AN INDUSTRIAL DYNAMICS ANALYSIS OF A DEFENSE PRODUCT DEVELOPMENT ORGANIZATION

by

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Certified by . . . .
Faculty Advisor of the Thesis

May 6, 1961

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

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "An Industrial Dynamics Analysis of a Defense Product Development Organization."

I should like to acknowledge the guidance offered me in this work by Professor Jay W. Forrester, and Mr. John M. Wynne, Director of Executive Development Programs, both of the School of Industrial Management.

Members of the Industrial Dynamics Research Staff, in particular Messrs. A. J. Pugh and E. B. Roberts, were helpful in model formulation and in the latter phases of the work. Their guidance is appreciated sincerely.

The facilities of the Massachusetts Institute of Technology Computation Center with its IBM 709 Computer were utilized in this study. Appreciation is due the staff of the Computation Center for their real cooperation and assistance.

Sincerely yours,

Philip W. Lett, Jr.

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Submitted to the School of Industrial Management on May 18, 1961, in partial fulfillment of the requirements for the degree of Master of Science.

Abstract

A business system in action is studied in this thesis. Flows of information, material, manpower, equipment, and money were simulated in a model. Included were feedback loops that allowed representation of decisions, actions, and response. Techniques of Industrial Dynamics employing the Dynamo program were utilized. The model was run on the IBM 709 computer at the M.I.T. Computation Center.

The purpose of this study was to determine what kind of policies might be adopted by management that would most likely enhance possibilities of long term growth and profitability of a Defense product development organization. Since the greatest resource of the engineering organization at the center of this study was its technical manpower, attention was concentrated on how best to use this resource.

Four main types of work were performed by the organization: company initiated research, contract production engineering work, contract research and development, and preparation of proposals in answer to requests from the customer (the government in this case). The technical manpower of the organization was allocated in accordance with priorities for each work area. The priorities were continuously variable and relative between work areas. The pressure felt by management to do something about the difference between manpower needed and manpower available in each work area was used as an indication of management's evaluation of the importance of the work being performed in each area. Optimum choices were not sought but rather an indication, from study of behavioral characteristics of the model, that policies (A) were more likely to enhance possibilities of growth and profitability than policies (B).

Results indicated:

1. In the assignment of technical manpower, first priority should be given company initiated research which leads to unsolicited proposals and negotiated contracts. These negotiated contracts reflect the developed competence of the organization and a desire of the customer for continuity of technical effort. This priority should apply only to the region of small differences between manpower needed and available (per cent differences less than 15 per cent approximately).

2. Contract work should be accorded a priority above all other work if the differential in manpower needed and available is significant, i.e., above the range referred to above when company initiated research has a slightly higher priority than contract work.

3. Strong preference should be given company initiated research over proposals prepared in response to requests from the customer where these requests are received with little or no previous work having been done by the organization.

Thesis Advisor: Jay W. Forrester

Title: Professor of Industrial Management

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CHAPTER I

INTRODUCTION

The Art Versus the Science of Management

Management "science" has become a reality. The foundations for this significant metamorphosis were laid practically speaking in the last twenty years. Two events stand out. The need became clearly evident, and the resources for promoting this transformation were developed.

A most important resource, the computer, evolved in this period. With the accompanying reduction in cost of arithmetic calculations by a factor of ten thousand to one, new fields were opened that previously were untouched, sealed off primarily by the sheer mass of computations involved in meaningful investigation.

A second resource was developed coincidentally with the increasing recognition of the need for a scientific approach to management, namely a growing body of knowledge and understanding in the minds of a few forward-thinking management scientists. While recognizing that at least in part management will remain an "art", these men have refused to submit to the idea that the control of human and material resources in the matrix of a business is all "art" and therefore not a proper subject for logical inquiry.

Industrial Dynamics

The management research conducted has been along two broad fronts. First studies of human relations and of the socio-psychological factors that affect the interactions of people. Though an inexact science, much tangible progress has been made in this field in the last two decades. Secondly, intensive efforts have been made to improve the decision making process of business managers by providing them with useful information about the nature of the business system in which they are engaged. In the latter category the development of the technique of industrial dynamics by the M.I.T. School of Industrial Management has ranked as an important step forward. Industrial dynamics allows the study of a business system in action including its flow of information, material, manpower, equipment, and money. It involves the programming on the computer of a business system with its essential feedback loops. It simulates environment, decision, action, and response.

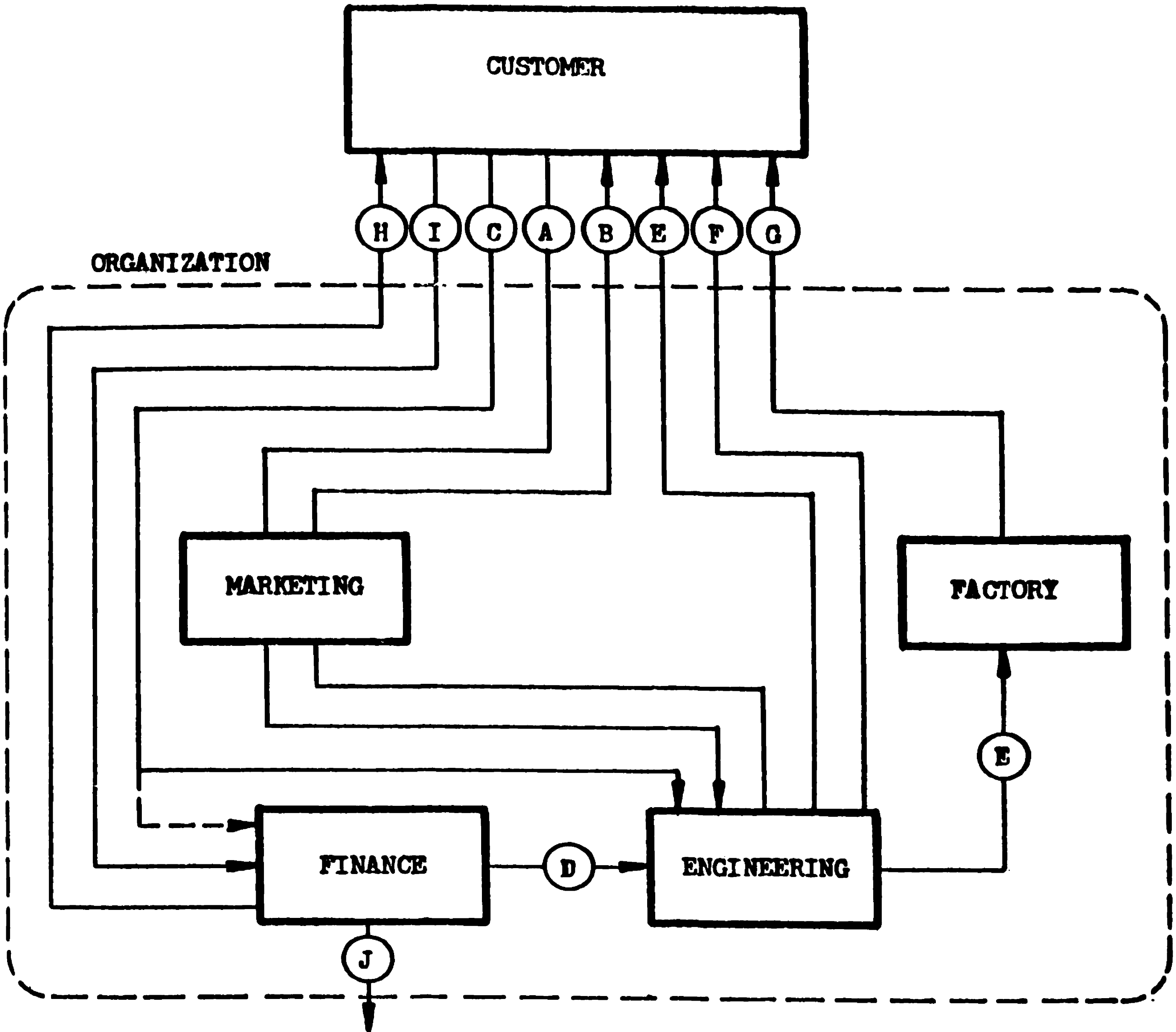
Lest the claims for this technique be overstated, it should be pointed out that this simulation technique is still in the early stages of development, that it does not provide answers as to the optimum choice or decision. Instead it indicates dynamic behavioral characteristics of a business system. These indications generally show that one set of policies is better than a second set of policies, or, choice A is more likely to achieve a desired result than choice B. Using an industrial dynamics model, a further gain is possible by instituting new untried policies and studying reactions. Policies can be tried that ordinarily would not be experimented with in the business enterprise because of risk, the investment required, or just plain resistance to change.

In a number of cases it has been found that a business system is inherently unstable because of its internal procedures or the time relationship of its internal processes. The revelation of knowledge of this type which would not be evident otherwise is a valuable function of industrial dynamics. The entire emphasis is on studying the performance of the business system as a whole rather than focusing attention on the parts. More useful is a little information about the whole than much information about the parts without the knowledge of how the parts work together to produce a desired result.

The Purpose and Approach of This Study

To date the more frequent application of industrial dynamics has been to manufacturing operations, processing industries, and advertising. In 1960, D. C. Beaumariage, a Sloan Fellow at M.I.T.'s School of Industrial Management, submitted a thesis on the application of industrial dynamics to a military product development group. Based on the preceding work, this study has been conducted to determine what policies should be adopted by the management of a defense product development group to build up the volume of business of the engineering organization and the parent division. Emphasis is placed on the management policies for the engineering group since it is felt that the group performs a key function for the rest of the organization. The term "organization" as used in this study refers to the company functional groups, marketing, engineering, finance, factory, etc., that work together to develop and produce defense products. Since it is necessary in order to complete the feedback loop, the model includes the customer, in this case the government or the military. The major flows that exist between the functional elements of the model are shown in Figure 1.

The customer requests proposals, and awards contracts after evaluation of proposals submitted by industry. The organization submits proposals, receives contracts, submits engineering drawings and specifications as well as equipments to the customer. What is not shown in this flow diagram is the time sequence of operations, the delays that exist in the various parts of the organization, the response to various actions, the information flows and the management policies that affect in a vital way the operating of the system.



LEGEND

A Requests for Proposal
B Proposals
C Contracts
D Authorizations
E Engineering Drawings and Specifications
F Prototype Equipments
G Production Equipments
H Charges
I Income
J Profit

Figure 1 - Flow Diagram, Customer-Defense Product Organization

The industrial dynamics model of the system attempts to include the more important of the latter with the flows of material, manpower, equipment, and money.

The most important resource of an organization whose primary product is engineering services is the brainpower and "know how" represented in its engineers. Based on this premise, major attention is given in this study to the use of the manpower resources of the technical organization. The importance attached by management to the needs for technical manpower in various areas of work is in fact a management policy of controlling significance--for based on its sense of urgency management acts to hire new employees, to transfer men from one area to another, etc. The effect of these policies over the long term can be to cause the business to grow or, contrariwise, to cause it to decline in size and in income. This is not to say that exogenous factors either alone or in combination with internal management policies cannot cause the same results. However, the existence of outside factors over which we have no control is not an adequate reason to fail to seek and apply the management policies most likely to benefit the business, to maximize its profits over the long term. Virtually all management decisions are made with incomplete knowledge. Anything that can be done to provide information that will permit more favorable decisions is obviously a help. The knowledge of the effects of a decision on other parts of the organization would no doubt cause many decisions thought to be optimum to be made differently. To the degree that the organization as a whole is treated, industrial dynamics offers at least a partial solution to the problem of sub-optimum decision making.

Conclusions

Management policies with regard to utilization of technical manpower in an Engineering group which is part of a Defense Product Organization can affect significantly the long term profitability of both the Engineering group and the parent organization. Results of this study indicated:

(a.) In the assignment of technical manpower first priority should be given company initiated research which leads to unsolicited proposals and negotiated contracts. This priority should be higher than that assigned contract work and work on requests for proposal received with little or no pre-request effort being spent by the company. The priority should apply only to the region of small differences between manpower needed and manpower available. Long term growth of the organization is enhanced by increasing and engineering technical competence which objective can be realized with greater probability by the policy just described.

(b.) Policies regarding utilization of manpower should accord contract work a priority above all other work if the gap is large between manpower needed and that available, and second only to company initiated research if the shortage in manpower is small. There should be no great difference in the priorities of contract work and company initiated research even in the region where the differences between needed and available manpower are small. Referring to policy (A) used in this study, insufficient priority was accorded contract work in the region where manpower needs were relatively small.

(c.) Strong preference should be given company initiated research over proposals prepared in response to requests from the Customer where these requests were received without foreknowledge. The returns to the organization from the latter type of proposal were consistently of small magnitude.

CHAPTER II

THE OBJECTIVES AND POLICIES OF THE BUSINESS

The objectives of a business may be definite and explicit, or as is more generally the case, may be a mixture of implicit and explicit objectives understood well by some responsible for managing the business and less well by others. A business may or may not have an objective of making money. The health of the competitive free enterprise system would not seem to be improved as the number of the latter increases. Generally, however, the situation is that the shareholders who own the business purchased stock with the expectation of receiving a fair return on their investment. The men hired to manage the business therefore accept the obligation to provide this fair return. Every manager, supervisor, and employee in the organization should recognize this obligation. How well the objective is recognized throughout the organization depends on how well management does its job of orienting all levels.

Given that making money is generally the primary and "necessary for life" objective of a business, other objectives ordinarily exist coincidentally. The managers of the business have an obligation to the employees. The business should be efficiently managed to offer a future with opportunity for advancement and financial security for employees.

The business has an obligation to the community, to the nation, and to society at large. This obligation is to provide a useful and desired service either directly or through its products. The managers of the business should be leaders in recognizing and meeting these civic responsibilities.

Objectives become more restricted in scope as one goes from top to lower management in an organization. At the level of plant manager it is impossible for the manager to make all decisions with full knowledge of the impact on other parts of the organization and its outside relationships. However, this does not relieve the plant manager from seeking to gain as much pertinent information as can be obtained in the time available before making a decision. His is a constant responsibility of deciding when to act on information available versus postponing a decision to get more information. In the latter case he also faces the danger of decision by postponement, in effect making "no choice" as the decision.

Management Decisions at Plant Level

The kinds of decisions made at plant level depend in large measure also on the character of the plant operation. A plant whose output is a product will obviously require management know how and decisions different from those required in a plant whose output is a service. Organizations whose salable output is a professional service require special management skills. This is particularly true of an organization whose output is primarily engineering services. One of the chief skills required, adeptness in human relations, will be considered in this study only as it affects the pressure felt by management to do something about manpower shortages or overages in various work areas. Primary attention will be focused on the management of technical manpower as the most important resource available in an engineering organization. How technical manpower is utilized within the organization likewise represents the priority assigned by management to each type of work being performed. The types of work which receive high priority will thus get prompt attention when needs and problems arise. The converse is true of the types of work that receive a lower priority. These priorities represent management policies directed toward increasing the long term profitability of the organization.

Management Policies Regarding Technical Manpower Utilization

In this study a means has been devised for simulating management policies with regard to technical manpower utilization. This in turn serves as a key to the functioning of the model. In essence this key is a definition of management's reaction to shortages or overages of manpower in each of the four work areas of the organization. This reaction, or pressure felt by management to do something about technical manpower needs, is a continuously variable function. Also it is relative in that the needs of one area are weighed against the needs of another area. The pressure felt by management to meet the requirements for technical manpower in each work area arises from the requests of area supervisors, from management's recognition of the importance of the work being performed, from communication with customers and higher management, etc.

Technical Manpower Management Policies (A) and (B)

Figures 2 and 3 represent, respectively, two possible management policies. Referring to Figure 2, per cent differential in manpower is plotted along the abscissa against pressure felt by the management as the ordinate. The three curves cover the types of work performed by the organization; the contract work includes production engineering and research and development contracts. Let us assume that at some particular time manpower shortages existed in each work area that could be represented by points A, B, and C on the curves. Proportionate pressure would be felt by management to meet the needs of each work area. Acting within the limit of technical manpower resources available, management would allocate these resources equally, i.e., in such a manner to equalize pressure relating to each work area. This reallocation of technical manpower would result in new per cent dif-

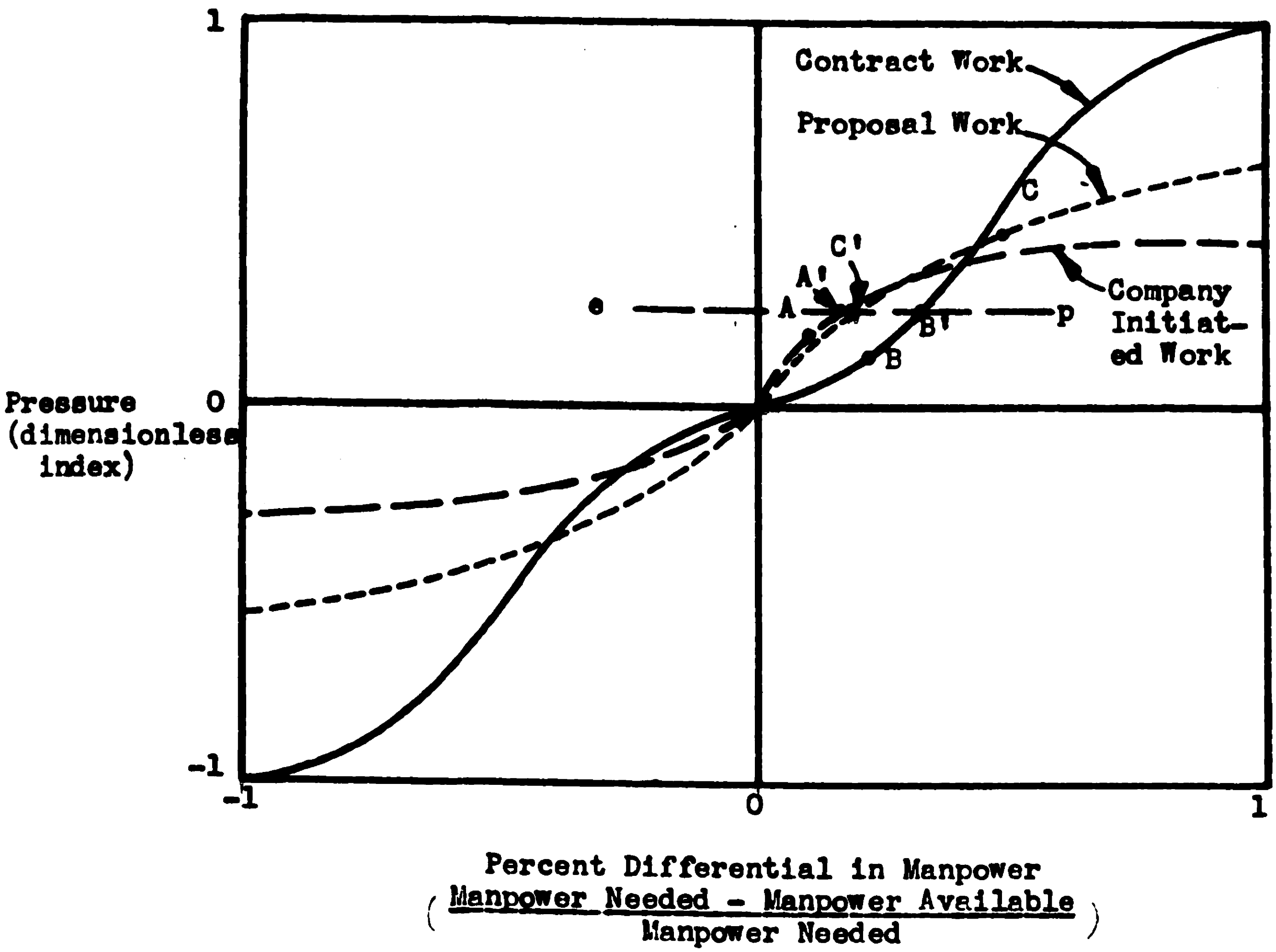


Figure 2, Management Policies (A) with Regard to Technical Manpower Utilization

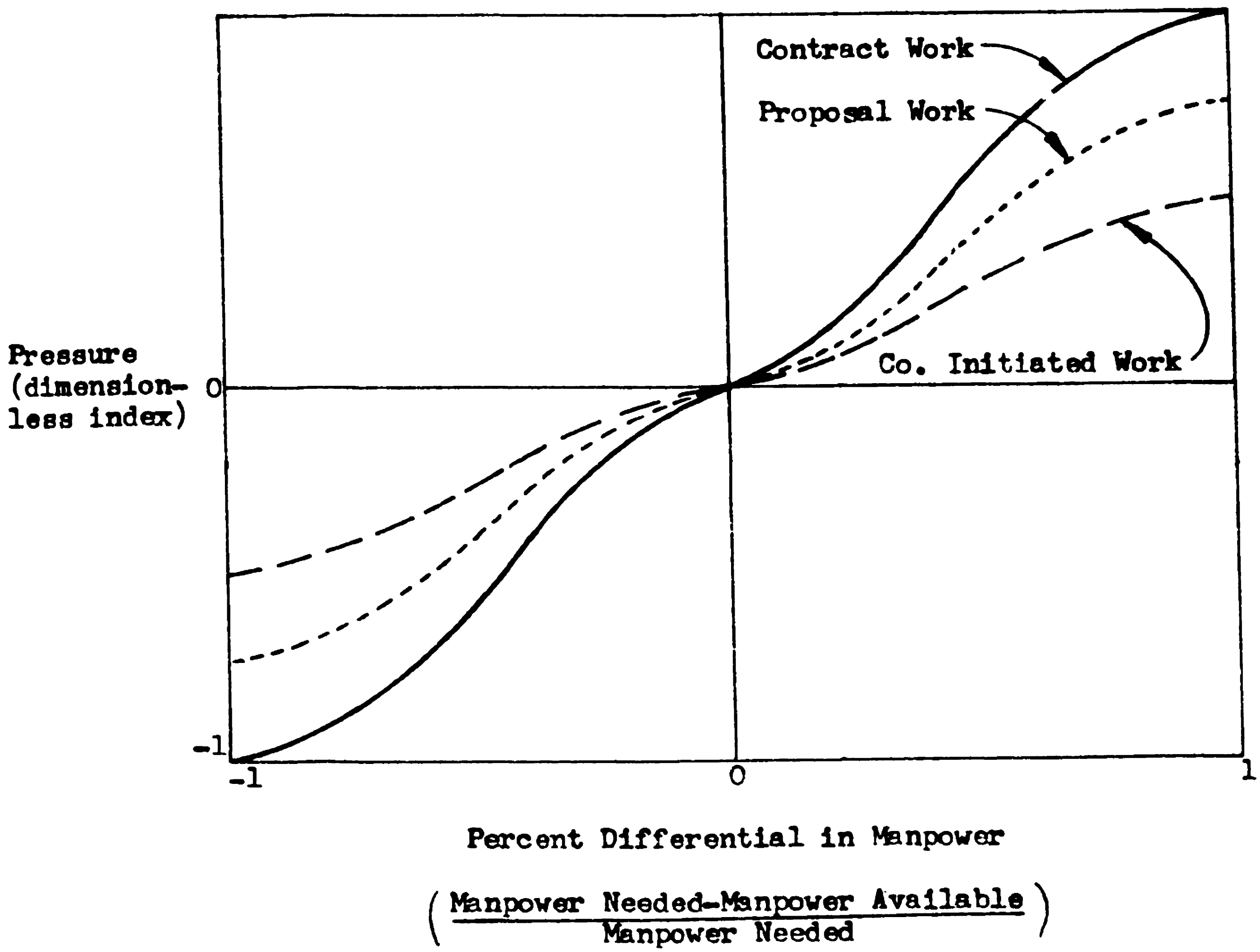


Figure 3, Management Policies (B) with Regard to Technical Manpower Utilization ferentials in manpower in each work area and a new averaged pressure. The situation could then be represented by points A', B', and C'. The change would, of course, not be instantaneous but would require time for accomplishment.

