD.K=(DMPG)(MGGRA.K)                                    D81100
12A     MISRD.K=(DMPS)(MOSRA.K)                                    D85100
3L      MRFPA.K=MRFPA.J+(DT)(1/TCAP)(MPFPE.JK-MRFPA.J)             D81200
3L      MCAEA.K=MCAEA.J+(DT)(1/TCAC)(MCAE.JK-MCAEA.J)              D81230
3L      MGGRA.K=MGGRA.J+(DT)(1/TCAG)(MGGRE.JK-MGGRA.J)             D82230
3L      MOSRA.K=MOSRA.J+(DT)(1/TCAS)(MOSRE.JK-MOSRA.J)             D83230
C       TCAP=6                                                     D84230
C       TCAC=6                                                     D85230
                                                                   D86230
```

```
C      TCAG=6
C      TCAS=6                                                        D87230
C      DMPP=3                                                        D88230
C      DMPC=3                                                        D81000
C      DMPG=3                                                        D87100
C      DMPS=3                                                        D87300
15N    MIRP=(DMPP)(MRFPA)+(DT)(MRFPE)                                D87200
15N    MICA=(DMPC)(MCAEA)+(DT)(MCAE)                                 D84001
15N    MIGR=(DMPG)(MGGRA)+(DT)(MGGRE)                                424002
3L     MRFPA.K=MRFPA.J+(DT)(1/TCAP)(MRFPE.JK-MRFPA.J)                D84003
6N     MRFPA=MRFPE                                                   D81230
6N     MCAEA=MCAE                                                    D81250
6N     MGGRA=MGGRE                                                   D82250
6N     MOSRA=MOSRE                                                   D83250
14A    PNUM.K=PNUMP.K+(DPMST)(PEMRA.K)                               D84250
16A    PNUMP.K=(DPPW)(MRFPA.K)+(DECW)(MCAEA.K)+(DGRW)(MGGRA.K)+(DSRW)(MOS   D80231
X1     RA.K)                                                         D81231
7N     DPMST=DPMS+DT                                                 D81231
10N    PEUMR=MIRP+MICA+MIGR+MISR+PNWP1+0                             D82231
16N    PNWP1=(DPPW)(MRFPA)+(DECW)(MCAEA)+(DGRW)(MGGRA)+(DSRW)(MOSRA)  D80254
21A    FUP1.K=(1/DT)(FUPS.K-FUPSD.K)                                 D81254
12A    FUPSD.K=(DNPF)(FSRPA.K)                                       D80162
15N    FUPS=(DNPF)(FSRPA)+(DT)(FSRP)                                 D80161
15N    FUEO=(1)(FUPS)+(DFPM)(FSRPA)                                  D80201
                                                                     420203
```

PEHP,PELT - PERSONNEL-ENGINEERING HIRING POLICY
AND LABOR TERMINATIONS

```
51R    PEHP.KL=CLIP(PECP.JK,0,PECP1.K,MAR1.K)
21R    PECP.KL=(1/TPCP)(PEMD.K-PETAT.K)                              D80236
7A     PECP1.K=PEMD.K-PETAT.K                                        D80235
7A     PETAT.K=PETA.K+PELP.K                                         D80237
51A    MAR1.K=CLIP(MAR.K,AETH1,MAR.K,AETH1)                          D81235
9A     PEMD.K=PEPWD.K+PECWD.K+PESWD.K+PEGWD.K                        D81236
7A     PEPWD.K=PEPW1.K+PEPW2.K                                       D86565
20A    PEPW1.K=MRFPA.K/AEPF                                          D86000
20A    PEPW2.K=PEPW3.K/AEPF                                          D87000
21A    PEPW3.K=(1/DAPB)(MIRP.K-MIRPD.K)                              D88000
7A     PECWD.K=PECW1.K+PECW2.K                                       D89000
20A    PECW1.K=MCAEA.K/AEPF                                          D83100
20A    PECW2.K=PECW3.K/AEPF                                          D84100
21A    PECW3.K=(1/DAPC)(MICA.K-MICAD.K)                              D85100
7A     PEGWD.K=PEGW1.K+PEGW2.K                                       D86100
20A    PEGW1.K=MGGRA.K/AEPF                                          D83300
20A    PEGW2.K=PEGW3.K/AEPF                                          D84300
21A    PEGW3.K=(1/DAPG)(MIGR.K-MIGRD.K)                              D85300
7A     PESWD.K=PESW1.K+PESW2.K                                       D26300
20A    PESW1.K=MOSRA.K/AEPF                                          D83200
20A    PESW2.K=PESW3.K/AEPF                                          D84200
21A    PESW3.K=(1/DAPS)(MISR.K-MISRD.K)                              D85200
C      DAPB=3                                                        D262
C      DAPC=3                                                        D83000
C      DAPG=3                                                        D88100
C      DAPS=3                                                        458300