Referring to Figure 2, management policy (A), the graph depicts a situation in which a small shortage in manpower in company initiated and proposal work would be viewed as more serious than a small shortage in contract work. However, if the difference between technical manpower needed and available gets sufficiently large, the contract work takes an increasing priority, even to the point of taking all men from non-contract work in the extreme case. The graph also states in effect that pressure felt by the management about manpower needs in a particular area is a maximum when manpower available is zero while a definite manpower need exists in that area.

A different set of management policies is depicted in Figure 3. Management policy (B) is to give top priority to contract work, second priority to proposal work, and third priority to company initiated work with regard to allocation of technical manpower. As the difference between manpower needed and available gets larger, contract work gets an even larger priority, while proposal work receives a moderately larger priority relative to company initiated work. Under normal business conditions the needs for manpower in each area will not vary abruptly so that recruiting activities can supply added requirements for men without serious problems. Cases do arise, however, where needs for manpower change suddenly, such as the receipt or cancellation of a large contract. In the model this kind of occurrence is simulated by changes in the input.

CHAPTER III

PERFORMANCE OF THE BUSINESS IN THREE SITUATIONS

Situation One, Customer Defense Expenditures at a Constant Level

Performance of the business was studied under a number of conditions. The first situation involved using management policy (A), followed by substituting management policy (B), with a steady flow of money being made available to industry by the Customer for the purpose of military procurement. The period of time covered in the simulation run was fifteen years.

Under policy (A) the long term profitability of the organization was better than under policy (B). This is indicated in Figure 4. As the organization accumulated experience over the years, its technical competence increased at a greater rate under policy (A) which gave a higher priority to company initiated work (see Figure 5). With the increase in technical competence, proposal worth increased and the rate of contract awards increased. Inasmuch as the situation represents stable conditions, these increases were all small in magnitude. As the rate of receiving contracts increased, the backlog of work began to grow. This in turn was reflected in an increased requirement for manpower. As the gap between manpower needed and that available grew, the

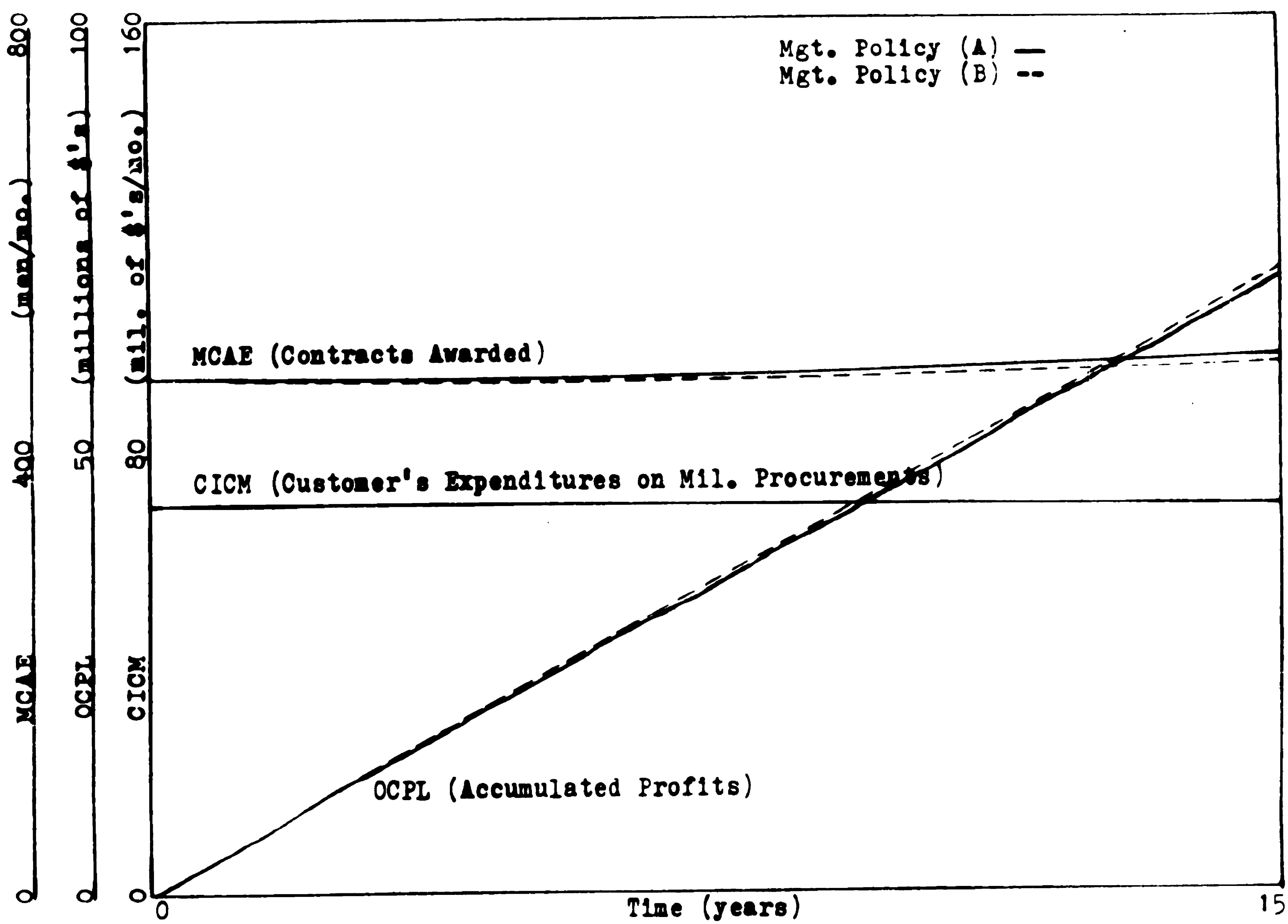


Figure 4, Effects of Management Policies (A) and (B) on Contracts and Profits -- Customer's Expenditures Steady

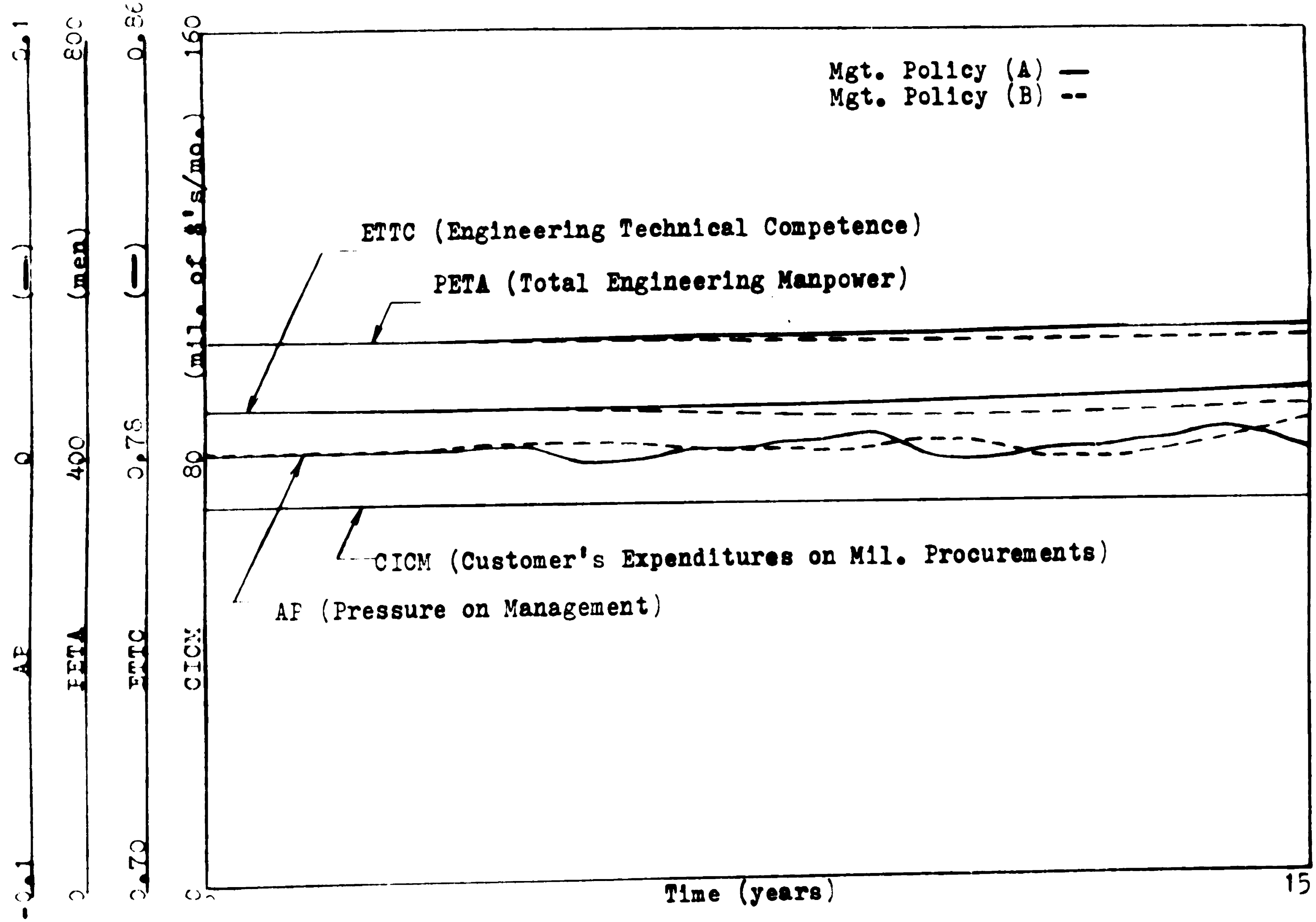


Figure 5, Effects of Management Policies (A) and (B) on Competence, Manpower, and Pressure -- Customer's Expenditures Steady pressure mounted until action was taken to meet the manpower needs either by hiring additional personnel or transfer between departments within the organization.

Under policy (A) a small manpower shortage in company initiated and proposal work caused a marked pressure increase. This step up in pressure caused transfer of men from contract work. This transfer was not as smooth under policy (A) as it might have been because the management policy does not regard as serious the manpower differentials for contract work in the range near zero, i.e., where requirements are met without any excess of manpower. Pressure would build up until a transfer of men was made. The transfer of personnel was usually sufficiently large to cause a noticeable drop in pressure. Under policy (A) where the needs of a small group of proposal engineers were regarded quite highly, the transfer of men from the large group on contract work occurred with frequency.

Under policy (B) where contract work received top priority, the engineering organization was operated with less expense because there was less disturbance of the large group of engineers working on contracts. Policy (B), however, did not result in technical competence increasing at quite the rate that occurred under policy (A).

The optimum policy would seem to be to a modification of policy (A) where contract work would receive somewhat higher priorities with small manpower differentials, but not as high as those for company initiated work. This modified policy would provide for a build up of technical competence over time while maintaining a large group on contract work with a higher priority than afforded by the original management policy (A).

Situation Two, Customer Defense Expenditures Varied Randomly about a Constant Level

The second situation studied was similar to the first except that the Customer's outlay of money for military procurements (CICM) was varied in a random manner within limits of ±5% of the basic monthly rate (see Figure 6). These limits could be considered conservative but the random nature of the input more closely approximates reality than a steady flow. The average monthly flow of CICM, the mean of the random inputs, was held constant. Management policies (A) and (B) were employed.

Under management policy (A) the emphasis on company initiated work resulted in more unsolicited proposals and a slightly greater rate of contract awards from this work. Also over the fifteen-year period the number of personnel in the Engineering department was increased between 4 and 5 per cent as compared to an increase between 1 and 2 per cent under policy (B). Revenues increased at a greater rate under policy (A) than under policy (B); however, expenses also grew

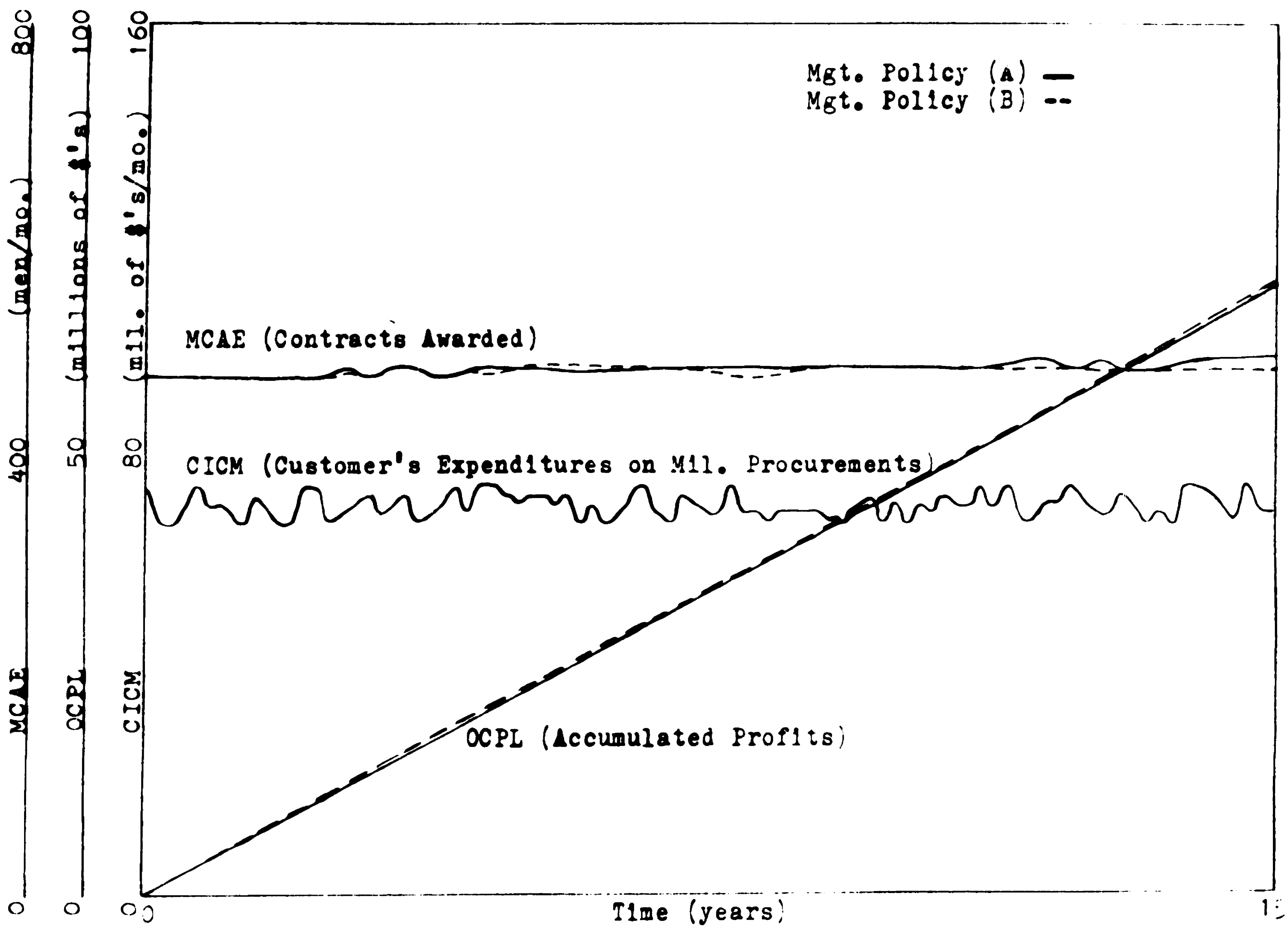


Figure 6, Effects of Management Policies (A) and (B) on Contracts and Profits -- Customer's Expenditures Varying Randomly faster under (A) than (B), so that the accumulation of profits over the fifteen-year period was greater with policy (B).

Pressure on the management varied more frequently and with less severe fluctuation under policy (A), as shown in Figure 7 . Likewise, the total number of men employed in Engineering varied more frequently and with less severity under policy (A). The trend of business measured in yearly dollar volume of contracts received appeared slightly upward to a greater extent under policy (A) than under policy (B).

In both the first situation and the second, results indicated that effort expended on class 2 proposals, in response to requests received without foreknowledge, was limited in effectiveness. The great bulk of contracts was negotiated as a result of the technical competence of the organization, its ability to maintain competitive prices for services and hardware, and its capacity to undertake work.

From both situations it seems clear that effort on class 1 proposals should be minimized and effort should be concentrated on company initiated projects and on work under contract. Work on company initiated projects is a small scale effort, nominally 3 per cent of the engineering work force, with a highly selective group. Contract work provides the revenue, the basic current support of the organization. It can continue to do so over the long term; however, only with an avant garde group working in conjunction with it as

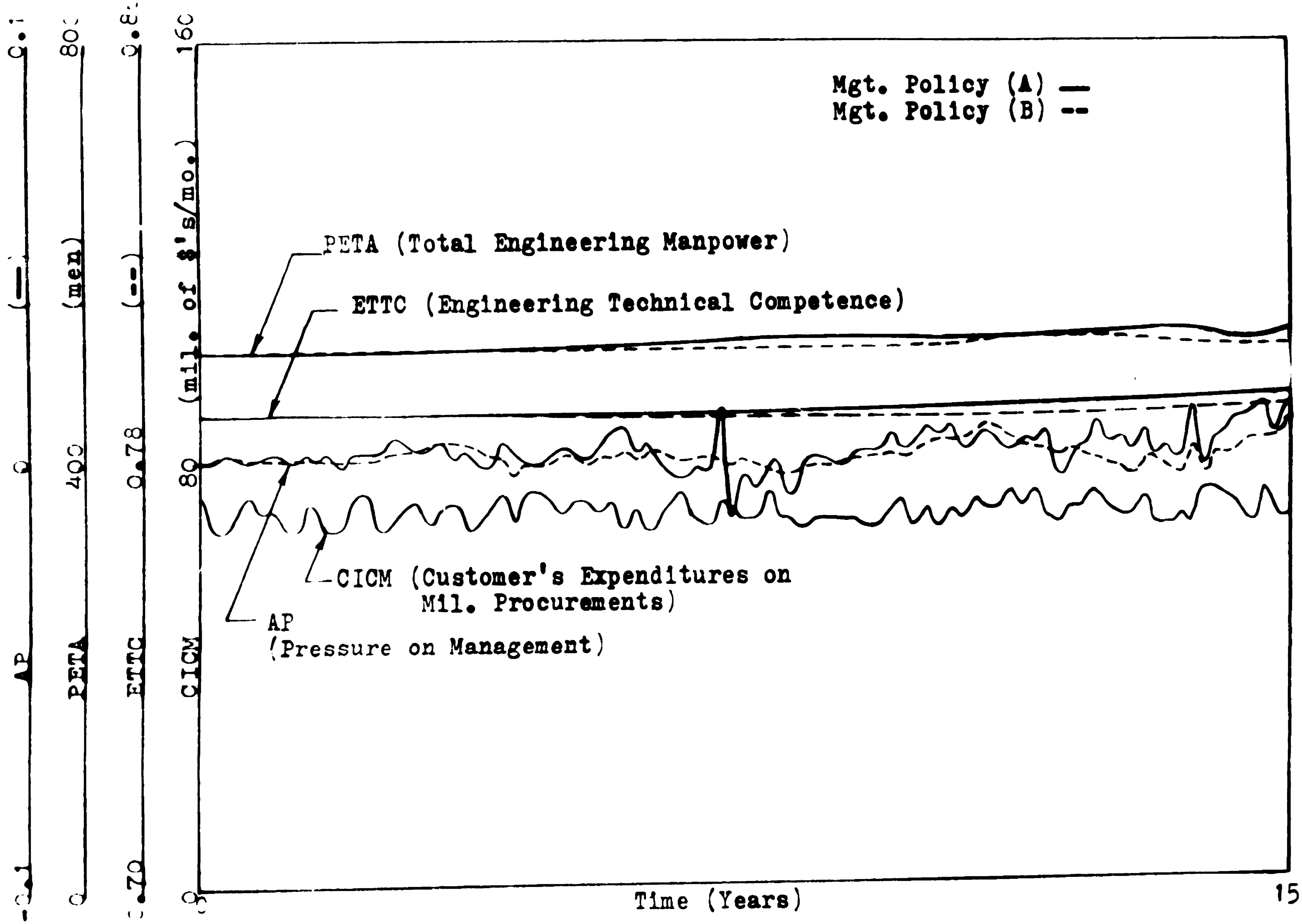


Figure 7, Effects of Management Policies (A) and (B) on Competence, Manpower, and Pressure -- Customer's Expenditures Varying Randomly is provided here on company initiated work.

<u>Situation Three, Customer Defense Expenditures Increased at a Constant Rate to a New Higher Level in a One-Year Period</u>

The third situation investigated was one in which the Customer's outlay of money for military procurements (CICM) was increased at a rate of 1 per cent per month for the period beginning at 12 months and ending at 24 months from start of the run. The rate of customer outlay for military procurements was held at a constant level before and after the ramp increase. This is illustrated in Figures 8 and 9 . Management policies (A) and (B) were again employed alternately.

As CICM was increased monthly for one year, three things happened that were important:

(a.) The dollar volume of the flow of requests for proposal to the organization increased. This in turn increased the average monthly requirement for proposal engineers. The backlog of requests for proposal grew larger than the desired backlog. The total manpower needed for proposal work was then increased as a function of the average inflow of requests, and by an additional amount needed to reduce over a period of time the actual backlog to the desired backlog. Since the manpower available for proposal work could not be made equal to that needed instantaneously, the difference created pressure on management. As the pres-

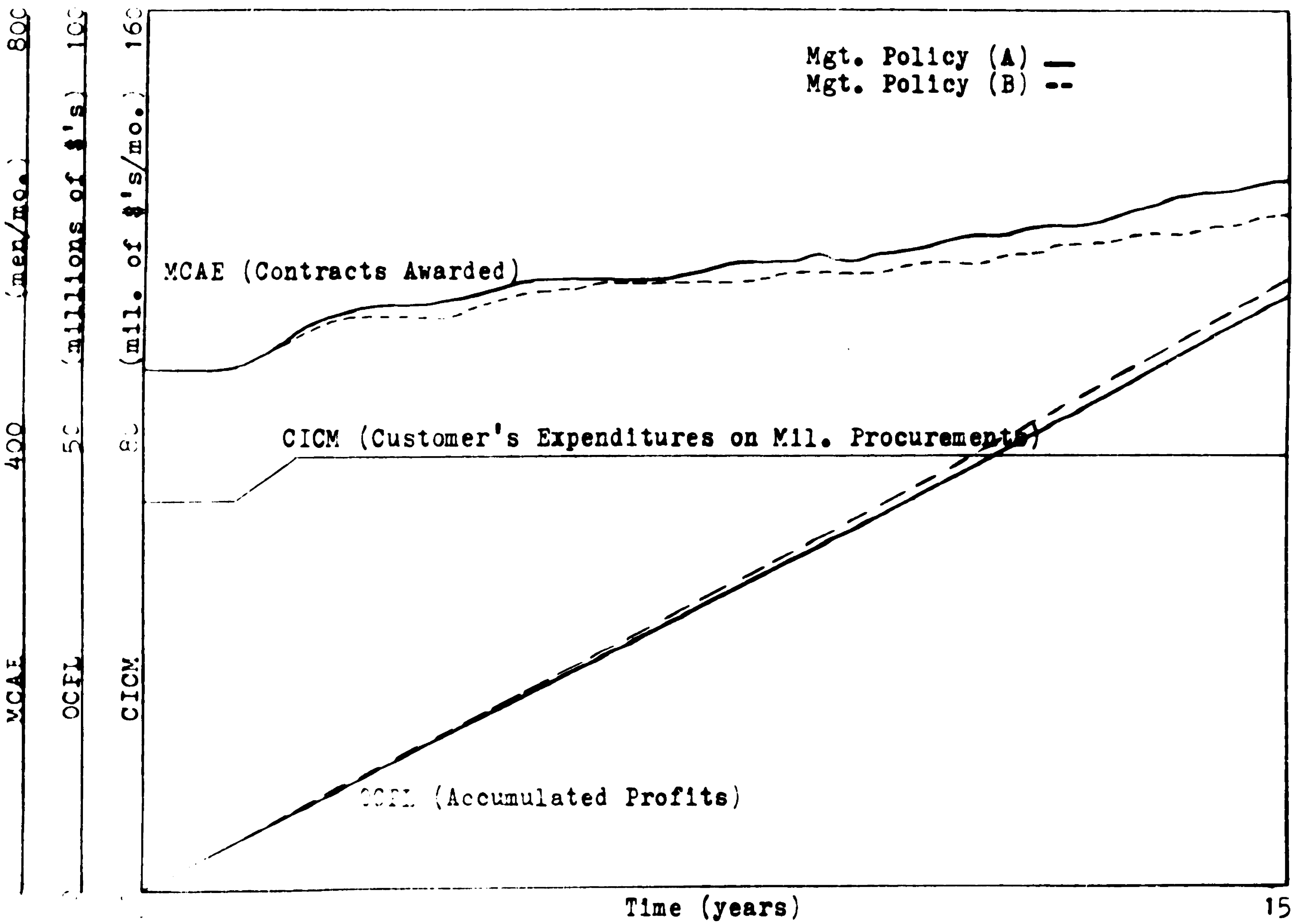


Figure 8, Effects of Management Policies (A) and (B) on Contracts and Profits -- Customer's Expenditures Increased Over a One Year Period

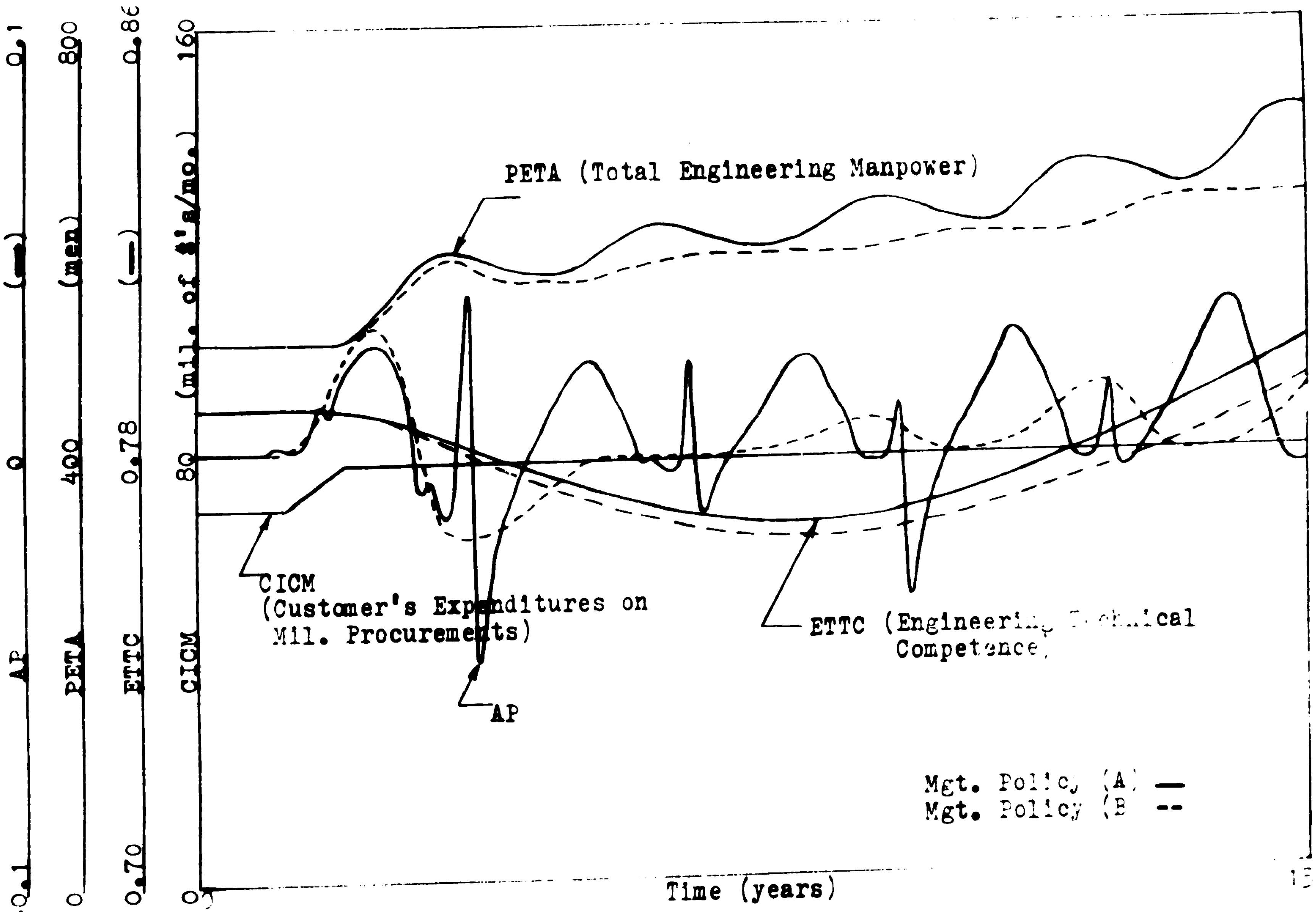


Figure 9, Effects of Management Policies (A) and (B) [illegible] tence, Manpower, and Pressure -- Customer's Expendit [illegible] ncreased Over a One Year Period sure rose, management started to hire new employees, and to transfer men between departments so as to equalize the pressure.

(b.) Simultaneously with an increase in the dollar volume of the requests for proposal circulated to industry, the Customer increased the money allocated to negotiated contracts. In this study the rates of increase of these two was assumed equal. This resulted in an increase in the dollar volume of negotiated contracts awarded the organization. These awards were mostly design and development for production contracts but included as well research and development contracts. Thus the average monthly effort needed for design and development for production contracts increased, and the average monthly effort for research and development contracts increased. This in turn caused an increase in the backlog of work in these two areas so that actual backlog exceeded the desired value. Manpower needed for these two areas of work was then increased first to meet the larger inflow of these contracts, and secondly, an added amount necessary to gradually reduce the backlog to the desired level. Again pressure on management rose due to the inability of the organization to supply additional manpower in these two areas as quickly as needed. Hiring was initiated, and steps taken to equalize pressure in the organization by transfer of personnel between departments.

(c.) As needs for manpower increased in the areas of proposal work, design and development for production, and research and development, additional personnel were recruited and hired. As the size of the Engineering group grew, the number of men assigned to company initiated projects increased since this is nominally a percentage of the engineering work force. This increase in men needed for company initiated work thus lagged the increase in requirements for added manpower in the other work areas. The effect on pressure felt by management to supply increased manpower requirements for company initiated work was similar to that previously described for the other areas of work. As formulated in the model, ETTC represented an index of engineering technical competence built up over the years by experience. This index was made a relative index. Engineering experience, weighted according to its value, was accumulated over an eight-year period and this experience, averaged, compared with the maximum engineering contract work the organization could be receiving currently. The maximum contract work that could be received currently is dependent on the Customer's outlay for military procurements currently. For this reason a ramp increase in CICM had the effect of decreasing ETTC since an eight-year weighted average was compared with a current monthly average of CICM. An expression for relative engineering technical competence that compared CICM averaged over an eight-year period with weighted engineering experience over that period would have added to the significance of the index ETTC. This point seems applicable to those situations where CICM is increased somewhat rapidly rather than to the case where CICM is fairly steady or varies in a random manner about some slowly changing average.

Under policies (A) and (B) manpower needed for proposal work was boosted upward by the increase in CICM that occurred between 12 and 24 months. However, manpower needed for proposal work reached a maximum at about 36 months and held steady at that level. This occurred because the manpower needed for proposal work is a function of the rate at which requests are received from the Customer. As described, CICM is held steady after 24 months in the third situation.

In contrast to the requirements for manpower for proposed work, the manpower needed for the three other areas of work continued to increase over the length of the 15-year run. Success begets success. As competence of the engineering organization improved, as capacity for incoming contracts was maintained, as financial results of operations enabled attractive price proposals to be made, the business of the organization grew, from the initial stimulus of the increase in CICM, throughout the period.

As business of the organization grew from the stimulus of an increase in CICM, the marketing effort of the organization diminished somewhat. This effort was stated in the model as dependent on the ratio of unfilled manpower requests to the normal backlog of work to be done. Engineering technical competence declined somewhat for a period of a few years as described previously after the increase in CICM. The net effect was to reduce the percentage of requests for proposal published (in dollar volume) that were sent to the organization by the Customer. This, however, was a temporary reduction which the organization remedied by increasing its marketing effort and technical competence over a period of time.

Under management policy (A) slight changes in the requirements for manpower on proposal and company initiated work caused marked increases in pressure felt by management. The readjustment of manpower assignments by transfer from contract work areas was accomplished in accordance with the policy that allowed rather large shifts of contract personnel before management became really concerned. This caused larger fluctuations in manpower assigned to contract work, and consequently total manpower, than occurred under policy (B). The time delays in recruiting, hiring, and training personnel, coupled with the above situation, meant that overshooting occurred. That is, more men would be hired than necessary; then a lag would occur before new men were requisitioned, and a shortage would develop before the new men joined the active work force (see Figure 10). This kind of operation caused some inefficiency in the utilization of manpower, more pronounced under policy (A) than under policy (B).

The tendency to overhire under policy (A) did provide in the long run adequate manpower for the important areas of contract work. This assured the maintenance of engineering output in these areas with consequent beneficial effects on the financial performance of the Engineering group and the factory. Likewise the priority given company initiated work under policy (A) insured a high rate of unsolicited proposals and negotiated contracts. Negotiated contracts over the period increased under policy (A) at a faster rate than under policy (B). Under policy (A) engineering technical competence was improved more than under policy (B) due to the emphasis on unsolicited proposals based on company initiated research. At the end of the period, the forecast for new business consequently was better under policy (A).

The inefficiency mentioned earlier in matching manpower needs with requirements quickly, and without excess of personnel, resulted in a less efficient engineering operation financially under policy (A). This in turn caused accumulated profits at the end of the fifteen-year period to be larger under policy (B). Also under policy (B) the output of engineering information was held much more steady due to the more stable manpower allocations to these areas of work.

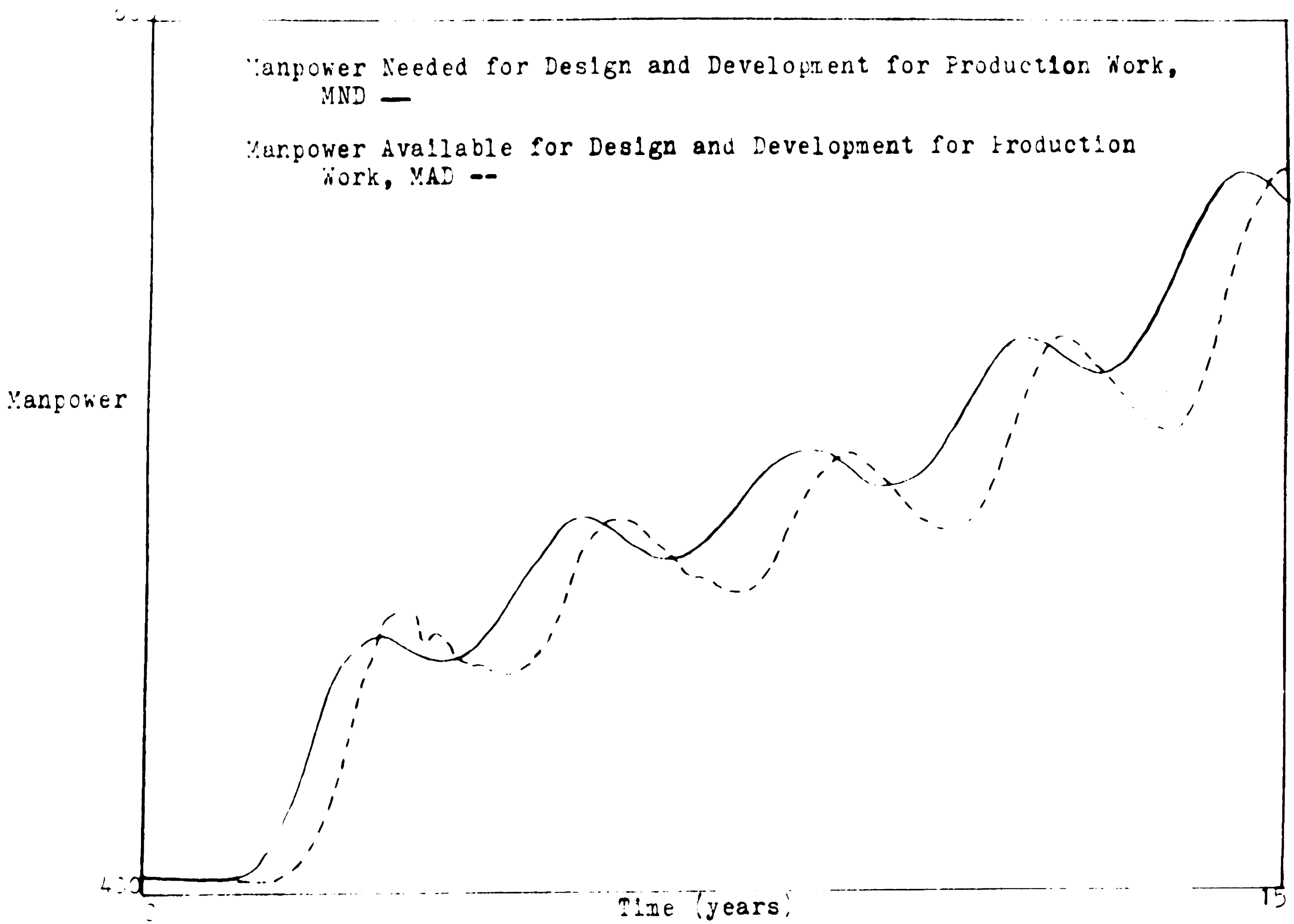


Figure 1[illegible], Manpower Needed and Available for Production Engineering, Management Policy (A), Customer's Expenditures Increased Over a One Year Period

Priorities under policy (B), however, meant that manpower needs for company initiated work were not met as fully or as quickly as occurred under policy (A).

CHAPTER IV

CONCLUSIONS

Management policies regarding the utilization of technical manpower in an Engineering group which is part of a Defense Product Organization can affect vitally the long term profitability of the organization. Such an Engineering group provides a continuing source of "know how" to the customer. It is therefore logical and to be expected that the majority of contracts received for engineering services are negotiated.

In general the model used in this study reacted in a manner that simulated reality. This is not to imply that the model contains the same details as a business in actuality. Rather, in investigating one aspect of the business, the model provided information that was pertinent. The important influence of human factors was not represented in the model except as a reaction on the part of management described as pressure when certain events took place. The model's effectiveness depends on the perceptiveness of the originator in recognizing what is important in a business with relation to the question being studied, and secondly, on the skill of the originator in translating this knowledge accurately into the model.

Two sets of management policies (A) and (B), relating to utilization of technical manpower were studied. These policies were incorporated alternately and the dynamic behavior of the business studied in three situations. These situations represented Customer defense expenditures at a normal steady level, a rate of expenditure varied in a random manner about a stable average, and a rate of Customer defense expenditure that was increased steadily to a new level which was then maintained. Behavior of the model indicated:

(a) Growth of technical competence of the Engineering group over a long period (in excess of five years) is more assured under policy (A) than under policy (B). Under policy (A) highest priority in assignment of technical manpower is granted company initiated research. The priority is highest in the area where differences between manpower needed and that available are small. Also the size of the work force assigned to company initiated projects is small and represents the most creative talent in the organization. Not only is technical competence increase more assured but a complementary increase in negotiated contracts received is also more likely when company initiated work is given the priority of policy (A).

(b.) For increased efficiency and improved earnings management should assign higher priorities to contract work than that indicated by policy (A). Specifically management should be more concerned about differences between manpower needed and manpower available for contract work in the region where these differences are not yet of major importance. The performance of the Engineering group on contract work represents the large share of the group's output. This production engineering is not only pertinent to the long term profitability of the factory but provides the current support for the Engineering group.

(c.) Effort within the Engineering group should be concentrated on company initiated research leading to unsolicited proposals in strong preference to answering requests for proposal where little or no work has been done by the organization prior to the receipt of the request. The results in contract awards from the latter effort were demonstrated to be definitely limited.

APPENDIX A

A DYNAMIC MODEL OF THE BUSINESS

It is impossible to construct a mathematical model of a business without stopping repeatedly to ask one's self what is important in the business, what really makes a difference on how the business prospers. Since no model can represent a business in all its details, no model is ever completely realistic. What is hoped is that the originator has been sufficiently perceptive in determining what is relevant and, secondly, that he has accurately translated this knowledge into the model by means of the equations formulated to represent the flows of manpower, money, information, etc.

What is relevant likewise is influenced considerably by the purpose of the inquiry. In this study a basic question has been underlying--how can engineering effort be utilized most effectively to stimulate growth of the business, particularly with regard to long-term profitability?

The model consists of five sectors. The organization is made up of four sectors--marketing, finance, engineering, and factory. The customer is the fifth sector represented in the model.

CUSTOMER SECTOR

The customer, in this case the government, has a certain amount of money to spend each year for services and hardware that can be provided by the organization studied. Most of this money is spent by the Defense Department although agencies like the Federal Aviation Agency also have procurements in the same market from time to time. The total amount of money available for services and hardware that could be provided by the organization, however, is not open to bidding to the organization. There are several reasons for this. One is that incomplete knowledge exists. The particular government office initiating a procurement action may not know of the interest and capability of the organization, and the organization in turn may not be aware of a procurement action. Secondly, a tendency exists for government contractors to become more closely affiliated with one branch of the service than another. This has the advantage that the customer knows from experience what an organization can do. It has the disadvantage of making it difficult for a contractor to get diversified experience by winning contracts from agencies with which he has not previously conducted business. A firm is likely to have an opportunity to bid on most of the procurements that are within the capabilities of the organization, initiated by the branch of the service with which they are most closely associated; but infrequently is the firm likely to have as extensive opportunities from all services. In the model the total amount of customer money available each month for procurements in the military product industry of which the organization is a part is represented by CICM.