                                                                     D88200
```

```
51R   PELT.KL=CLIP(PELT1.K,0,MAR.K,AETH)
17A   PELT1.K=(0.5)(APTE)(MARC*1.K)+(1)(APTE)(MARC*2.K)+(2)(APTE)(MARC*3   DB0238
X1    .K)                                                                  DB9876
37B   MARC=BOXLIN(3,1)                                                     DB9876
1L    MARC*1.K=MARC*2.J+(DT)+(MARF.J+0)                                    DB1239
18A   MARF.K=(ACMAR)(MAR.K-MARC*1.K)                                       DB2239
C     ACMAR=0.50                                                           DB3239
C     MARC*=0/0/0                                                          DB5239
                                                                           DB4239

21A   PFCP.K=(1/TPFR)(PFLD.K-PFMPT.K)
7A    PFMPT.K=PFMP.K+PFLP.K                                                DB0278
21A   PFLD3.K=(1/DFBA)(FUPS.K-FUPSD.K)                                     DB1278
7A    PFCP1.K=PFLD.K-PFMPT.K                                               DB3277
```

APPENDIX THREE

DYNAMO COMPUTER RUN RESULTS

This appendix presents the results of the computer runs made at the MIT Computation Center. After considerable effort, consistent runs of the complete model were obtained using the equations of Appendix One, which include the modifications of Appendix Two. Tables III-1 and III-2 give the significant parameters and results for each of fourteen different runs. The approach to this selection is discussed in Chapter Five. All runs except 0707-1, 0708-1 and 0710-1 were made with Equations 0115, 0117, 0119 on page 94 changed to:

6A	ETC1 * 1.K	=	ECWCA.K	DB 0115
6A	ETC2 * 1.K	=	EGRCA.K	DB 0117
6A	ETC3 * 1.K	=	ESRCA.K	DB 0119.

The previous equations incorrectly weighted the past years work too heavily.

The OCNPR "Frequency" given as A-B/C-D is interpreted as follows: a) numbers before / indicate months between maximum values of OCNPR; b) two numbers indicate double peak; c) numbers after / indicate months between minimum peaks, d) two numbers indicate double peak.

The dimensions for the variables are as follows:

OCIT, OCNPR, OCPL	thousands of dollars per month
PETA, PFMP, MAR	men
FECE	equipments per month
ETTC, EPW, TAUW, OCPC	dimensionless
EPRE, ECAE, EGRE, ESRE	man months/month
EPC, ECWC, EGRWC, ESRWC	man months/month

Figures III-1 through 6 are reproductions of the computer runs for Runs 0708, 0714, 0745, 0711, 0746 and 0747 respectively. Brief descriptions of these are given below. In each case only a few variables are graphed.

Figure III-1 gives the response of the system with order rule gamma (S-P-G-C) to a large step input equivalent to the total applicable defense budget on a basic input of $10,000,000 per month proposal requests.

Figures III-2 and 3 give the response to a ten percent step on a steady input of $364,000,000 per month. It is seen that the response to order rule delta (S-C-P-G, 0745) is much less oscillatory than that to order rule eta (P-C-G-S, 0714). In addition, the net profit level when the proposal efforts have lowest priority is seen from Table III-2 to be less than half the other cases. The granting of higher priority to special research also yields the greater final profit level. All the responses to order rules alpha, gamma, and epsilon closely resembled that of order rule delta.

Figure III-4 shows the response to an impulse input of one month's input in time DT. While the transient response to order rule epsilon (P-C-G-S, 0711) is quite similar to that for order rule gamma (S-P-G-C, 0713) the assignment of higher priority to special research results in a higher net profit level, rate and income (see Table III-2).

Figures III-5 and 6 show the responses to ramp inputs of $20,400,000 dollars per month per month. Again the response to order rule eta(C-G-S-P, 0746) is seen to be much more oscillatory than that to a different order rule, epsilon (P-C-G-S, 0747). The responses to order rules eta and alpha are very similar (oscillatory) as are the responses to order rules gamma and epsilon (damped oscillations at lower frequencies). Since the amount of special research is zero in all four cases, and the general research not too dissimilar, the reason for the variation appears to be due to the relative ordering of the priorities assigned to proposals as compared to contracts. The placing of higher relative priority on proposals is seen to provide not only a less oscillatory system but a factor improvement in profit of three times.