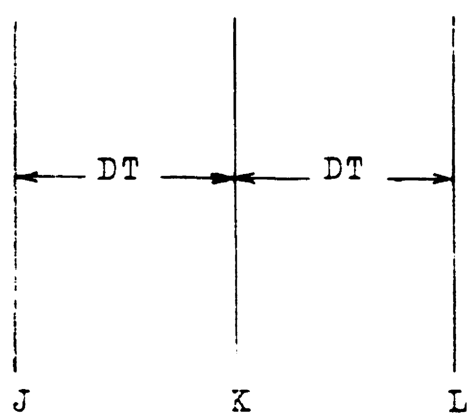
CICM = Customer Income Capital for Military procurements ($/month)

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

CRFPO = Customer Requests For Proposal that are sent to the Organization, expressed in dollar volume ($/month)

CPPO = Customer Percentage of requests for Proposal forwarded to the Organization (%)

The postscripts KL, K, and JK are defined as follows:



J, K, and L represent a point in time. DT represents the time interval between computations that are made by the computer. In the model DT is set to equal 0.2 of a month. In other words, every equation in the model is calculated five times a month. JK is the time postscript used with a flow or rate that exists between two points in time, specifically between time J and time K. Similarly, KL is the time postscript used with a flow or rate that exists between time K and time L.

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

CRFPC = Customer Requests For Proposal that are sent to Competitors, expressed in dollar volume ($/month)

CPPC = Customer Percentage of requests for Proposal forwarded to Competitors

CPPC.K = 1 - CPPO.K

CPPO.K = DMESB.JK + DETTC.JK + DTAUW.JK

DMESB.KL = DELAY 3 (AMESB.K, DEME)

AMESB.K = (AME)(MESB.K)

DMESB = Delayed effect of Marketing Effort in Soliciting Business (% of total percentage of requests for proposal received)

DELAY 3 = third order delay, i.e., a delayed effect that starts gradually and tapers off near the end of the time interval involved.

AMESB = Average Marketing Effort in Soliciting Business (% of total percentage of requests for proposal received)

DEME = Delay of Effect of Marketing Effort, i.e., the average time period over which the marketing effort has its delayed effect (months)

AME = weighting factor that Apportions Marketing Effort to the other factors in determining percentage of requests for proposal received by the organization (dimensionless).

MESB = Marketing Effort in Soliciting Business (dimensionless)

DETTC.KL= DELAY 3 (AETTC.K, DEEE)

AETTC.K = (ATC)(ETTC.K)

DETTC = Delayed effect of Engineering Total Technical Competence in determining the percentage of requests for proposal received (% of total percentage of requests for proposal received)

AETTC = Average effect of Engineering Total Technical Competence (% of total percentage of requests for proposal received)

DEEE = Delay of Effect of Engineering Effort (months)

ATC = Weighting factor that Apportions engineering total Technical Competence to the other factors in determining percentage of requests for proposal received by the organization (dimensionless)

ETTC = Engineering Total Technical Competence

DTAUW.KL= DELAY 3 (ATAUW.K, DEAW)

ATAUW.K = (AUW)(TAUW.K)

DTAUW = Delayed effect of Total Ability to Undertake Work in determining the percentage of requests for proposal received (% of total percentage of requests for proposal received)

ATAUW = Average effect of Total Ability to Undertake Work (% of total percentage of requests for proposal received)

DEAW = Delay of Effect of total Ability to undertake Work (months)

AUW = weighting factor that Apportions total ability to Undertake Work to the other factors in determining the percentage of requests for proposal received by the organization (dimensionless)

TAUW.K = EAUW.K + FAUW.K

EAUW = Engineering Ability to Undertake Work (dimensionless) See page 83.

FAUW = Factory Ability to Undertake Work (dimensionless) See page 96.

MRFPL.K = MRFPL.J = (DT)(CRFPO.JK - PURPT.JK)

PURPT.KL = PURP.JK + DMPRC.JK

PURP.K = (ACAE)(RRRA)(EPC2.JK)/(AAPO)

DMPRC.K = (ACAE)(RRRA)(MPRC.JK)/(AAPO)

MRFPL = Marketing Requests For Proposal Level ($)

PURPT = Proposals and Unanswered Requests for Proposals Total, i.e., cancelled proposals are included with those which the organization has declined the invitation to bid ($/months)

PURP = Proposals and Unanswered Requests for Proposal expressed in dollar volume ($/month)

DMPRC = Dollar volume of Marketing Proposal Requests Cancelled ($/month)

RRRA = factor based on averaged experience for converting the value of proposals submitted in response to requests to the value of the total number of requests for proposal received (dimensionless). In other words, this is the ratio of the dollar volume of proposal requests received to proposal requests answered

ACAE = factor based on averaged experience for converting effort of proposal engineers into effort of engineers (dimensionless). In other words, it is the ratio of engineers total in the organization to the average number of engineers employed in preparation of proposals in response to requests from the customer

1/AAPO = factor based on averaged experience for converting contract engineering effort expressed in man months/month into equivalent engineering contract work expressed in \$/month (\$/man month). AAPO is, of course, the converse.

EPC2 = Engineering Proposals Completed of class 2 type, i.e., proposals prepared in response to specific requests from the customer where little or no work on the proposal was done prior to receipt of the request (man months/month of proposal engineering effort)

MPRC = Marketing Proposal Requests Cancelled (man months/month of proposal engineering effort.) These are requests the organization would like to answer but cannot due to the work load and the time limitation on the submission of a proposal (See page 52)

MRFPE.KL = (AAPO)(CRFPO.JK)/(ACAE)(RRRA)

MRFPE = Marketing Requests For Proposal Entering (man months/month of proposal engineering effort)

MCAE.KL = MCAE1.JK + MCAE2.JK

MCAE1.KL = (CCAE1)(CO1.K)(CCPE1.JK)

MCAE2.KL = (CCAE2)(CMCO2.K)(CCPE1.JK)

MCAE = Marketing Contract Awards Entering (man months/month)

MCAE1 = Marketing Contract Awards Entering from class 1 proposals (man months/month)

MCAE2 = Marketing Contract Awards Entering from class 2 proposals (man months/month)

CCAE1 = Conversion factor for Contract Awards Entering from class 1 proposals. The average ratio of contract awards entering expressed in man months/month to the engineering effort assigned to company initiated work (man months/month of contract work to man months/month of company initiated engineering effort)

CCAE2 = Conversion factor for Contract Awards Entering from class 2 proposals. The average ratio of contract awards entering expressed in man months/month to the engineering effort assigned to proposals that were received with little or no preproposal work having been performed by the company (man months/month of contract work to man months/month of proposal engineering effort)

CMCO1 = Customer Marketing Contracts Obtained as a percentage of class 1 proposals submitted (% successful of proposals submitted)

CMCO2 = Customer Marketing Contracts Obtained as a percentage of class 2 proposals submitted (% successful of proposals submitted)

CCPE1 = Customer Completed Proposals Evaluated of the class 1 type (man months/month of company initiated engineering effort)

CCPE2 = Customer Completed Proposals Evaluated of the class 2 type (man months/month of proposal engineering effort)

CMCO1.K = Function of EPW1.K (see Figure 11)

CMCO2.K = Function of EPW2.K (see Figure 11)

Defense contracts are awarded by the government on the basis of their evaluation of a number of pertinent factors. It is here assumed that the most important factor is the worth of the proposal submitted where proposal worth is defined to include engineering technical competence, ability to undertake the work, and price attractiveness. Thd percentage of proposals that result in contracts can therefore be expected to increase as the worth of proposals increase. This relationship is described graphically in Figure 11.

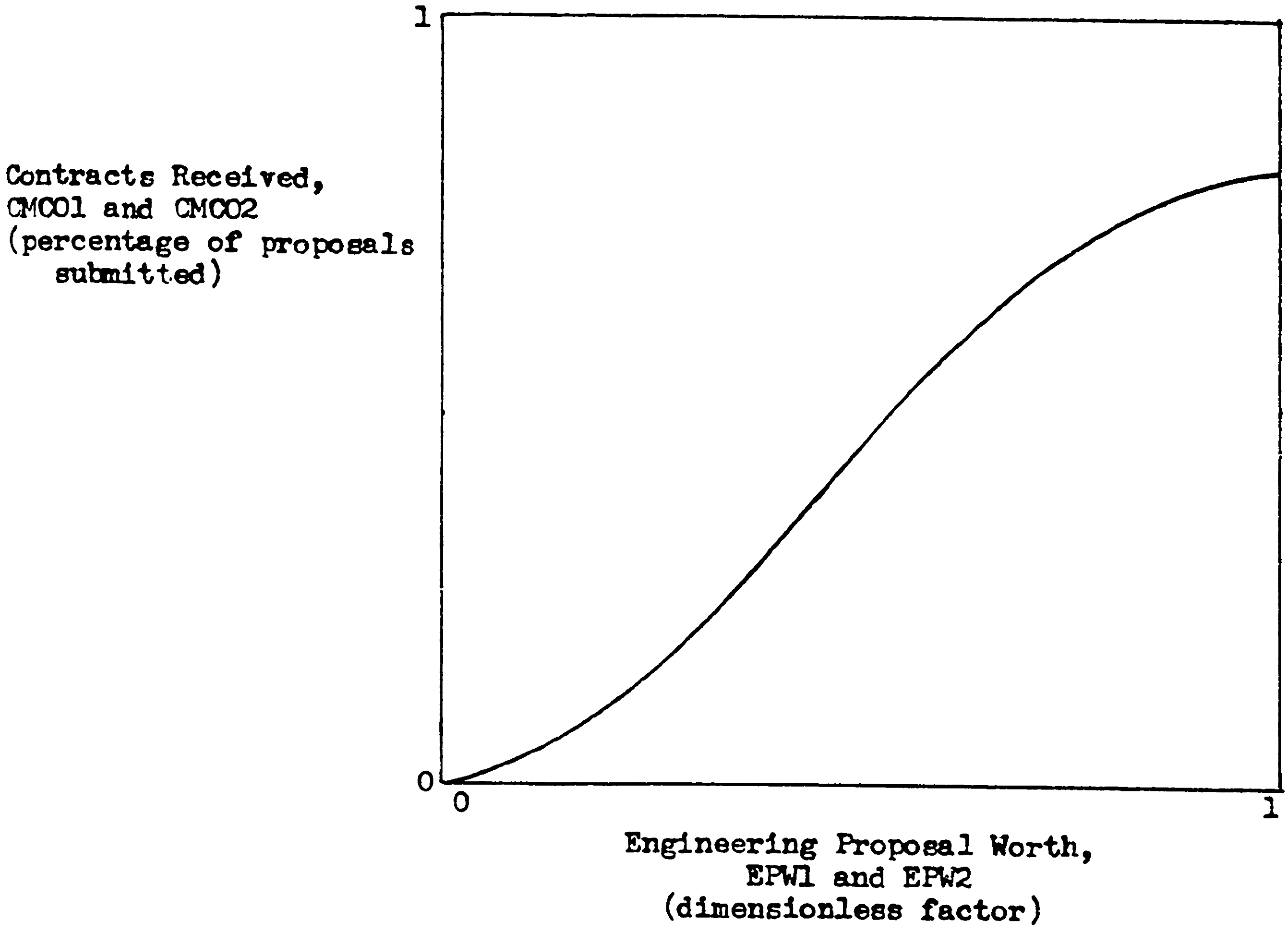


Figure 11, Contracts Received as a Function of Proposal Worth

Where there is an increase in the Customer's budget for military procurements, this change is reflected in two ways. First there is an increase in the flow of requests for proposal that are circulated to contractors, and secondly the Customer awards more contracts in response to unsolicited proposals. The latter are customarily negotiated contracts.

CO1.K = (RNC.K)(CMCO1.K)

RNC.K = MRFPA.K/RPN

RNC = Ratio by which the Customer increases or decreases Negotiated Contract awards (dimensionless)

CO1 = Contracts Obtained as a percentage of class 1 proposals submitted (%)

RPN = Level of incoming Requests for Proposal under Normal conditions (man months of proposal engineering effort)

EPW1.K = (AET1)(ETTC.K) + (AAUW)(TAUW.K) + (APP)(OCPC.K)

EPW2.K = (A2)(EPW1.K)

EPW1 = Engineering Proposal Worth of class 1 proposals (dimensionless)

EPW2 = Engineering Proposal Worth of class 2 proposals (dimensionless)

AET1 = An Averaged weighting factor of Engineering Technical competence applied to proposal worth of class 1 proposals (dimensionless)

ETTC = Engineering Total Technical Competence (dimensionless)

AAUW = Averaged Ability to Undertake Work, a weighting factor (dimensionless)

TAUW = Total Ability to Undertake Work (dimensionless)

APP = An Averaged weighting factor for Price Provision (dimensionless)

OCPC = Operations Control Price Constant. This is an index of price attractiveness (dimensionless)

A2 = The Average ratio based on experience of the engineering proposal worth of class 2 proposals to class 1 proposals (dimensionless)

CCPE1.KL = DELAY 3 (EPC1.JK, DCEP)

CCPE2.KL = DELAY 3 (EPC2.JK, DCEP)

EPC1 = Engineering Proposals Completed of the class 1 type (man months/month of company initiated engineering effort)

EPC2 = Engineering Proposals Completed of the class 2 type (man months/month of proposal engineering effort)

DCEP = Average Delay in Customer Evaluation of Proposals (months)

The flow diagram for the Customer Sector is shown in Figure 12.

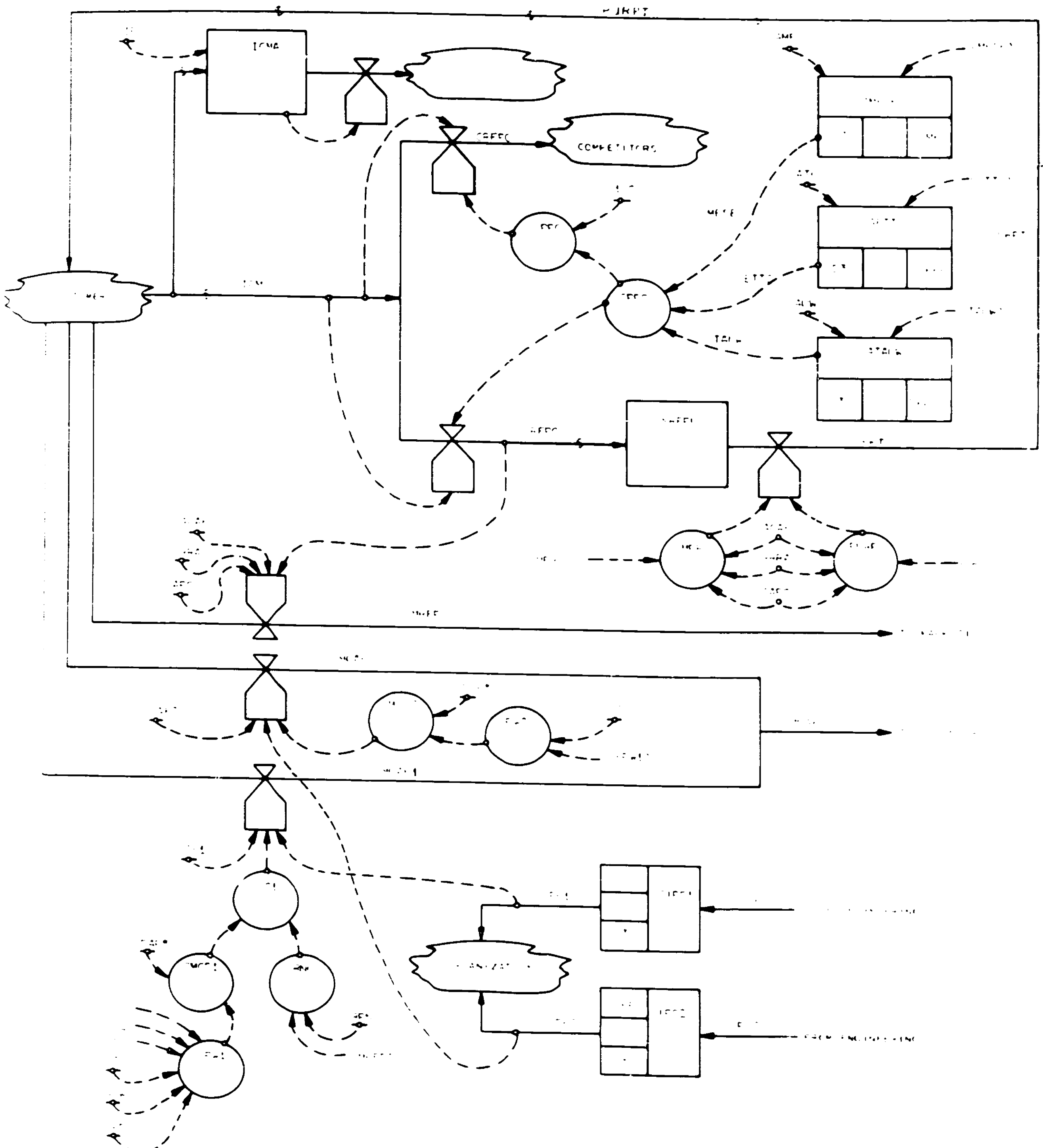


FIGURE 12 CUSTOMER SECTOR FLOW DIAGRAM

MARKETING SECTOR

The Marketing Sector is responsible for exposing the organization to as many opportunities for new business as possible. This involves extensive liaison with the customer in which knowledge of his requirements is sought as well as orientation of the customer with regard to the organization's capabilities. Marketing effort in soliciting new business is intensified as the backlog of engineering work decreases.

MESB.K = 1.0 - (AMS)(PEUMR.K)/(PNUM.K)

MESB = Marketing Effort in Soliciting Business (dimensionless)

AMS = A constant Marketing Solicitation weighting factor (dimensionless)

PEUMR = Personnel Engineering Unfilled Manpower Requests (man months) See page 87

PNUM = Personnel Normal Unfilled Manpower requests (man months) See page 87

Requests for proposal that are received by Marketing are forwarded to Engineering for action. In certain cases a percentage of these requests are cancelled in Marketing where the backlog builds up to the point that due dates for proposals cannot be met.

MIRP.K = MIRP.J + (DT)(MRFPE.JK - EPRE.JK - MPRC.JK)

MIRP = Marketing Inventory of Requests for Proposals (man months)

EPRE = Engineering Proposal Requests Entering (man months/month of proposal engineering effort)

MIRPD.K = DMPP(MRFPA.K)

MRFPA.K = MRFPA.J + (DT)(1/TCAP)(MRFPE.JK - MRFPA.J)

MIRPD = Marketing Inventory of Requests for Proposal, Desired (man months)

DMPP = Desired Marketing backlog, for Planning purposes, of Proposal work (%)

MRFPA = Marketing Requests For Proposal Averaged (man months)

TCAP = Time Constant for Averaging the incoming flow of requests for Proposal (months)

MPRC.KL = CLIP(MPE.K, 0, MIRP.K, MPC.K)

MPE.K = (1/DPCC)(MIRP.K - MPC.K)

MPC.K = (A5)(EPWP.K)

MPE = Marketing Proposals Excess (man months/month)

DPCC = Delay in Proposal Cancellation by the Customer (months)

MPC = Marketing Proposal Capability (man months)

A5 = Average ratio of a manageable backlog of proposal work to the engineering proposal work in process (dimensionless)

EPWP = Engineering Proposal Work in Process. Class 2 proposals result from this effort (man months)

The flow diagram for the Marketing Sector is shown in Figure 13.

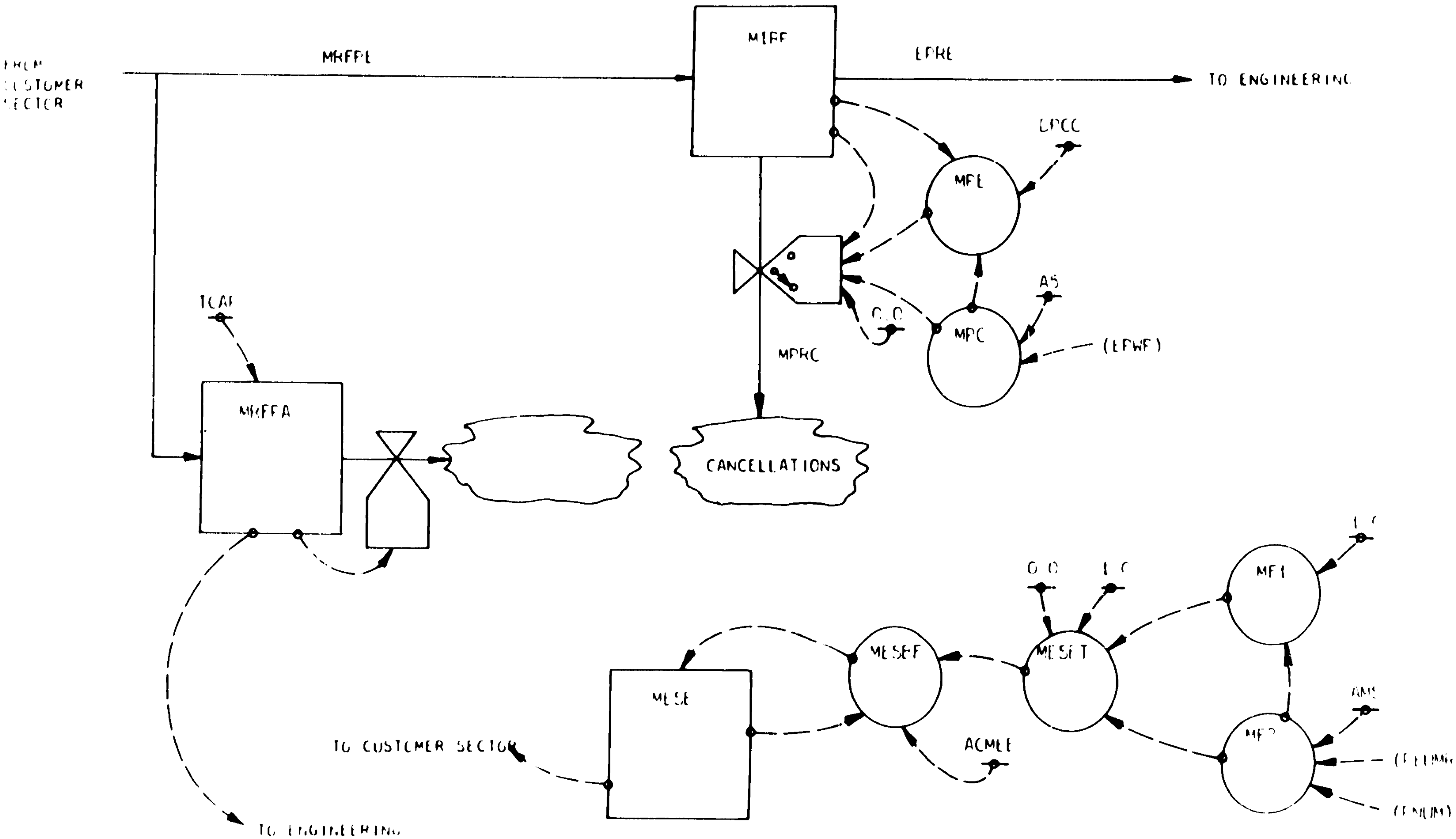


FIGURE 1: MARKETING SECTOR FLOW DIAGRAM

ENGINEERING SECTOR

The Engineering Sector of the organization performs work in four different areas: (a) design and development for production under contract to the government, (b) research and development contract work, (c) preparation of proposals in response to customer requests where little or no work is done by the organization prior to receipt of the request, and (d) company initiated work which consists primarily of research and engineering that is ultimately submitted to the customer in proposal form. Many of the latter proposals are unsolicited. These proposals reflect the engineering technical competence of the organization established by experience. Primarily they achieve negotiated contracts for the organization. The contracts received by the organization are either design and development for production (production engineering), or research and development.

MCAED.KL = (A3)(MCAE.JK)

MCAER.KL = (A4)(MCAE.JK)

A4 = 1.0 - A3

MCAED = Marketing Contract Awards Entering for Design and development for production work (man months/month)

MCAER = Marketing Contract Awards Entering for Research and development work (man months/month)

A3 = Average ratio of marketing contract awards entering for design and development for production contracts to the total marketing contract awards entering (dimensionless)

A4 = Average ratio of marketing contract awards entering for research and development contracts to the total contract awards entering (dimensionless)

The greatest resource of an engineering organization is its manpower. By this is inferred not only the quantity but the quality of the men, their technical competence. In such an organization it follows that the policies concerning utilization of manpower represent perhaps the most important area of management decision.

Management can apply the resource of engineering manpower in any proportion felt appropriate to the four areas of work being done. The decision affects productivity, customer satisfaction, growth and profitability of the organization. At any point in time each of the four areas of work in the organization will, in the opinion of management, have too little, too much, or the right amount of manpower to do the work required. As the differential varies from zero, i.e., from the point where the amount of manpower assigned equals the amount needed, management feels a pressure to return to the point where needs are fully met with no excess manpower. The pressure felt by management may come from the requests of the supervisors of an area, from contractual commitments, from their own appreciation of the importance or urgency of a particular kind of work, from communication with higher management. The reaction to a shortage of manpower will be different for each work area and will change relatively as the desired manpower grows larger than manpower available. Management's reaction to a manpower shortage, or excess, in each work area represents management policy for that area of work. The pressures felt by management operating under one set of policies are represented by Figure 14.

Positive pressure indicates a shortage of manpower; negative pressure is an indication that actual exceeds desired manpower. In either case management feels pressure to bring actual manpower to the level desired in each area of work. At any particular time the manpower difference between desired and actual in each area of work might be represented by:

contract work, per cent desired - actual manpower = 0b

proposal work, per cent desired - actual manpower = 0c

company initiated work, per cent desired - actual manpower = 0a

Likewise, pressure felt by management to do something to correct this difference is represented by:

contract work, pressure felt by management = 0b'

proposal work, pressure felt by management = 0c'

company initiated work, pressure felt by management = 0a'

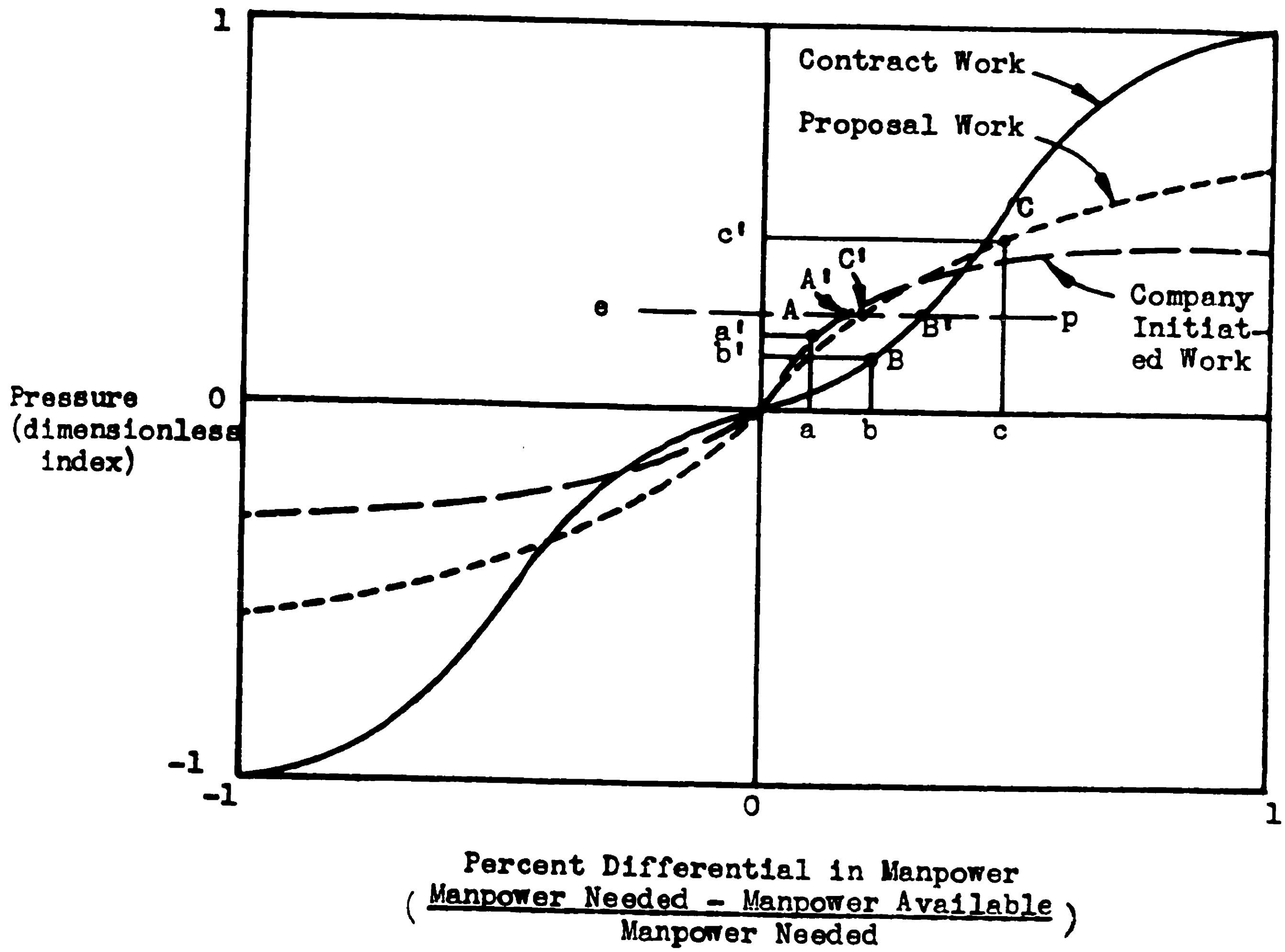


Figure 14, Management Policies (A) with Regard to Technical Manpower Utilization

Management then takes steps (a) to equalize pressures from the various work areas, and (b) to reduce the pressures. The equalization of pressures is achieved by transferring men from one area of work to another. Pressure is equalized along line ep. Points A, B, and C representing the initial condition shift to points A', B', and C' with their corresponding new per cent differences between desired and actual manpower.

With regard to reducing total pressure, management starts to hire personnel if personnel are needed (represented by a positive pressure), or to face terminations both voluntary and forced if actual manpower is greater than needed for more than a few weeks. This is handled in the Personnel section of the Engineering Sector. Management also may resort to overtime if the pressure due to manpower shortages gets high enough. Resistance, however, exists to increasing the work week length. Management will resist overtime because of the cost penalties involved. In most cases contracting officer approval is needed for overtime and this is not granted without real justification. Also as the work week gets quite long, resistance from employees is encountered. The cumulative resistance to increasing the length of the work week beyond forty hours is shown in Figure 15. It is assumed that the resistance reaches an infinite value between 80 and 90 hours a week, considered to be the limit

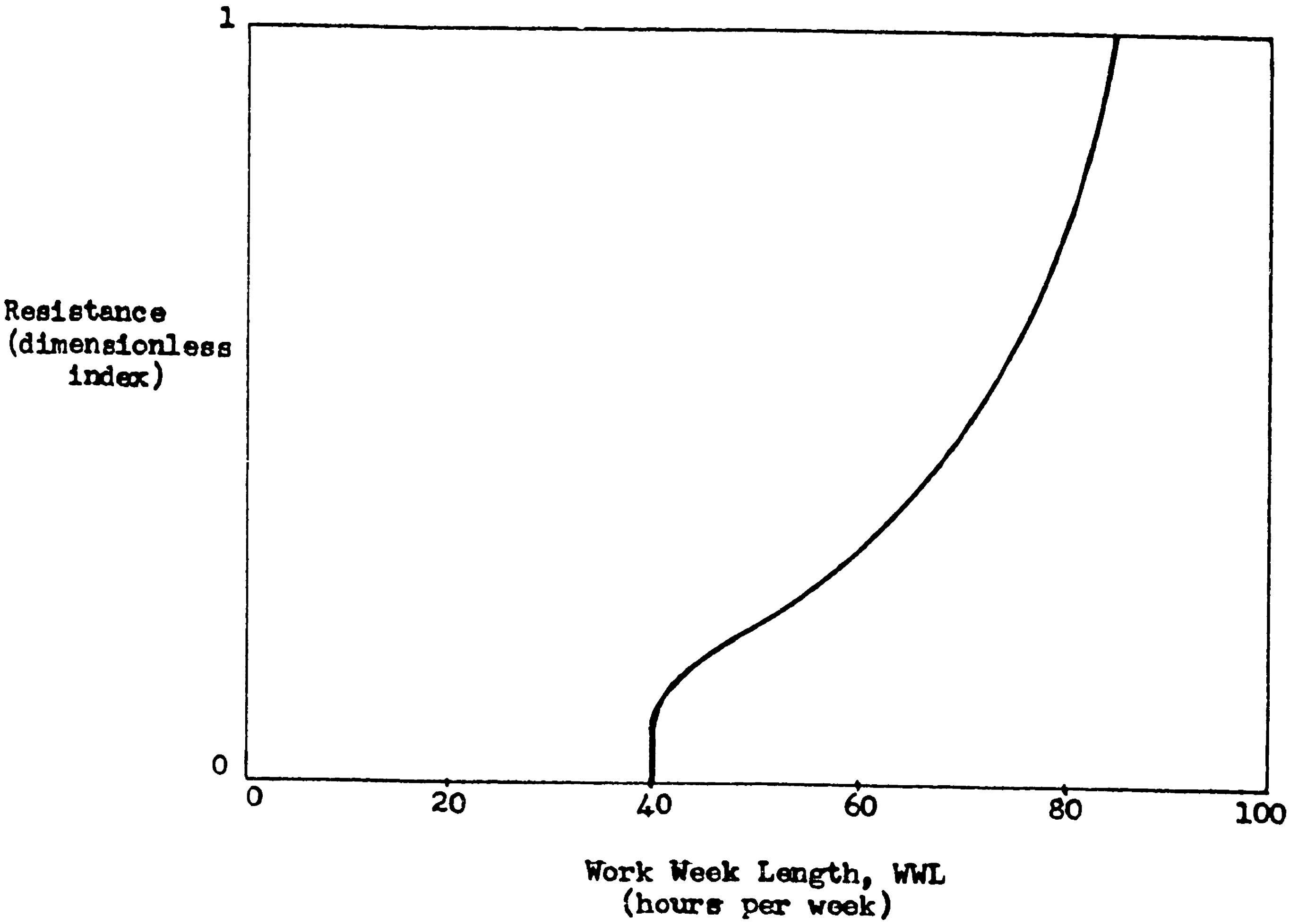


Figure 15, Resistance to Overtime

of endurance of an individual. Length of work week is determined by equating the total pressure felt by management to the cumulative resistance to increasing the length of the work week.

A work week less than forty hours will not be scheduled. Where insufficient work exists for the work force--and this appears to be a situation that will exist for some months--a reduction in force will be made rather than reduce the work week to less than forty hours for the organization.

Two results are significant as the work week is increased in length beyond forty hours. First, the costs of operation increase. This is reflected in the Financial Sector. The increased costs reduce the price attractiveness of proposals since the cost of doing business is increased by overtime. Secondly, the output of the organization is increased. However, the increase in output diminishes relatively as the work week gets longer. This relationship is depicted graphically in Figure 16.

The relationship in the above-mentioned figure is defined by the following equation:

$$MUL.K = 1 + 0.64\left[1 - e^{1.5(1-\frac{WWL}{40})}\right]$$

The output multiplier is applied to the work in process.

Contracts and requests for proposals received determine the requirements for manpower in these areas of work. However, no such definite requirement exists in the case of the

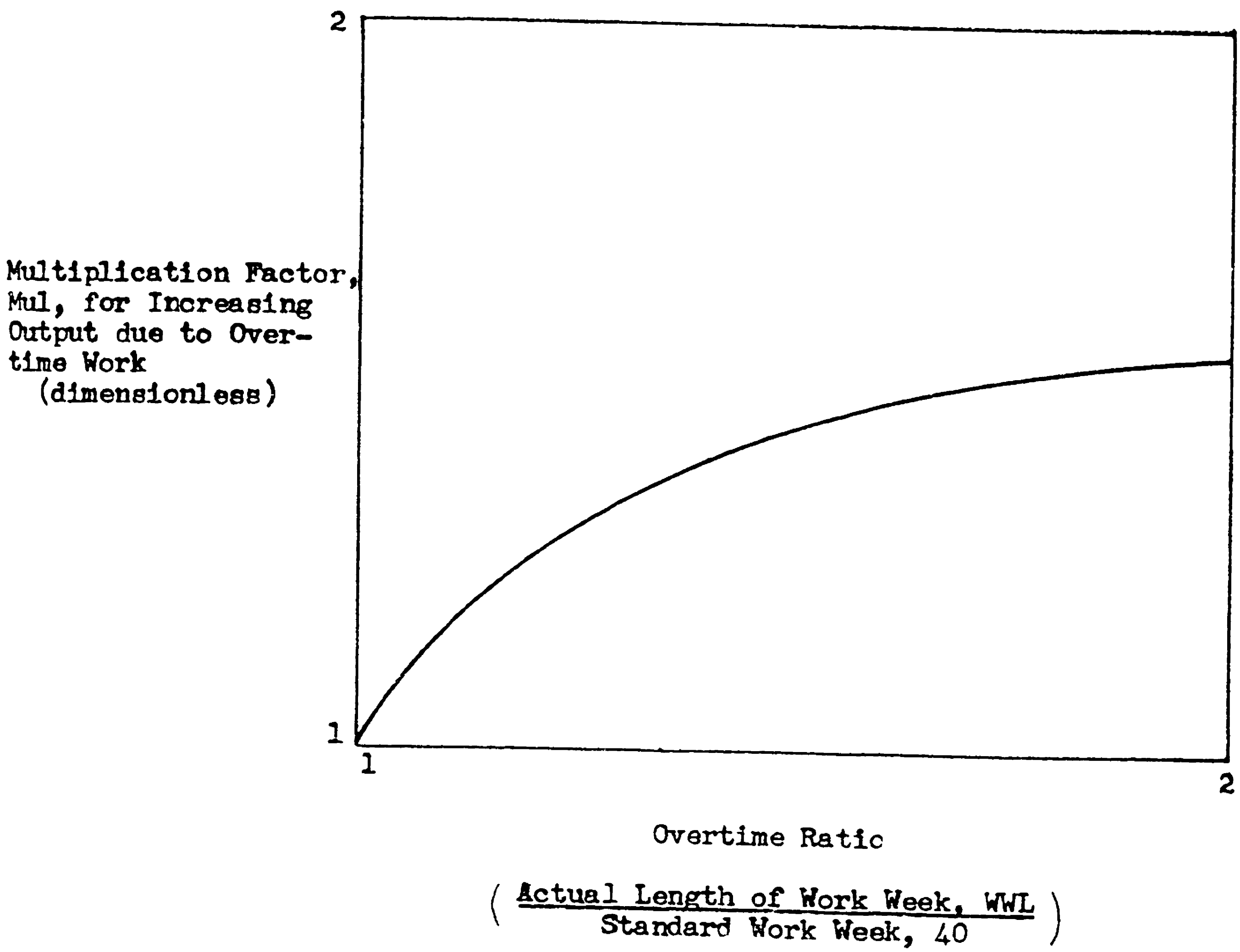


Figure 16, The Variation of Output with Overtime level of effort to be applied to company initiated work. Perhaps the most important determinant in the latter case is the prospect for future contracts. If the prospects are good, one might reasonably expect less effort on company initiated work than would be the case if prospects indicated a decline in business. In the latter case, company initiated work would be intensified in an effort to change upward the projected trend of business. If we take annual total contract work over the past five years and average it, giving heavier weight to the more recent years, then compare this average with the total contract work for the past twelve months, we can establish a trend, as shown in Figure 17. The slope of a trend line so established indicates whether business is increasing or decreasing and, extrapolated, indicates what might be expected in the next few years if no action is taken to change the trend.

The expectation of future business serves to stimulate, or depress to some degree, the nominal level of company initiated work. The desired level of manpower for company initiated work is thus a nominal level multiplied by the intensification factor which may be a fraction of one, or as high as four, depending on the feeling of need for this effort (see Figure 18).

The equations that follow describe how the management policies concerning utilization of technical manpower are

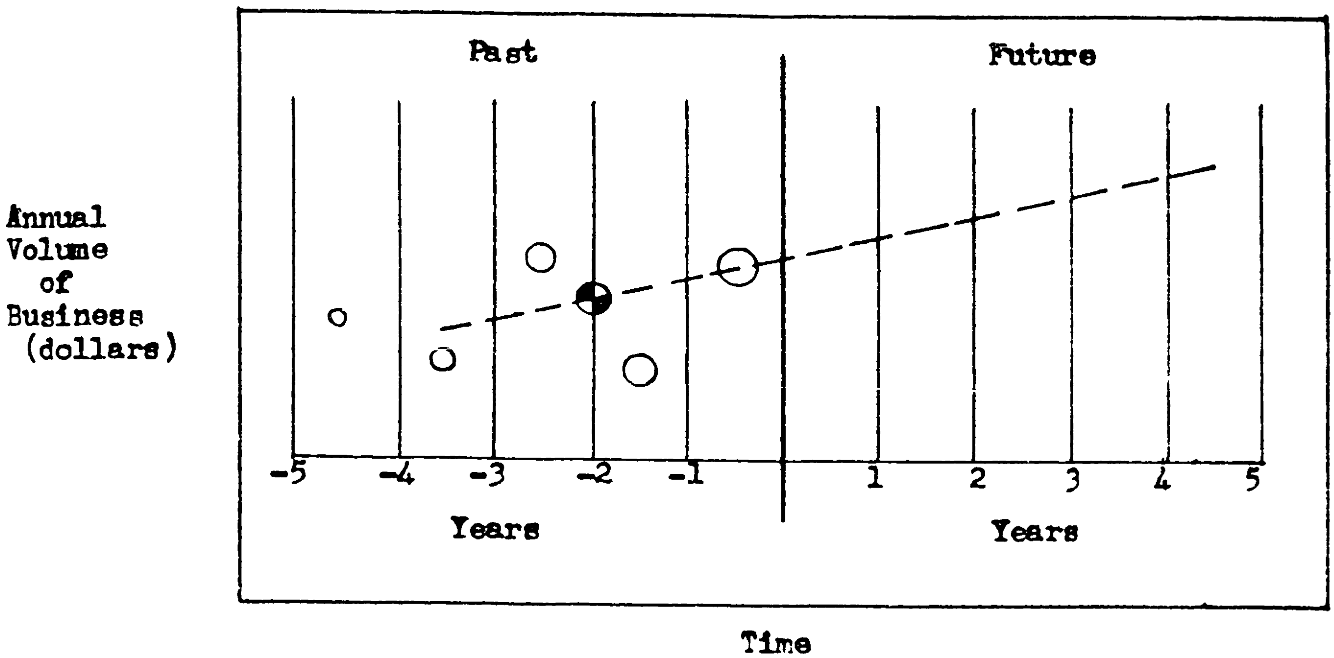


Figure 17, The Projection of Business Trends implemented.