RUN	0707-1	0708-1	0710-1	0704	1057	0747	0746
ORDER RULE	ALPHA C-P-G-S	GAMMA S-P-G-C	DELTA S-C-P-G	ALPHA C-P-G-S	GAMMA S-P-G-C	EPSILON P-C-G-S	ETA C-G-S-P
Input	Step 364,000	Step 364,000	Step 364,000	Ramp 20,400/m	Ramp 20,400/m	Ramp 20,400/m	Ramp 20,400/m
Values at Time =	100m	100m	100m	180m	180m	180m	180m
OCIT	3,499	3,376	3,404	22,125	28,007	26,953	21,524
OCNPR	+11	-106	-70	-551	+301	+203	-827
OCPL	-24,683	-24,419	-23,810	-134,760	-55,043	-52,477	-150,040
PETA	436	440	437	3,315	3,389	3,388	3,425
PFMP	689	843	806	4,213	5,775	5,213	3,973
EPRE	58	46	46	412	415	414	412
ECAE	373	382	386	1,651	2,869	2,772	1,277
EGRE	5	11	3	78	105	100	74
ESRE	0	0	0	0	0	0	0
EPC	22	45	45	676	400	399	774
ECWC	332	363	354	2,112	2,758	2,553	2,060
EGRWC	9	10	15	55	89	81	61
ESRWC	0	2	3	0	1	0	0
MAR	0	0	3	1,173	0	101	1,660
FECE	64	5.6	5.8	36.5	49.6	48.5	34.4
ETTC	.31	.34	.33	.04	.06	.05	.04
EPW	.60	.63	.62	.45	.55	.53	.44
TAUW	.94	.94	.94	.94	.94	.94	.94
OCPC	.80	.82	.82	.68	.97	.91	.66
OCNPR "FREQ."	55/45	55/47	7-13/22	4-11/11	18/17	15/14-21	4-11/11

TABLE III- 1 DYNAMO RESULTS FOR CICMN = 10,000, ETTC = 0

RUN	0703	0702	0745	0712	0714	0713	0711
ORDER RULE	ALPHA C-P-G-S	GAMMA S-P-G-C	DELTA S-C-P-G	EPSILON P-C-G-S	ETA C-G-S-P	GAMMA S-P-G-C	EPSILON P-C-G-S