EPRE.KL = CLIP(MNP.K, MAP.K, MAP.K, MNP.K)

ECAED.KL = CLIP(MND.K, MAD.K, MAD.K, MND.K)

ECAER.KL = CLIP(MNR.K, MAM.K, MAM.K, MNR.K)

ECIP.KL = CLIP(MNC.K, MAC.K, MAC.K, MNC.K)

EPRE = Engineering Proposal Requests Entering (man months/month of proposal engineering effort)

ECAED = Engineering Contract Authorizations Entering for Design and development for production work (man months/month)

ECAER = Engineering Contract Authorizations Entering for Research and development work (man months/month)

ECIP = Engineering Company Initiated Project work (man months/month of company initiated engineering effort)

MNP.K = MRFPA.K + (1/DPA)(MIRPD.K - MIRP.K)

MAP.K = MAP.J + (DT)(TIP.JK - TOP.JK)

MND.K = MCADA.K + (1/DD)(EICDD.K - EICD.K)

MAD.K = MAD.J + (DT)(TID.JK - TOD.JK)

MNR.K = MCARA.K + (1/DR)(EICRD.K - EICR.K)

MAM.K = MAM.J + (DT)(TIR.JK - TOR.JK)

MNC.K = (ICW.K)(CIWN.K)

MAC.K = MAC.J + (DT)(TIC.JK - TOC.JK)

MNP = Manpower Needed for Proposal work. This is for class 2 proposal preparation (men)

MAP = Manpower Available for Proposal work. This is for preparation of class 2 proposals (men)

MND = Manpower Needed for Design and development for production work (men)

MAD = Manpower Available for Design and development for production work (men)

MNR = Manpower Needed for Research and development work (men)

MAM = Manpower Available for Military research and development work (men)

MNC = Manpower Needed for Company initiated work (men)

MAC = Manpower Available for Company initiated work (men)

Equations for MNP:

MRFPA.K = MRFPH.J + DT(1/TCAP)(MRFPE.JK - MRFPA.J)

MIRPD.K = (DMPP)(MRFPA.K)

MIRP.K = MIRP.J + (DT)(MRFPE.JK - EPRE.JK - MPRC.JK)

DPA = Delay in reducing requests for Proposal inventory, Average (months)

MRFPA = Marketing Requests For Proposal Averaged (man months)

MIRPD = Marketing Inventory of Requests for Proposal Desired (man months)

MIRP = Marketing Inventory of Requests for Proposal (man months)

TCAP = Time Constant for Averaging the incoming flow of requests for Proposal (months)

DMPP = Desired Marketing backlog, for Planning purposes, of Proposal work (%)

Equations for MAP:

TIP.KL= (PROP.K)(TOT.JK)

PROP.K = PDTPP.K/SPDT.K

PDTPP.K = CLIP(DTPP.K, 0, DTPP.K, 0)

SPDT.K = PDTPP.K + PDTPD.K + PDTPR.K + PDTPC.K

TIP = Transfer of personnel In to Proposal work (men/month)

PROP = PROportional factor for determining per cent of total available manpower that will be transferred into Proposal work (%)

PDTPP = Positive Desired Transfer of Personnel into Proposal work (men/month)

SPDT = Sum of the Positive Desired Transfers of personnel (men/month)

TOP.KL = CLIP(0, - OUTP.K, DTPP.K, 0)

OUTP.K = DTPP.K/TDTP

PTO.KL = TOP.JK + TOD.JK + TOR.JK + TOC.JK + TNP.JK

PT01.KL = PTO.JK + PELE.JK

TOT.KL = PT01.JK - PELT.JK

TOP = Transfer Out of personnel on class 2 Proposal work (men/month)

OUTP = Transfer of personnel OUT of Proposal work (men/month)

TDTP = Time Delay in Transferring Personnel (months)

PTO = Personnel Transferred Out from all departments (men/month)

PT01 = Personnel Transferred Out from all departments plus new hires (men/month)

PELE = Personnel Engineering Labor Entering

PELT = Personnel Engineering Labor Terminating

TOT = Rate of transfer of TOTal personnel being transferred (men/month)

DTPP.K = DIFP.K - DDP.K

DIFP.K = MNP.K - MAP.K

PDP.K = DIFP.K/MNP.K

DTPP = Desired Transfer of Personnel to or from Proposal work (men). Positive values indicate transfer in desired. Negative values for this term indicate transfer out desired

DIFP = DIFferential in needed and available manpower on class 2 Proposal work (men)

DDP = Desired Differential in manpower needed and available on class 2 Proposal work (men)

PDP = Per cent Differential, manpower needed minus manpower available, in Proposal work (%)

PMDP.K = Function of PDP (see Figure 14)

AP.K = (1/4)(PMDP.K + PMDD.K + PMDR.K + PMDC.K)

DPDP.K = Function of AP (see Figure 14)

DDP.K = (DPDP.K)(MNP.K)

PMDP = Pressure due to Manpower Differential, needed minus available, in Proposal work (dimensionless)

AP = Average Pressure (dimensionless)

DPDP = Desired Per cent Differential in manpower needed and available in Proposal work (%)

PMDD = Pressure due to Manpower Differential, needed minus available, in Design and development for production work (dimensionless)

PMDR = Pressure due to Manpower Differential, needed minus available, in Research and development work (dimensionless)

PMDC = Pressure due to Manpower Differential, needed minus available, in Company initiated work (dimensionless)

Equations for MND:

MCADA.K = MCADA.J + (DT)(1/TCAD)(MCAED.JK - MCADA.J)

EICDD.K = (DMPC)(MCADA.K)

EICD.K = EICD.J + (DT)(MCAED.JK - ECAED.JK)

DD = Delay in equalizing desired and actual inventory of engineering authorizations for Design and development for production work (months)

MCADA = Marketing Contract Awards entering for Design and development for production work, Averaged (man months)

EICDD = Engineering Inventory of Contract authorizations for Design and development for production work, Desired (man months)

EICD = Engineering Inventory of Contract authorizations for Design and development for production work (man months)

TCAD = Time Constant for Averaging the flow of contracts awards entering for Design and development for production work (months)

DMPC = Desired Marketing backlog, for Planning purposes, of Company initiated work (%)

Equations for MAD:

TID.KL= (PROD.K)(TOT.JK)

PROD.K = PDTPD.K/SPDT.K

PDTPD.K = CLIP(DTPD.K, 0, DTPD.K, 0)

TID = Transfer of personnel In to Design and development for production work (men/month)

PROD = PROportional factor for determining per cent of total available manpower that will be transferred into Design and development for production work (%)

PDTPD = Positive Desired Transfer of Personnel into Design and development for production work (men/month)

TOD.KL = CLIP(0, - OUTD.K, DTPD.K, 0)

OUTD.K = DTPD.K/TDTP

TOD = Transfer Out of personnel on Design and development for production work (men/month

OUTD = Transfer of personnel OUT of Design and development for production work (men/month)

DTPD.K = DIFD.K - DDD.K

DIFD.K = MND.K - MAD.K

PDD.K = DIFD.K/MND.K

DTPD = Desired Transfer of Personnel to or from Design and development for production work (men)

DIFD = DIFferential in needed and available manpower on Design and development for production work (men)

DDD = Desired Differential in manpower needed and available on Design and development for production work (men)

PDD = Per cent Differential, manpower needed minus manpower available, in Design and development for production work (%)

PMDD.K = Function of PDD (see Figure 14)

AP.K = (1/4)(PMDP.K + PMDD.K + PMDR.K + PMDC.K)

DPDD.K = Function of AP (see Figure 14)

DDD.K = (DPDD.K)(MND.K)

PMDD = Pressure due to Manpower Differential, needed minus available, in Design and development for production work (dimensionless)

DPDD = Desired Per cent Differential in manpower needed and available in Design and development for production work (%)

Equations for MNR:

MCARA.K = MCARA.J + (DT)(1/TCAR)(MCAER.JK - MCARA.J)

EICRD.K = (DMPG)(MCARA.K)

EICR.K = EICR.J + (DT)(MCAER.JK - ECAER.JK)

DR = Delay in equalizing desired and actual inventory of engineering authorizations for Research and development work (months)

MCARA = Marketing Contract Awards entering for Research and development work, Averaged (man months)

EICRD = Engineering Inventory of Contract authorizations for Research and development work, Desired (man months)

EICR = Engineering Inventory of Contract authorizations for Research and development work (man months)

TCAR = Time Constant for Averaging the flow of contract awards entering for Research and development work (months)

DMPG = Desired Marketing backlog, for Planning purposes, of Government research and development contracts (%)

Equations for MAM:

TIR.KL = (PROR.K)(TOT.JK)

PROR.K = PDTPR.K/SPDT.K

PDTPR.K = CLIP (DTPR.K, 0, DTPR.K, 0)

TIR = Transfer of personnel In to Research and development work (men/month)

PROR = PROportional factor for determining per cent of total available manpower that will be transferred into Research and development work (%)

PDTPR = Positive Desired Transfer of Personnel into Research and development work (men/month)

TOR.KL = CLIP (0, - OUTR.K, DTPR.K, 0)

OUTR.K = DTPR.K/TDTP

TOR = Transfer Out of personnel from Research and development work (men/month)

OUTR = Transfer of personnel OUT of Research and development work (men/month)

DTPR.K = DIFR.K - DDR.K

DIFR.K = MNR.K - MAM.K

PDR.K = DIFR.K/MNR.K

DTPR = Desired Transfer of Personnel to or from Research and development work (men)

DIFR = DIFferential in needed and available manpower for Research and development work (men)

DDR = Desired Differential in manpower needed and available on Research and development work (men)

PDR = Per cent Differential, manpower needed minus manpower available, in Research and development work (%)

PMDR.K = Function of PDR (see Figure 14)

AP.K = (1/4)(PMDP.K + PMDD.K + PMDR.K + PMDC.K)

DPDR.K = Function of AP (see Figure 14)

DDR.K = (DPDR.K)(MNR.K)

PMDR = Pressure due to Manpower Differential, needed minus available, in Research and development work (dimensionless)

DPDR = Desired Per cent Differential in manpower needed and available in Research and development work (%)

Equations for MNC:

ICW.K = TABLE (TIFC, ECHAN.K, -1.0, 1.0, 0.1) (see Figure 18)

CIWN.K = (APEC)(PETA.K)

ICW = Intensification factor for Company initiated Work (dimensionless multiplier)

ECHAN = Effective yearly percentage CHANge in the level of business (per cent)

CIWN = Company Initiated Work Normal level of activity (men)

APEC = Average Percentage of Engineering work force assigned to Company initiated work (per cent)

PETA = Work force Personnel, Engineers Total Available (men)

ECHAN.K = CLIP(1, CHAN.K, CHAN.K, 1) (see Figure 17)

CHAN.K = CLIP (CHANG, -1, CHANG, -1)

CHANG.K = (12)(PERCH.K)/TPDIF

TPDIF = (1/2)(DTP - RTP)

PERCH.K = (1/WAV5.K)(WAV1.K - WAV5.K)

WAV5.K = WAV5.J + (DT)(1/DTP)(MCAE.JK - WAV5.J)

WAV1.K = WAV1.J + (DT)(1/RTP)(MCAE.JK - WAV1.J)

ECHAN = Effective yearly percentage CHANge in the level of business (%)

CHAN = Yearly percentage CHANge in the level of business

CHANG = Yearly per cent CHANGe in the level of business (%)

PERCH = PERiod CHange, referring to business activity (%)

WAV5 = Weighted AVerage of 5 years previous contract work (%)

WAV1 = Weighted AVerage of 1 year's contract work, i.e., the year just past (%)

DTP = Distant Time Period (months)

RTP = Recent Time Period (months)

TPDIF = Time Period DIFference (months)

Equations for MAC:

TIC.KL= (PROC.K)(TOT.JK)

PROC.K = PDTPC.K/SPDT.K

PDTPC.K = CLIP(DTPC.K, 0, DTPC.K, 0)

TIC = Transfer of personnel In to Company initiated work (men/month)

PROC = PROportional factor for determining per cent of total available manpower that will be transferred into Company initiated work (%)

PDTPC = Positive Desired Transfer of Personnel into Company initiated work (men/month)

TOC.KL = CLIP(0, - OUTC.K, DTPC.K, 0)

OUTC.K = DTPC.K/TDTP

TOC = Transfer Out of personnel from Company initiated work (men/month)

OUTC = Transfer of personnel OUT of Company initiated work (men/month)

DTPC.K = DIFC.K - DDC.K

DIFC.K = MNC.K - MAC.K

DPC.K = DIFC.K/MNC.K

DTPC = Desired Transfer of Personnel to or from Company initiated work (men)

DIFC = DIFferential in needed and available manpower for Company initiated work (men)

DDC = Desired Differential in manpower needed and available on Company initiated work (men)

PDC = Per cent Differential, manpower needed minus manpower available, in Company initiated work (%)

PMDC.K = Function of PDC (see Figure 14)

AP.K = (1/4)(PMDP.K + PMDD.K + PMDR.K + PMDC.K)

DPDC.K = Function of AP (see Figure 14)

DDC.K = (DPDC.K)(MNC.K)

PMDC = Pressure due to Manpower Differential, needed minus available, in Company initiated work (dimensionless)

DPDC = Desired Per cent Differential in manpower needed and available in Company initiated work (%)

The average time required to complete a unit of work varies with the type of work given equal ability on the part of the engineers doing the work. In the model the delays DCP, DCD, DCR, and DCC indicate average times to complete a unit of work in each of the four areas.

EPWP.K = EPWP.J + (DT)(EPRE.JK - EPC2.JK)

EDWP.K = EDWP.J + (DT)(ECAED.JK - EDWC.JK)

ERWP.K = ERWP.J + (DT)(ECAER.JK - ERWC.JK)

ECWP.K = ECWP.J + (DT)(ECIP.JK - EPC1.JK)

EPWP = Engineering Proposal Work in Process (man months)

EDWP = Engineering Design and development for production Work in Process (man months)

ERWP = Engineering Research and development Work in Process (man months)

ECWP = Engineering Company initiated Work in Process (man months)

EPC2.KL = (MUL.K)(EP2.JK)

EDWC.KL = (MUL.K)(EDW.JK)

ERWC.KL = (MUL.K)(ERW.JK)

EPC1.KL = DELAY 3 (ECIP.JK, DCC)

EPC2 = Engineering Proposals Completed of the class 2 type (man months/month of company initiated engineering effort)

EDWC = Engineering Design and development for production Work Completed (man months/month)

ERWC = Engineering Research and development Work Completed (man months/month)

EPC1 = Engineering Proposals Completed of the class 1 type (man months/month of proposal engineering effort)

DCC = Average Delay in Completion of Company initiated work (months)

EP2.KL = DELAY 3 (EPRE.JK, DCP)

EDW.KL = DELAY 3 (ECAED.JK, DCD)

ERW.KL = DELAY 3 (ECAER.JK, DCR)

EP2 = Engineering Proposals completed of the class 2 type without overtime (man months/month of proposal engineering effort)

EDW = Engineering Design and development for production Work completed without overtime (man months/month)

ERW = Engineering Research and development Work completed without overtime (man months/month)

DCP = Average Delay in Completion of class 2 Proposals (months)

DCD = Average Delay in Completing Design and development for production work (months)

DCR = Average Delay in Completing Research and development work (months)

$$MUL.K = 1 + 0.64\left[1 - e^{1.5\left(1 - \frac{WWL}{40}\right)}\right]$$

(see Figure 16)

MUL = MULtiplier for increasing output due to overtime work (dimensionless)

WWL = Work Week Length (hours/week)

Technical competence of the organization is built up by experience. However, the kind of experience is important. Work experience in some areas affects technical competence very little while other kinds of work contribute greatly to competence. It is assumed here that answering proposals in response to requests that arrive without prior knowledge of the competition results in no addition to technical competence in the long run. It is further assumed that work on current design and development for production has its greatest value in the year following its completion with a diminishing contribution to technical competence of the organization as additional time passes. Work on research and development contracts is estimated to contribute most heavily to technical competence some three years after the work is performed. Company initiated work adds to technical competence most significantly some five years after the work is performed. These relationships are shown in Figure 19.

Engineering experience of the three types mentioned in the above figure is stored each year in a table. ETC1, ETC2, and ETC3 represent these tables (box cars) in the model. As the current year's experience is stored, the value for the engineering work performed nine years ago drops out so that the table always contains the last eight years' experience.

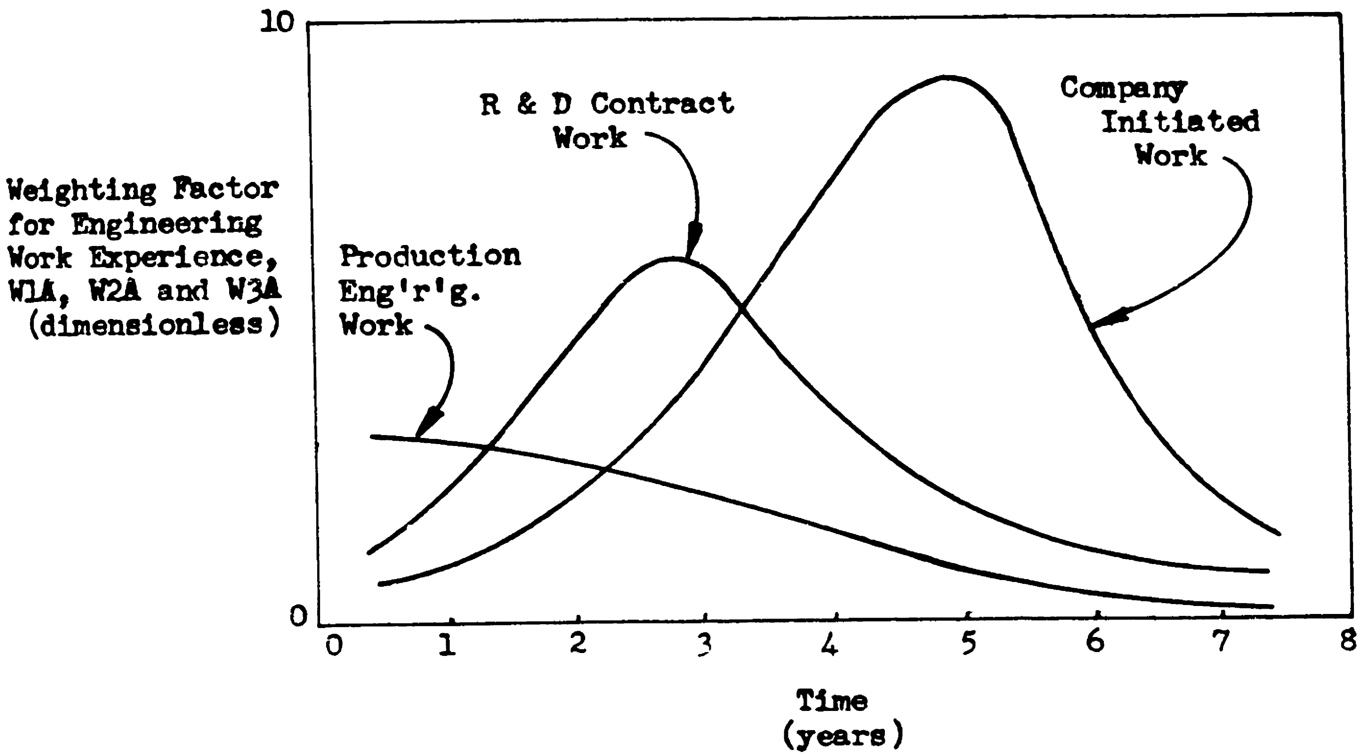


Figure 19, The Variation in Value of Engineering Experience with the Passage of Time

The work performed each year, in each table, is then multiplied by the appropriate weighting factor, reference Figure 19 . This gives a weighted engineering experience when summed. Next this sum of experience or work accomplished is compared to the maximum work the organization might conceivably have obtained. This then becomes an index of engineering technical competence. In fact, this is a relative rather than an absolute index. Relative technical competence, however, is the important factor in determining proposal attractiveness to the customer. It is thus assumed that the technical competence of the organization has increased relative to the technical competence of competition as the share of the market gained by the organization has grown. Likewise an absolute gain in technical competence may have been experienced by the organization with no change in relative position if the competition had the same gain in technical competence. The equations follow for determining the relative index of engineering technical competence, ETTC.

ECWCA.K = ECWCA.J + (DT)(1/TCWC)(EDWC.JK - ECWCA.J)

EGRCA.K = EGRCA.J + (DT)(1/TGRC)(ERWC.JK - EGRCA.J)

ESRCA.K = ESRCA.J + (DT)(1/TSRC)(EPC1.JK - ESRCA.J)

ECWCA = Engineering design and development for production Contract Work Completed, Averaged (man months)

EGRCA = Engineering Government Research and development Contract work completed, Averaged (man months)

ESRCA = Engineering Special Research, Company initiated work completed, Averaged (man months)

TCWC = Time Constant for design and development for production Work Completed (months)

TGRC = Time constant for Government Research and development work Completed (months)

TSRC = Time constant for Special Research company initiated work Completed (months)

ETC1 = BOXLIN (8, 12)

ETC2 = BOXLIN (8, 12)

ETC3 = BOXLIN (8, 12)

ETC1 = Engineering Technical Competence from previous work on design and development for production contracts (man months)

ETC2 = Engineering Technical Competence from previous work on research and development contracts (man months)

ETC3 = Engineering Technical Competence from previous company initiated work (man months)

ETC1*1.K = ECWCA.K

ETC2*1.K = EGRCA.K

ETC3*1.K = ESRCA.K

ETC1*1 = Most recent year's experience in design and development for production work which is stored in box car ETC1 (man months)

ETC2*1 = Most recent year's experience in research and development work which is stored in box car ETC2 (man months)

ETC3*1 = Most recent year's experience in company initiated work which is stored in box car ETC3 (man months)

ETC1S.K = SUM 2(8,W1A,ETC1)

ETC2S.K = SUM 2(8,W2A, ETC2)

ETC3S.K = SUM 2(8, W3A, ETC3)

ETC1S = Engineering Technical Competence gained from design and development for production work summed over the past eight years (man months)

ETC2S = Engineering Technical Competence gained from research and development work Summed over the past eight years (man months)

ETC3S = Engineering Technical Competence gained from company initiated work Summed over the past eight years (man months)

ETC1W.K = ETC1S.K/WFD

ETC2W.K = ETC2S.K/WFD

ETC3W.K = ETC3S.K/WFD

ETC1W = Engineering Technical Competence gained from design and development for production work over the past eight years, Weighted (man months)

ETC2W = Engineering Technical Competence gained from research and development work over the past eight years, Weighted (man months)

ETC3W = Engineering Technical Competence gained from company initiated work over the past eight years, Weighted (man months)

WFD = Weighting Factor common Denominator for engineering technical competence (dimensionless)

ETCT.K = ETC1W.K + ETC2W.K + ETC3W.K

ETCR.K = ETCT.K/RELF.K

RELF.K = (AAPO)(CPPOT)(CICMA.K)/(NF)

CICMA.K = CICMA.J + (DT)(1/CIP)(CICM.JK - CICMA.J)

ETCT = Weighted Engineering Technical Competence, Total (man months)

ETCR = Engineering Technical Competence Relative (dimensionless)

RELF = RELativizing Factor for engineering technical competence (man months)

CICMA = Customer Income Capital for Military procurements, Averaged ($)

NF = Normalizing Factor (%/month)

CIP = Customer Income for military procurement averaging Period (months)

ETTC.K = ETTC.J + (DT)(ETCI.J + 0)

ETCI.K = (INC)(ETCR.K - ETTC.K)

ETTC = Engineering Total Technical Competence (dimensionless)

ETCI = Engineering Technical Competence Increment (dimensionless)

INC = INcrement of change in engineering technical competence to be applied each computation (dimensionless)

The relationship of engineering to the factory is an important one. Engineering prepares the specifications for material produced by the Factory and provides production engineering services during the course of production. The design and development for production output of Engineering becomes the input to the Factory.

PSE.KL = (ACSS)(EDW.JK)

PSE = Production Specifications from Engineering (equipments/month)

ACSS = Constant based on Averaged experience Converting Specifications to equipment Shipments (equipments/man month)

One of the factors considered by the customer in evaluating proposals is the ability of an organization to undertake additional work. The ability of Engineering to undertake additional work is in large measure dependent on the backlog of unfinished work. This relationship is depicted in Figure 20.

EAUW.K = Function of ETEI (see Figure 20)

ETEI.K = MTBL.K/(PETA.K)(ADPMS)

MTBL.K = MIRPD.K + EICDD.K + EICRD.K + MNCD.K

EAUW = Engineering Ability to Undertake Work (dimensionless)

ETEI = Engineering Times to Exhaust Inventory (man month/man month)

MTBL = Manpower needed for the Total BackLog of work (man months)

ADPMS = Average Delay in reaching Planned Manpower Size (months)

MNCD = Manpower Needed for Company initiated work, based on Desired backlog (man months)

Adjustments to the size of the work force to meet the requirements of the organization are made through the Personnel Department. When additional men are needed the job of recruiting is handled by Personnel, with a time delay before new employees actually join the organization. When the work load drops below normal, personnel will begin to leave. The men available for reassignment are the men who are not really needed for any of the current programs. However, as the work load drops below normal, the men that leave are generally

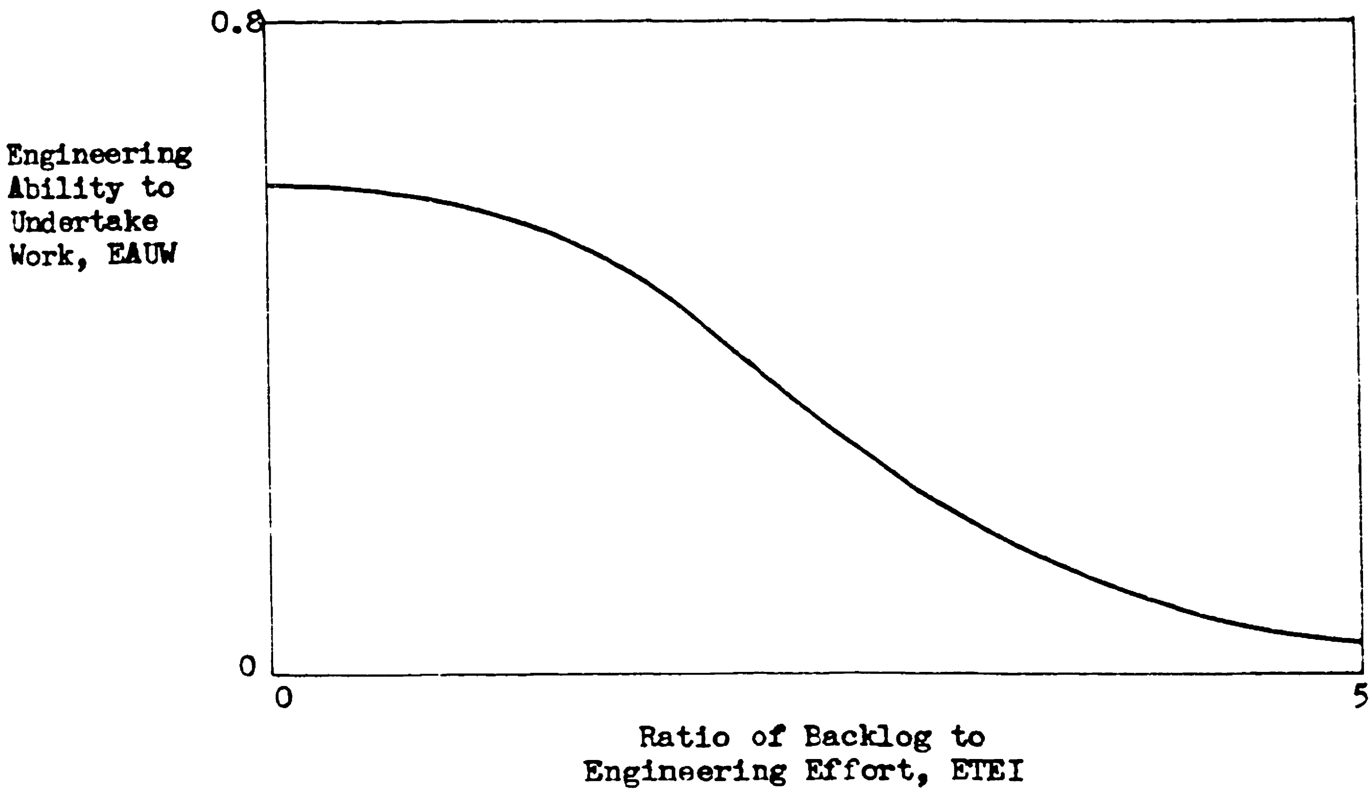


Figure 20, Engineering Ability to Undertake Work as a Function of Backlog Ratio the better men with shorter periods of service rather than those men that would normally be made available first. Provision is made in the model for attrition of the work force based on work load, i.e., whether there are men without real work to do. Such action would, of course, occur over a period of time. No distinction in the model is made between voluntary and forced terminations but this is not felt to be significant to the overall behavior being studied.

The equations for the Engineering Personnel Department follow:

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

PELE.KL = DELAY 3(PEHP.JK, DFRP)

PELT.KL = CLIP(PELT1.K, 0, MAR.K, AETH)

PEHP.KL = DELAY 3(PERP.JK, DELH)

PETA = Personnel Engineering Total Available (men)

PELE = Personnel Engineering Labor Entering (men/month)

PELT = Personnel Engineering Labor Terminating (men/month)

PEHP = Personnel Engineering Hiring Policy (men/month)

DFRP = Delay in Finding Replacement Personnel (months)

PELT1 = Personnel Engineering Labor Terminating due to having a larger work force than work load (men/month)

AETH = A constant, level of Engineering Total manpower Held excess, above which terminations begin to occur (men)

DELH = DELay in Hiring engineering personnel (months)

MAR.K = CLIP(MARN.K, 0, MARN.K, 0)

MARN.K = PETA.K - EPRE.JK - ECAED.JK - ECAER.JK - ECIP.JK

MAR = Manpower Available for Reassignment (men)

MARN = Manpower Available for Reassignment Net (men)

PELP.K = PELP.J + (DT)(PERP.JK - PELE.JK)

PERP.KL = CLIP(PECP.K, 0, PECP.K, PECP2.K)

PELP = Personnel Engineering Labor requisitions in Process (men)

PECP.K = (1/DT)(PECP1.K - MAR.K)

PECP2.K = (0.01)(PETA.K)/DT

PECP1.K = PEMD.K - PETAT.K

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

PETAT.K = PETA.K + PELP.K

PECP = Personnel Engineering Change Policy (men/month)

PECP2 = Personnel Engineering Change Policy allowance for personnel in process of transfer (men/month)

PEMD = Personnel Engineering Manpower Desired (men)

PETAT = Personnel Engineering Total Aavailable including those in process of entering (men)

PEPWD = Personnel Engineering for Proposal Work Desired (men)

PECWD = Personnel Engineering for production engineering Contract Work Desired (men)

PESWD = Personnel Engineering for Special (company initiated) project Work Desired (men)

PEGWD = Personnel Engineering for Government research and development Work Desired (men)

PEMRT.KL = MRFPE.JK + MCAED.JK + MCAER.JK + MNC.K

PEMRT = Personnel Engineering Manpower Requests Total (man months/month)

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

PEMRA = Personnel Engineering Manpower Requests Averaged (man months)

DAMP = Delay for Averaging ManPower requests (months)

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

ETWC.K = EPC1.JK + EPC.JK + EDWC.JK + ERWC.JK

PEUMR = Personnel Engineering Unfilled Manpower Requests (man months)

ETWC = Engineering Total Work Completed (man months/month)

PNUM.K = PNUMP.K + NBUW.K

PNUMP.K = (DCP)(MRFPA.K) + (DCD)(MCADA.K) + (DCR)(MCARA.K) + (DCC)(MNCA.K)

NBUW.K = (PLANP)(MRFPA.K) + (PLAND)(MCADA.K) + (PLANR)(MCARA.K) + (PLANC)(MNCA.K)

PNUM = Planned Normal inventory of Unassigned work expressed as Manpower requirements, total, that is including requirements in the pipeline (man months)

PNUMP = Planned Normal Unassigned inventory of work expressed as ManPower requirements (man months)

NBUW = Normal Backlog of Unassigned Work in the planning stage, that is in the pipeline (man months)

DCP = Delay in Completing Proposal work (months)

DCD = Delay in Completing Design and development for production work (months)

DCR = Delay in Completing Research and development work (months)

DCC = Delay in Completing Company initiated work (months)

PLANP = PLANning delay in Proposal work (months)

PLAND = PLANning delay in Design and development for production work (months)

PLANR = PLANning delay in Research and development work (months)

PLANC = PLANning delay in Company initiated work (months)

The flow diagram for the Engineering Sector is shown in Figure 21.

FACTORY SECTOR

Engineering information in the form of drawings and specifications becomes an input to the factory where this information is utilized for manufacturing. Also the factory bids on production contracts and receives awards as an independent group. Flows into the factory include not only specifications for equipment as a result of contract awards but also raw materials, assemblies, parts, etc. The factory labor force is in fact more of an assembly group than a manufacturing group in the usual sense of the word.

Factory management sets production rates based on factory orders waiting to be filled. Available manpower and facilities may also affect the production rate. Where an insufficient labor force exists, output is reduced and inventories of materials build up until adequate personnel can be employed. Materiel is produced with a time delay for the process of manufacturing. Income is then received from the materiel delivered to the customer while expenses are accrued due to expenditures for labor, material, and burden.

ECWS.KL = PSE.JK + PCS.JK

PSE.KL = (ACSS)(EDW.JK)

PCS.KL = (CAS)(PCA.JK)

ECWS = Engineering Contract Work Specifications (equipments/month)

PSE = Production Specifications from Engineering (equipments/month)

PCS = Production Contract Specifications received independently of Engineering (equipments/month)

PCA = Production Contract Awards independent of Engineering, averaged rate ($/month)

CAS = Conversion factor, production contract Awards to Specifications for equipment (equipments/$)

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

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

FSEP = Factory Specifications from Engineering in Process (equipments)

FSRP = Factory Specifications Ready for Production (equipments/month)

DSPF = Delay due to Specifications Processing at the Factory (months)

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

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

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

FUEO = Factory Unfilled Equipment Orders (equipments)

FECE = Factory Equipments Completed and Exited (equipments/month)

DFPM = Delay due to Factory Process of Manufacturing (month)

FECEA = Factory Equipments Completed and Exited Average (equipments)

TFEA = Time constant for Factory Equipment Average (months)

FUPS.K = FUPS.J + (DT)(FSRP.JK - FPRD.JK)

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

FPRD.KL = CLIP (FPRDD.K, FPRM.K, FPRM.K, FPRDD.K)

FPRDD.K = CLIP (FSRP.JK, FPRB.K, FUPSD.K, FUPS.K)

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

FPRB.K = FSRP.JK + (1/DFBA)(FUPS.K - FUPSD.K)

FUPS = Factory Unordered Production Specifications (equipments)

FEPM = Factory Equipment in Process of Manufacturing (equipments)

FPRD = Factory Production Rate Decision (equipments/month)

FPRM = Factory Production Rate Maximum (equipments/month)

PFMP = Personnel Factory ManPower (men)

APLF = Average Productivity Labor Factor (equipments/man)

FPRDD = Factory Production Rate Decision Desired (equipments/month)

FPRB = Factory Production Rate decision necessary to eliminate the Backlog of orders (equipments/month)

DFBA = Desired Factory Backlog Adjustment period (months)

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

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

FUPSD = Factory Unordered Production Specifications Desired (equipments)

DNPF = Delay for Normal Planning in the Factory

FSRPA = Factory Specifications Ready for Production Average (equipments/month)

TSPA = Time constant for Specifications for Production Average (months)

The Personnel Department is responsible for recruiting employees for the factory. The factory work force is adjusted to meet contract requirements, i.e., to the level needed to produce at the rate required to meet contract requirements. The hiring of personnel is accomplished only with certain time delays, however. Inventories of material increase while delivery rate to the customer is less than desired until adequate personnel can be applied to the job of manufacturing.

Terminations occur when the work load of the factory drops below the level needed to fully employ the manpower on the rolls.

The equations follow:

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

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

PFLT.KL = CLIP (0, -PFCP.K, PFCP1.K, -AFTH)

PFMP = Personnel Factory ManPower (men)

PFLE = Personnel Factory Labor Entering (men/month)

PFLT = Personnel Factory Labor Terminating (men/month)

DPFT = Delay due to Personnel Factory Training and recruiting (months)

PFHP.KL = CLIP (PFCP.K, 0, PFCP1.K, AFTH1)

PFCP.K = (1/TPFR)(PFLD.K - PFMPT.K)

PFCP1.K = PFLD.K - PFMPT.K

PFHP = Personnel Factory Hiring Policy (men/month)

PFCP = Personnel Factory Change Policy (men/month)

PFCP1 = Personnel Factory Change Policy due to the difference between personnel desired and personnel available (men)

AFTH = A constant, level of Factory Total manpower Held excess, above which terminations begin (men)

AFTH1 = A constant, level of Factory Total manpower, short of requirements which establishes the point at which Hiring of additional personnel begins (men)

TPFR = Time constant for Personnel Factory Recruiting (months)

PFLD = Personnel Factory Labor Desired (men)

PFMPT = Personnel Factory ManPower Total, that is including those employees in process of entering (men)

Assuming a constant rate of productivity, the desired work force is PFLD. The equation for PFLD states that the desired work force is equal to the average equipment production rate, plus an adjustment for backlog, both divided by the labor productivity factor.

PFLD.K = FSRPA.K/APLF + (1/DFBA)(FUPS.K - FUPSD.K)/APLF

FSRPA = Factory Specifications Ready for Production Averaged (equipments)

APLF = Average Productivity Labor Factor (equipments per month/man)

DFBA = Delay in Factory Backlog Aadjustment period (months)

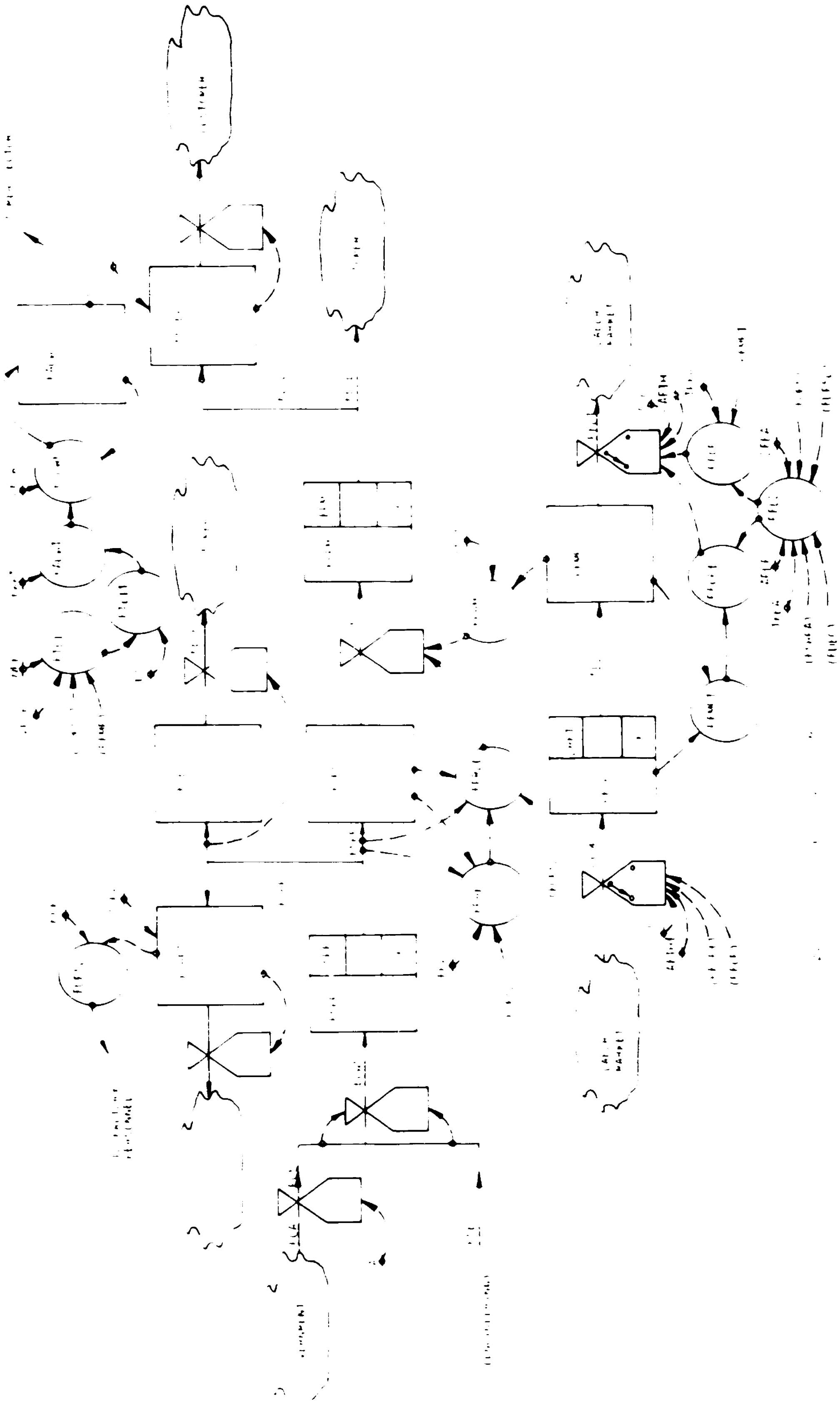
FUPSD = Factory Unfilled Production Specifications Desired (equipments)

The process of recruitment and induction of new personnel is described by the equations for PFLP and PFLE.

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

PFLP = Personnel Factory Labor in Process (men)

The flow diagram for the Factory Sector is shown in Figure 22.



FINANCIAL SECTOR

The flows of money into and out of the organization are controlled by the Financial Sector. In this model the primary interest has been to study the management of technical manpower rather than financial operations per se. The model therefore does not deal with cash management, capital budgeting or other financial policies, but rather with the effects on financial health of engineering management policies.

Income or revenue is received from the sale of hardware by the Factory and from the sale of engineering services. Income from the factory is improved slightly as engineering technical competence increases since as a consequence a more efficient production operation could be maintained.

Expense, engineering and factory, is charged against income received to determine profit before taxes. Profit is taken on contract engineering work and costs of proposal preparation are negotiated with the customer as a reimbursable part of indirect expense. Indirect expense, and general and administrative expense are included in the expense rate per engineer (ARE).

Factory expense is made up of labor costs and costs of purchased materials, parts, assemblies, and services. The expense rate per factory employee (ARF) includes overhead as well as general and administrative expense.

Tax payments are figured as 50 per cent of before tax earnings. Net or after tax profits are designated as OCNPR.

An important factor in determining desirability of a proposal to the customer is the price offer for doing the work. In the model OCPC has been used as an index of the price attractiveness of proposals. This index or factor has been formulated so that it is unity when the organization has all the men it needs to do the work at hand, and no excess manpower exists. If there is a manpower shortage and overtime operations are scheduled, the price factor is diminished proportionately. If the work price exceeds the work load with manpower becoming excess, likewise the price factor is proportionately reduced since operations would become inefficient.

The equations for the Financial Sector follow:

OCPL.K = OCPL.J + (DT)(OCRP.JK - OCPLT.JK)

OCRP.KL = OCIT.JK - OCET.JK

OCPLT.KL = (APLT)(OCRP.JK)

OCPL = Operations Control Profit Level ($)

OCRP = Operations Control Rate of Profit ($/month)

OCPLT = Operations Control Profit Loss to Taxes ($/month)

APLT = Average Profit Loss to Taxes expressed as a fraction of revenue (%)

OCIT.KL = OCIE.K + OCIF.K

OCET.KL = OCEF.K + OCEE.K

OCIT = Operations Control Income Total ($/month)

OCET = Operations Control Expense Total ($/month)

OCIE.K = (AERP)(ARE)(CWC.K) + (ARE)(PWC.K)

CWC.K = EDWC.JK + ERWC.JK

PWC.K = EPC1.JK + EPC2.JK

OCIE = Operations Control Income from Engineering ($/month)

AERP = Average Engineering Rate of Profit (%)

ARE = Average Rate for Engineers ($/man month)

CWC = Contract Work Completed (man month/month)

PWC = Proposal Work Completed (man month/month)

OCIF.K = (FECE.K)(OCRPF.K)(ARFI)

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

OCIF = Operations Control Income from the Factory ($/month)

OCRPF = Operations Control Rate of Profit for the Factory (%)

ARFI = Average Rate for Factory Income ($/equipment)

ARFP = Average Rate of Factory Profit (%)

ARITC = Average Rate Increase for Technical Competence improvement (%)

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

OCEF = Operations Control Expense from Factory ($/month)

ARF = Average Rate for Factory personnel ($/man month)

ARFM = Average Rate for Factory Material ($/equipment)

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

OCEE = Operations Control Engineering Expenses ($/month)

OCNPR.KL = OCRP.JK - OCPLT.JK

OCNPR = Operations Control Net Profit Rate ($/month)

OCPC.K = CLIP (OCP.K, OCO.K, MAR.K, MPT.K)

OCP.K = 1 - EMR.K

EMR.K = MAR.K/PETA.K

OCO.K = 1.3 - (AWR)(R.K)

R.K = WWL.K/40

MPT.K = PPT (PETA.K)

OCPC = Operations Control Price Constant (dimensionless)

OCP = Operations Control Price constant when an excess of manpower exists (dimensionless)

EMR = Excess Manpower Ratio (men/men)

OCO = Operations Control price constant when shortage of manpower exists and Overtime is necessary (dimensionless)

AWR = Average Weighting for the Ratio of actual work week length to a standard forty hour week (dimensionless)

R = Ratio of actual work week length to the standard forty hour week (hours per week/hours per week)

MPT = Manpower in Process of Transfer (men)

PPT = Per cent manpower in Process of Transfer (%)

The flow diagram for the Financial Sector is shown in Figure 23.