Input	Step 34,000					Impulse one mo.	
OCIT	5,153	5,151	5,151	4,876	4,464	4,771	4,601
OCNPR	129	129	129	114	100	117	100
OCPL	18,557	18,559	18,562	16,910	8,582	18,194	16,171
PETA	548	548	548	525	522	500	493
PFMP	986	986	986	932	847	930	896
EPRE	47	47	47	47	47	43	43
ECAE	462	462	462	437	300	419	410
EGRE	23	23	23	22	19	21	20
ESRE	11	11	11	9	0	10	9
EPC	47	47	47	47	84	43	43
ECWC	458	458	457	436	391	421	405
EGRWC	22	22	22	21	20	21	19
ESRWC	10	10	10	9	2	10	9
MAR	5	5	5	0	156	6	12
FECE	9.6	9.6	9.6	9.0	8.0	8.9	8.6
ETTC	.40	.40	.40	.38	.35	.41	.39
EPW	.71	.71	.71	.66	.55	.71	.69
TAUW	.94	.94	.94	.94	.95	.94	.94
OCPC	.97	.97	.97	.87	.58	.95	.92
OCNPR "FREQ."					10/11		

TABLE III-2 DYNAMO RESULTS FOR CICMN = 340,000

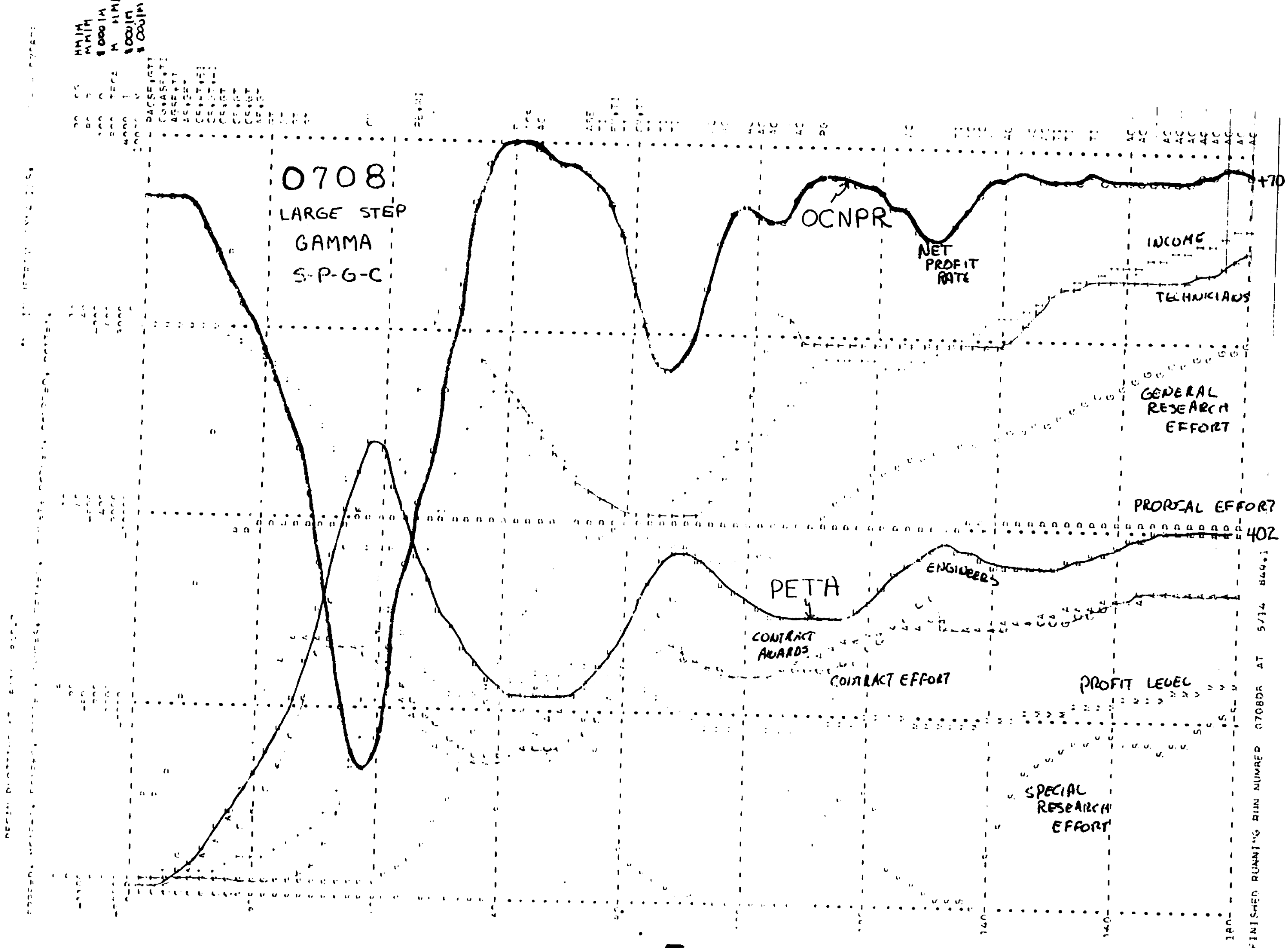

0708
LARGE STEP
GAMMA
S-P-G-C
OCNPR
NET PROFIT RATE
INCOME
TECHNICIANS
GENERAL RESEARCH EFFORT
PROPOSAL EFFORT
402
+70
PETA
ENGINEERS
CONTRACT AWARDS
CONTRACT EFFORT
PROFIT LEVEL
SPECIAL RESEARCH EFFORT

FIGURE III-1

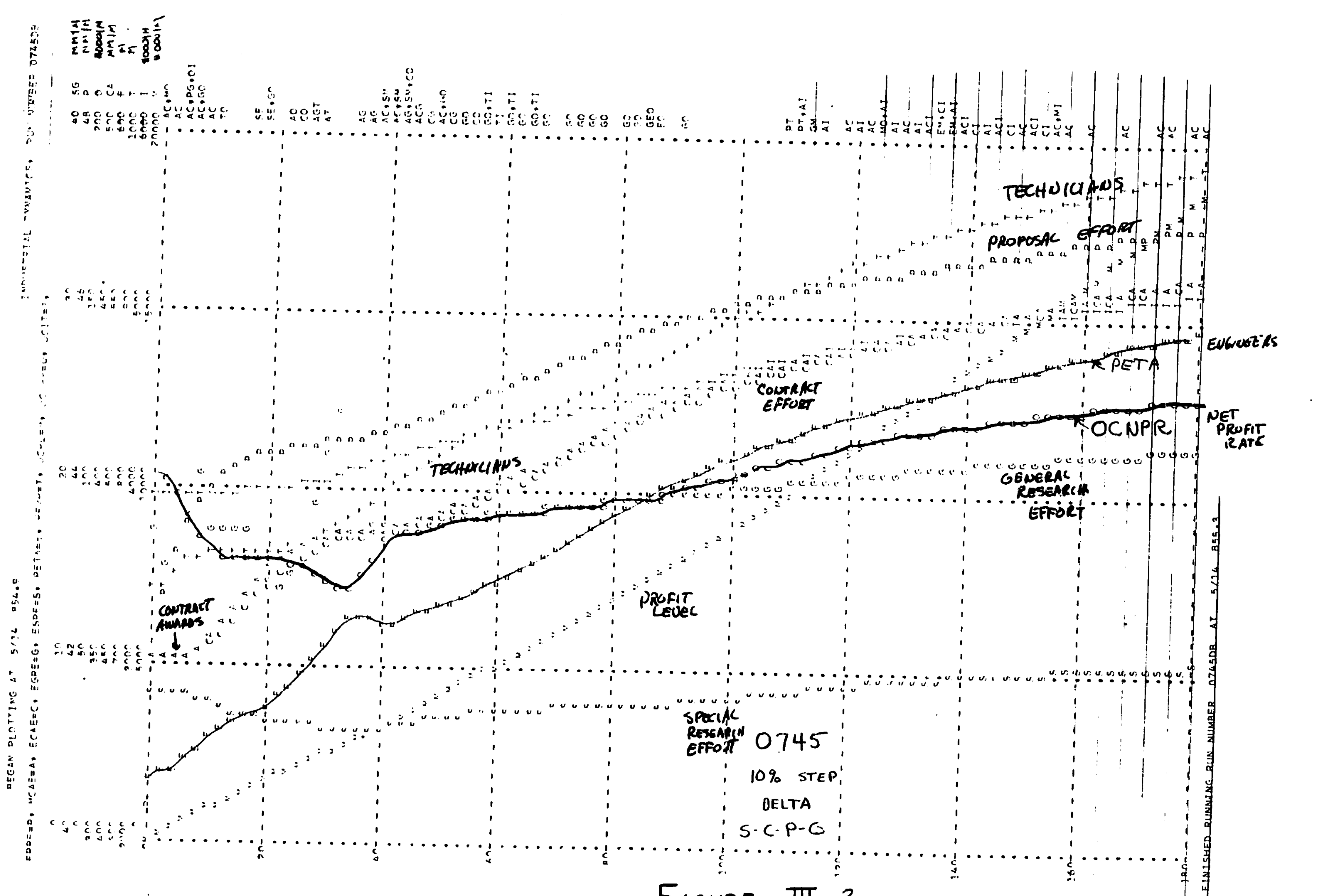
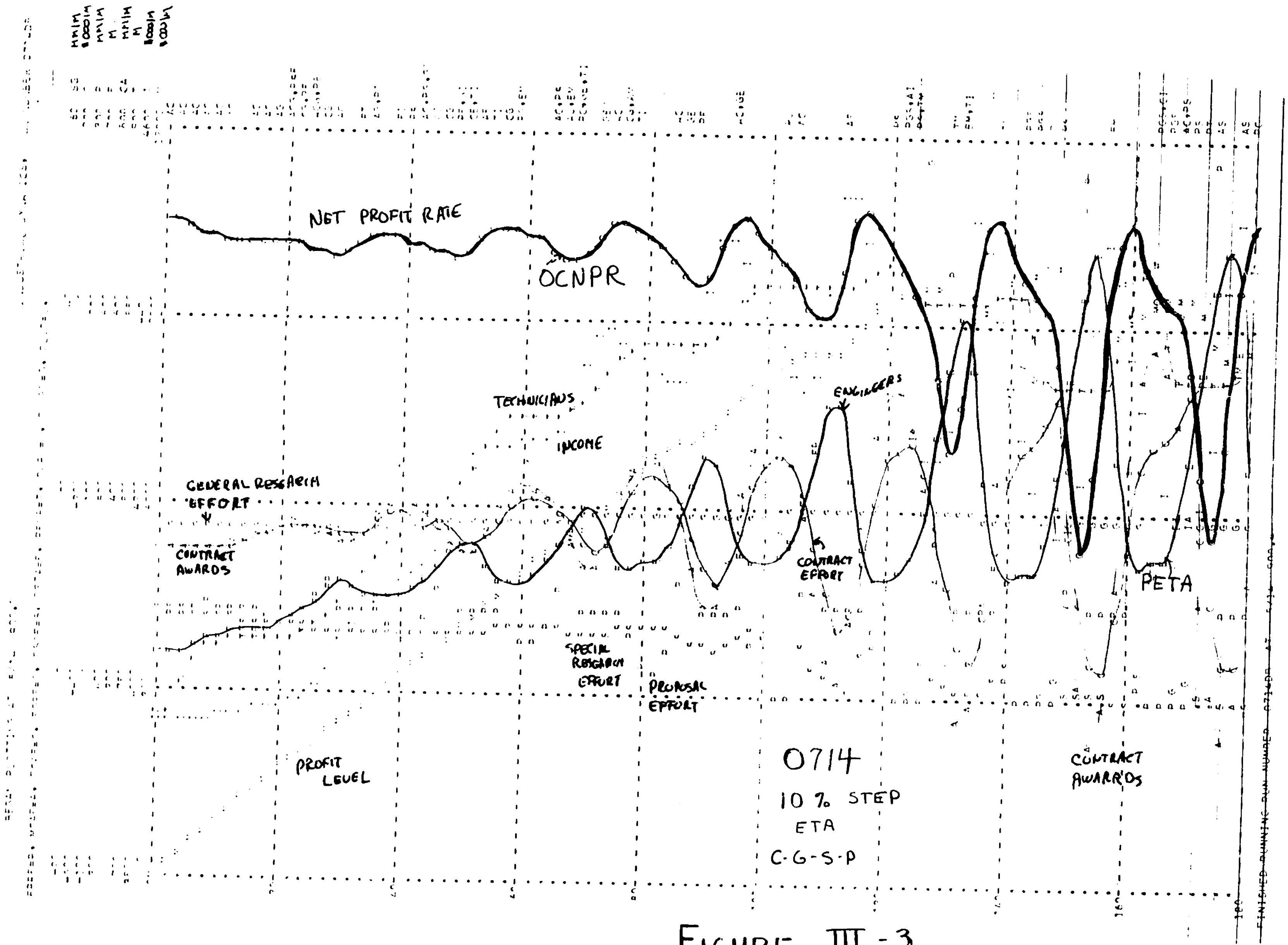

TECHNICIANS
PROPOSAL EFFORT
ENGINEERS
PETA
NET PROFIT RATE
OCNPR
CONTRACT EFFORT
TECHNICIANS
GENERAL RESEARCH EFFORT
PROFIT LEVEL
CONTRACT AWARDS
SPECIAL RESEARCH EFFORT
0745
10% STEP
DELTA
S-C-P-G

FIGURE III-2



NET PROFIT RATE
OCNPR
TECHNICIANS
INCOME
ENGINEERS
GENERAL RESEARCH EFFORT
CONTRACT AWARDS
CONTRACT EFFORT
PETA
SPECIAL RESEARCH EFFORT
PROPOSAL EFFORT
PROFIT LEVEL
0714
10 % STEP
ETA
C-G-S-P
CONTRACT AWARD'S

FIGURE III-3

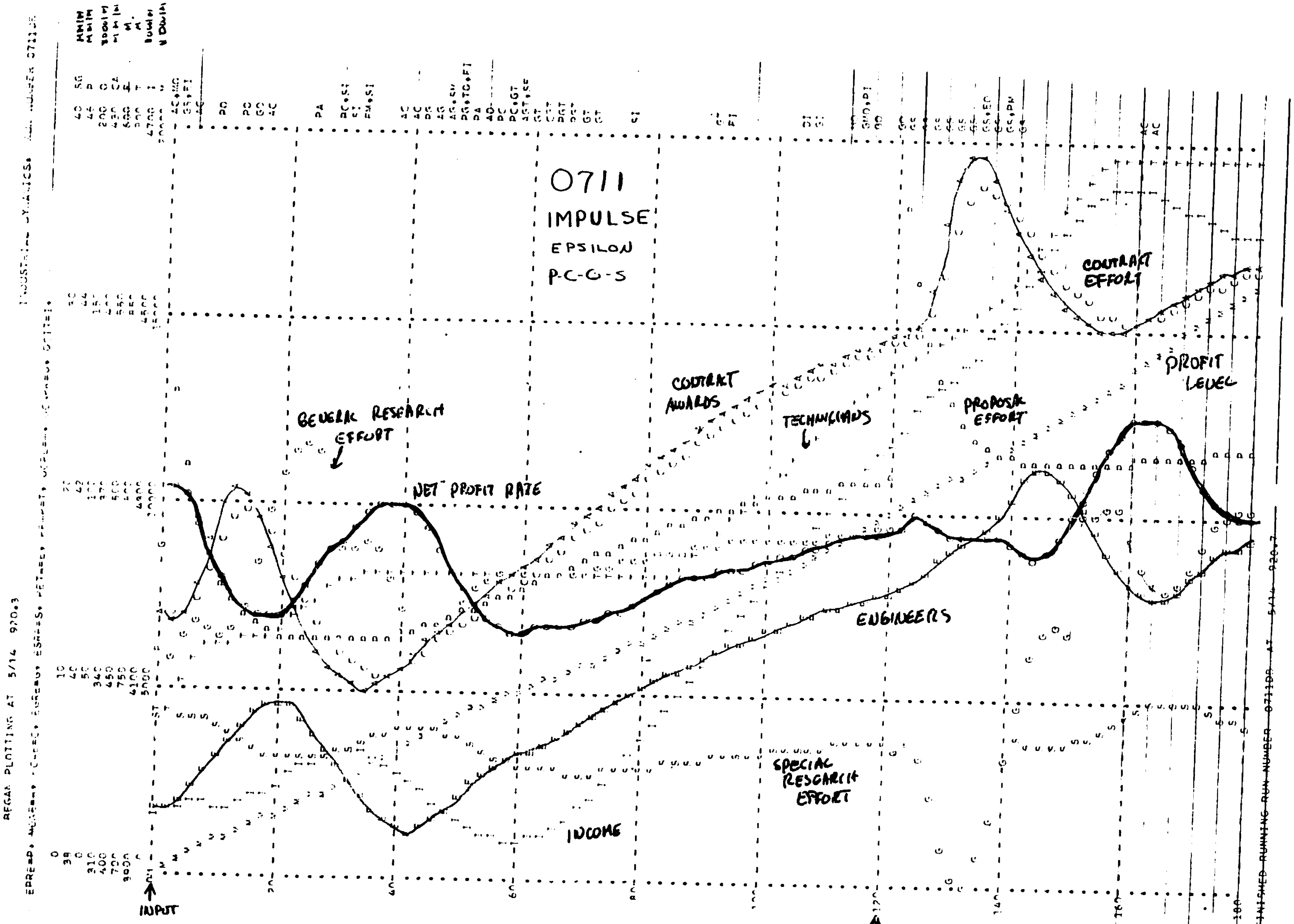

0711
IMPULSE
EPSILON
P-C-G-S
CONTRACT EFFORT
PROFIT LEVEL
CONTRACT AWARDS
TECHNICIANS
PROPOSAL EFFORT
GENERAL RESEARCH EFFORT
NET PROFIT RATE
ENGINEERS
SPECIAL RESEARCH EFFORT
INCOME
INPUT
INPUT

FIGURE III-4

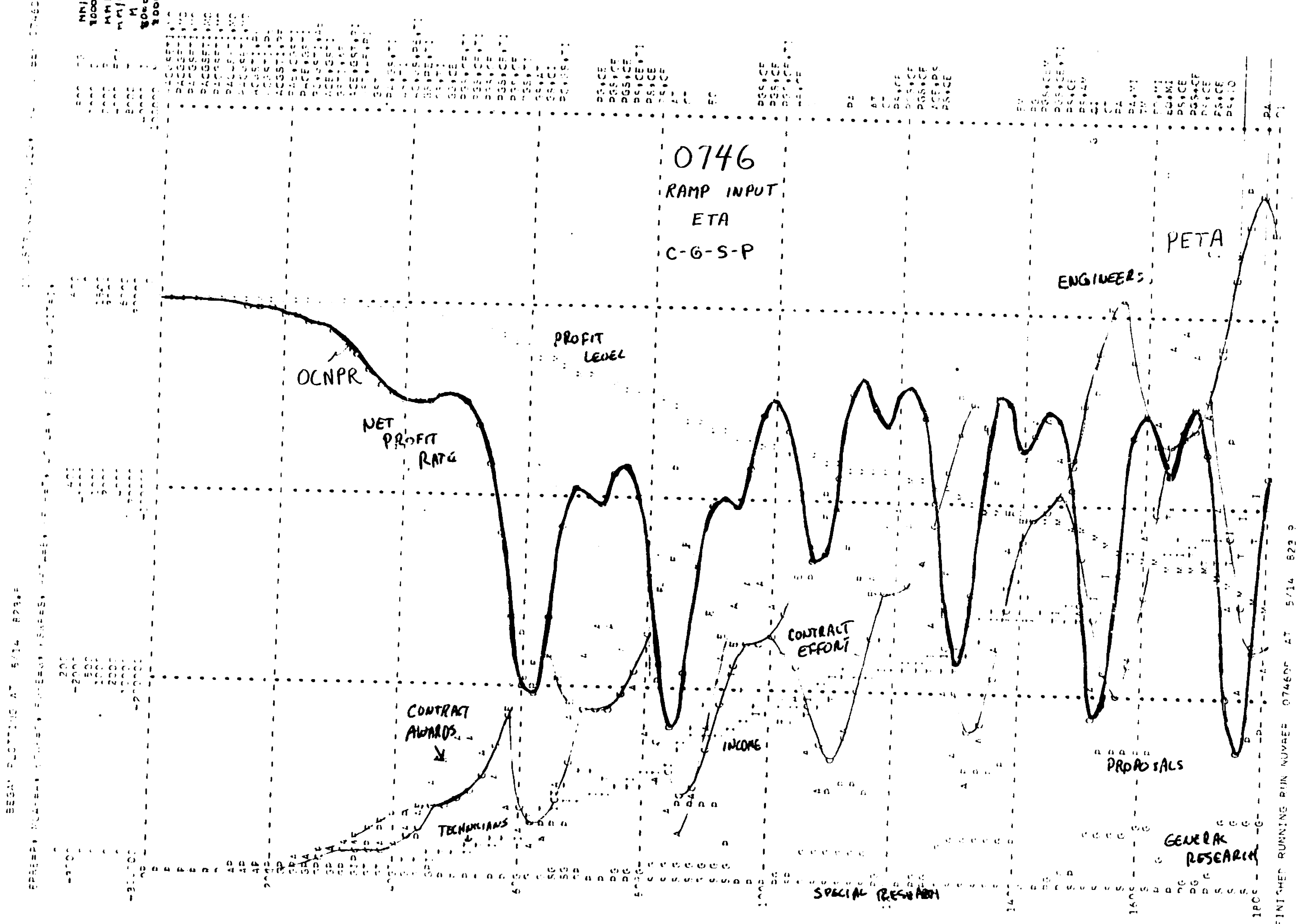

0746
RAMP INPUT
ETA
C-G-S-P
PETA
ENGINEERS
PROFIT LEVEL
OCNPR
NET PROFIT RATE
CONTRACT AWARDS
TECHNICIANS
INCOME
CONTRACT EFFORT
PROPOSALS
GENERAL RESEARCH
SPECIAL RESEARCH

FIGURE III-5

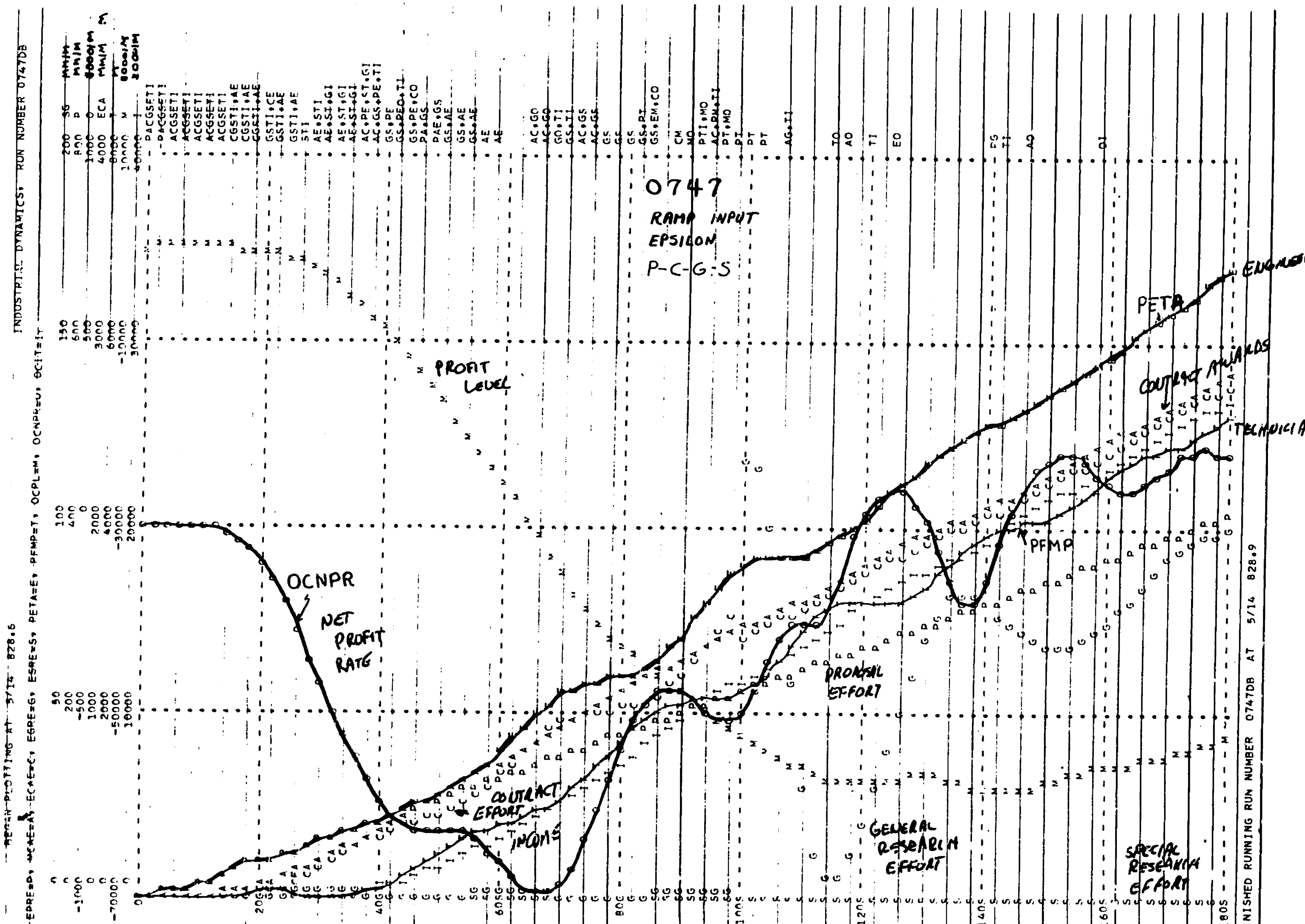

INDUSTRIAL DYNAMICS, RUN NUMBER 0747DB
BEGIN PLOTTING AT 5/14 828.6
EPRE=P, ECAE=C, EGRE=G, ESRE=S, PETA=E, PFMP=T, OCPL=M, OCNPR=O, OCIT=I
FINISHED RUNNING RUN NUMBER 0747DB AT 5/14 828.9
0747
RAMP INPUT
EPSILON
P-C-G-S
ENGINEERS
PETA
CONTRACT AWARDS
TECHNICIANS
PFMP
PROFIT LEVEL
OCNPR
NET PROFIT RATE
CONTRACT EFFORT
INCOME
PROPOSAL EFFORT
GENERAL RESEARCH EFFORT
SPECIAL RESEARCH EFFORT

FIGURE III-6