The flow diagram for the overall organization is shown in Figure 24.

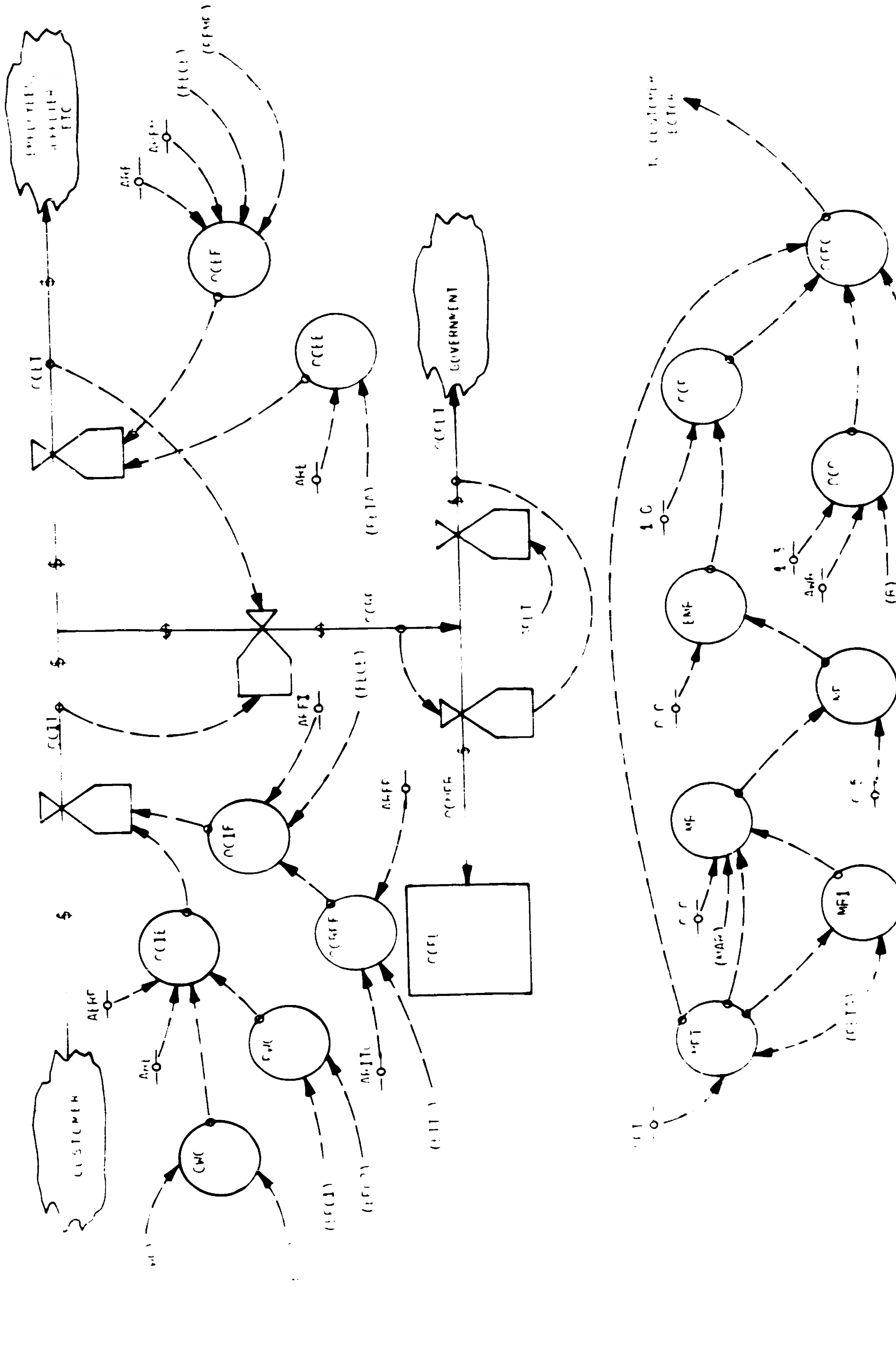
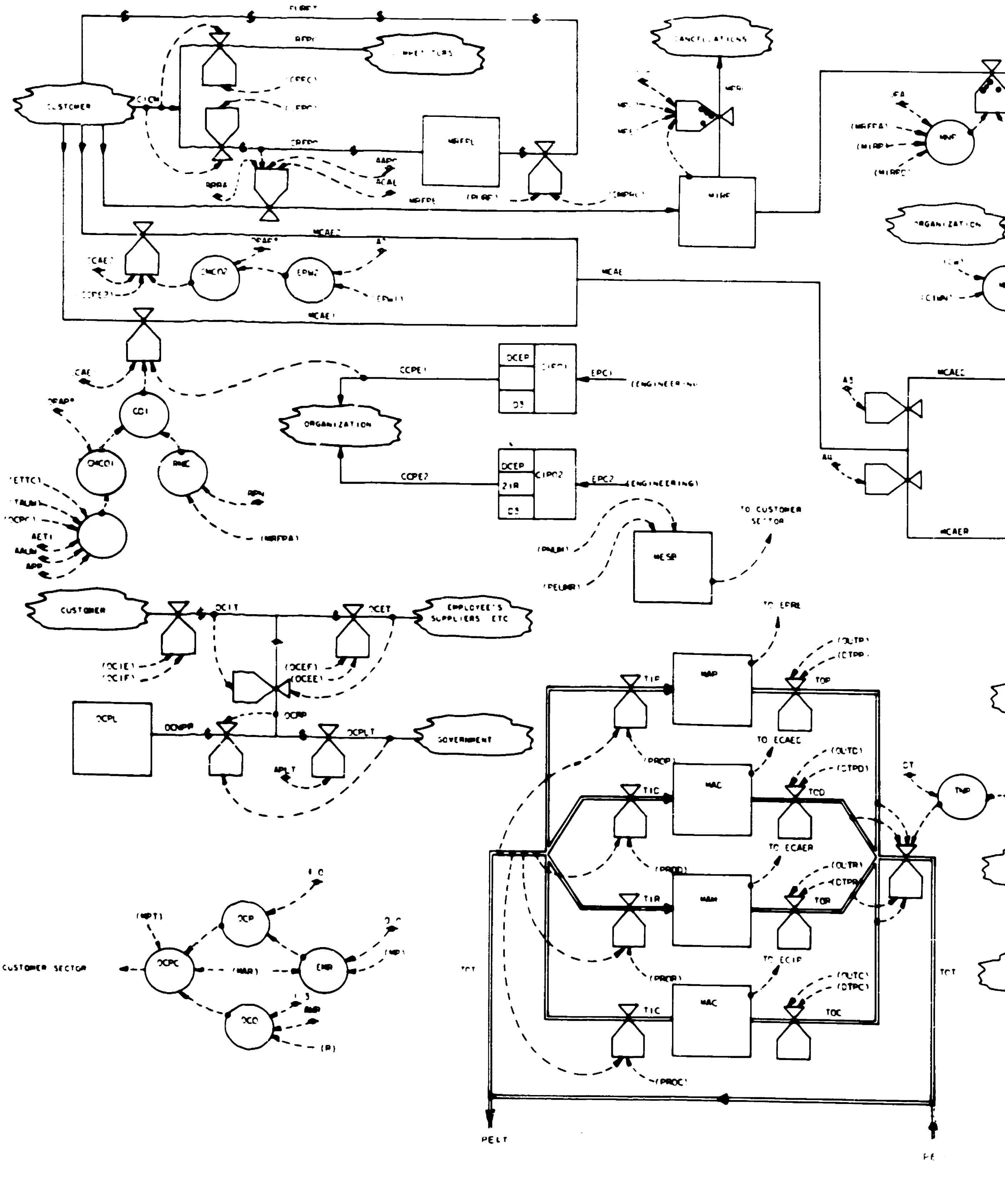


FIGURE [illegible] - FINANCIAL SECTOR FLOW DIAGRAM



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CCPE1-	CLASS 1 PROPOSALS EVALUATED BY THE CUSTOMER
CCPE2-	CLASS 2 PROPOSALS EVALUATED BY THE CUSTOMER
CRFPC-	REQUESTS FOR PROPOSALS TO COMPETITORS
CRFPC-	REQUESTS FOR PROPOSALS TO OWN ORGANIZATION
EAUW-	ABILITY TO UNDERTAKE ENGR'G WORK
ECAEC-	PRODUCTION ENGR'G CONTRACT AUTHORIZATIONS
ECAER-	R AND D CONTRACT AUTHORIZATIONS
ECIP-	COMPANY INITIATED ENGR'G PROJECTS
ECMS-	SPECIFICATIONS FOR MATERIEL
EDWC-	PRODUCTION ENGR'G CONTRACT WORK COMPLETED
EPC1-	CLASS 1 ENGR'G PROPOSALS COMPLETED
EPC2-	CLASS 2 ENGR'G PROPOSALS COMPLETED
EPRE-	ENGR'G PROPOSAL REQUESTS

ERWC-	R AND D
ETWC-	TOTAL EN
FAUW-	ABILITY
FECE-	FACTORY
FPRC-	PRODUCTI
FSRP-	SPECIFIC
MCAE-	CONTRACT
MCAE1-	CONTRACT
MCAE2-	CONTRACT
MCAED-	PRODUCTI
MCAER-	R AND D
MFSB-	MARKETIN
MPRC-	PROPOSAL
MRFPE-	REQUESTS

APPENDIX B

LIMITATIONS AND SUGGESTIONS

The prevalence of computers in business and institutions today tempts many to ask questions of these machines. The answers provided depend on the validity of the questions. There is always the issue before the model builder, "Are these the right questions to ask--have I recognized in the model the things that are important to the problem being studied?" This questioning attitude should be the approach of all who use the powerful tool of computers, and those who review the output of computers.

A recognized limitation exists in this and any similar attempt to handle by a mathematical model a complex management problem that in reality has interwoven human and intangible factors in great profusion. Recognition of this limitation, however, is not a valid reason for failing to learn as much as possible about the dynamic behavior of a business subjected to a variety of policies. Objectivity eliminates in essence the claim that too much reliance is being placed on a mathematical technique. Any information that aids the manager in making the best decisions possible in a given situation is worth while.

More specifically a technique was employed, necessary to a degree in formulating any model, of averaging discrete events to obtain a flow. This represents generally the real situation accurately if the time of the averaging period is of sufficient length. For instance, in this study the inflow of contract awards was treated as a flow instead of considering each contract awarded as a discrete event.

It is recognized that engineers are not always interchangeable, that talents as well as personality are involved in the assignment of personnel. A simplifying assumption made was that engineers were interchangeable in the Engineering group modeled.

Another point concerns the application of overtime. This is generally applied in practice with selectivity unless the majority of the organization is affected. The assumption made in the model was that overtime would be applied to all but company initiated work if it were required at all.

One might question the intersector constants, first for being represented as constants, and secondly for their particular assigned value. The particular values represent the estimate of the writer based on his experience. The added complexity of making these constants variable was not felt to offset the possible gain in reality.

A further development of the model would include modification of the formulation for engineering technical competence to take into account an averaged value for Customer defense expenditures (CICM) over a period of years. This would enhance the meaning of this index in situations where CICM was increasing or decreasing rapidly.

Likewise a further development of the formulation for recruiting and hiring engineering personnel is needed to assure that the manpower requirements of the organization are met with timeliness and without overhiring.

APPENDIX C

LIST OF REFERENCES

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Forrester, Jay W. "The Impact of Feedback Control Concepts on the Management Sciences," The Foundation for Instrumentation Education and Research Distinguished Lecture, School of Industrial Management, Mass. Institute of Technology, Cambridge, 1960.

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_______. "Models of Dynamic Behavior of Industrial and Economic Systems--A Section of Industrial Dynamics Class Notes," Memorandum D-46, (an unpublished paper), Industrial Dynamics Research Group, School of Industrial Management, Mass. Institute of Technology, Cambridge, August 1, 1959.

Pugh, A. "User's Manual for Dynamo II," Memorandum D-111, (an unpublished paper), Industrial Dynamics Research Group, School of Industrial Management, Mass. Institute of Technology, Cambridge, October 7, 1960.

Roberts, Edward B. "Simulation Techniques for Understanding R and D Management" (a speech delivered at the National Convention of the Institute of Radio Engineers, at the Waldorf-Astoria, New York City, March 23, 1959), Industrial Dynamics Research Group, School of Industrial Management, Mass. Institute of Technology, Cambridge.

APPENDIX D

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DYN     M1372-1117-DEFENSE PRODUCT DEVELOPMENT ORGANIZATION SIMULATION
RUN     1987PL/DT=.2/LENGTH=180/PRTPER=6/PLTPER=2
NOTE    AN INDUSTRIAL DYNAMICS ANAL OF A DEFENSE PRODUCT DEVELOPMNT GROUP
NOTE    THESIS,SCHOOL OF INDUSTRIAL MANAGEMENT,APRIL 1961, BY P.W.LETT
NOTE    MANAGEMENT POLICIES (A)                                          PL0907
C       C1=0/C2=1/C3=0/C4=0        RAMP                                  PL0910
C       CVAR=0                                                           PL0194
C       APEC=0.03
NOTE
NOTE
NOTE
NOTE    EQUATIONS FOR CUSTOMER SECTOR
NOTE
NOTE
NOTE                                                                     PL0001
12R     CRFPO.KL=(CPPO.K)(CICM.JK)
NOTE    CRFPO CUSTOMER REQUESTS FOR PROPOSALS TO ORGANIZATION            PL0002
12R     CRFPC.KL=(CPPC.K)(CICM.JK)
NOTE    CRFPC CUSTOMER REQUESTS FOR PROPOSALS TO COMPETITION             PL0813
8A      CPPO.K=DMESB.JK+DETTC.JK+DTAUW.JK
NOTE    CPPO CUSTOMER PERCENTAGE PROPOSALS TO ORGANIZATION               DB0023
7A      CPPC.K=1.0-CPPO.K
NOTE    CPPC CUSTOMER PERCENTAGE PROPOSALS TO COMPETITION                PL0818
1L      MRFPL.K=MRFPL.J+(DT)(CRFPO.JK-PURPT.JK)
NOTE    MRFPL MARKETING REQUESTS FOR PROPOSAL LEVEL                      PL0084
46R     MRFPE.KL=(AAPO)(CRFPO.JK)(1)/((ACAE)(RRRA)(1))
NOTE    MRFPE MARKETING REQUESTS FOR PROPOSALS ENTERED                   PL0814
13R     MCAE1.KL=(CCAE1)(CO1.K)(CCPE1.JK)
NOTE    MCAE1=MKTNG CONTR AWARDS ENTERING FROM CLASS 1  PROPOSALS        PL0815
13R     MCAE2.KL=(CCAE2)(CMCO2.K)(CCPE2.JK)
NOTE    MCAE2=MKTNG CONTR AWARDS ENTERING FROM CLASS 2  PROPOSALS        PL0019
59A     CMCO1.K=TABLE(OPAP,EPW1.K,0,1.0,0.05)                            PL0025
59A     CMCO2.K=TABLE(OPAP,EPW2.K,0,1.0,0.05)                            PL0486
12A     CO1.K=(RNC.K)(CMCO1.K)                                           PL0487
20A     RNC.K=MRFPA.K/RPN                                                PL0488
C       RPN=10.1                                                         PL0005
39R     DMESB.KL=DELAY3(AMESB.K,DEME)                                    PL0006
12A     AMESB.K=(AME)(MESB.K)                                            PL0008
39R     DETTC.KL=DELAY3(AETTC.K,DEEE)                                    PL0009
12A     AETTC.K=(ATC)(ETTC.K)                                            PL0011
39R     DTAUW.KL=DELAY3(ATAUW.K,DEAW)                                    PL0012
12A     ATAUW.K=(AUW)(TAUW.K)                                            PL0016
        CCPE1.KL=DELAY3(EPC1.JK,DCEP)
```

2

```
39R   CCPE2.KL=DELAY3(EPC2.JK,DCEP)                                     PL0022
NOTE  CCPE2=CUSTOMER COMPLETED PROPOSALS EVALUATED, CLASS 2
1L    CIPO1.K=CIPO1.J+(DT)(EPC1.JK-CCPE1.JK)                            PL0017
1L    CIPO2.K=CIPO2.J+(DT)(EPC2.JK-CCPE2.JK)                            PL0021
7R    PURPT.KL=PURP.JK+DMPRC.JK                                         PL0817
46A   PURP.K=(ACAE)(RRRA)(EPC2.JK)/((AAPO)(1)(1))                       PL0816
46A   DMPRC.K=(ACAE)(RRRA)(MPRC.JK)/((AAPO)(1)(1))                      PL0834
16A   EPW1.K=(AET1)(ETTC.K)+(AAUW)(TAUW.K)+(APP)(OCPC.K)+(0)(0)         PL0826
NOTE  EPW1=ENGRG PROPOSAL WORTH OF CLASS 1 PROPOSALS
12A   EPW2.K=(A2)(EPW1.K)                                               PL0825
NOTE  EPW2=ENGRG PROPOSAL WORTH OF CLASS 2 PROPOSALS
7R    MCAE.KL=MCAE1.JK+MCAE2.JK                                         PL0034
12R   MCAED.KL=(A3)(MCAE.JK)                                            PL0172
12R   MCAER.KL=(A4)(MCAE.JK)                                            PL0173
C     A3=0.85                                                           PL0174
C     DEME=18.0 MO                                                      PL0007
C     DEEE=24.0 MO                                                      PL0010
C     DEAW=9.0                                                          PL0004
C     ACAE=28                                                           PL0845
C     AET1=0.4                                                          PL0844
C     AAUW=0.1                                                          PL0031
C     AME=0.03                                                          DB0020
C     ATC=0.04                                                          PL0843
C     AUW=0.03                                                          DB0021
C     APP=0.2                                                           PL0383
C     DCEP=6                                                            DB0024
C     CCAE1=54.12                                                       PL0808
C     CCAE2=28                                                          PL0809
C     RRRA=10                                                           PL0970
C     OPAP*=0/0.02/0.04/0.07/0.10/0.15/0.20/0.26/0.32/0.38/0.45/0.50/0.5 PL0810
X1    5/0.60/0.65/0.69/0.73/0.75/0.77/0.79/0.80                         PL0810
C     A2=0.3                                                            PL0824
C     AAPO=.0005                                                        PL0831
C     CICMN=70000000                                                    PL0804
NOTE
NOTE
NOTE
NOTE  INITIAL CONDITIONS FOR CUSTOMER SECTOR
NOTE
NOTE
```

```
                                                                DB0047
12N   CRFPC=(CPPO2)(CICM)                                       DB0048
7N    CPPO2=1-CPPO1                                             DB0043
6N    MRFPL=0                                                   PL0821
13N   MCAE1=(CCAE1)(CO1)(CCPE1)                                 PL0822
13N   MCAE2=(CCAE2)(CMCO2)(CCPE2)                               DB0039
6N    CICM=CICMN                                                PL0840
8N    CPPO1=AMESB+AETTC+ATAUW                                   PL0841
8N    CPPOT=AME+ATC+AUW                                         PL0056
59N   CMCO1=TABLE(OPAP,EPW1,0,1.0,0.05)                         PL0051
12N   AETTC=(ATC)(ETTC)                                         PL0050.
12N   AMESB=(AME)(MESB1)                                        PL0052
12N   ATAUW=(AUW)(TAUW1)                                        PL0055
7N    MCAE=MCAE1+MCAE2                                          PL0057
59N   CMCO2=TABLE(OPAP,EPW2,0,1.0,0.05)                         PL0036
12N   CIPO1=(DCEP)(EPC1)                                        PL0037
12N   CIPO2=(DCEP)(EPC2)                                        PL0812
46N   MRFPE=(AAPO)(CPPO1)(CICM)/((RRRA)(ACAE)(1))               PL0821
46N   PURP=(ACAE)(RRRA)(EPC2)/((AAPO)(1)(1))                    PL0820
6N    PURPT=PURP                                                PL0835
6N    DMPRC=0                                                   PL0827
16N   EPW1=(AET1)(ETTC)+(AAUW)(TAUW1)+(APP)(OCPC1)+(0)(0)       PL0828
12N   EPW2=(A2)(EPW1)                                           PL0857
6N    TAUW1=0.8927                                              PL0854
6N    OCPC1=1.0                                                 PL0030
6N    CO1=CMCO1                                                 PL0998
6N    CO1=CMCO1
NOTE
NOTE
NOTE                                                            PL0952
NOTE  EQUATIONS FOR MARKETING SECTOR
NOTE
NOTE
NOTE                                                            PL0169
2L    MIRP.K=MIRP.J+(DT)(MRFPE.JK-EPRE.JK-MPRC.JK+0+0+0)
NOTE  MIRP MARKETING INVENTORY OF REQUESTS FOR PROPOSALS        PL0167
51R   MPRC.KL=CLIP(MPE.K,0,MIRP.K,MPC.K)                        PL0168
21A   MPE.K=(1/DPCC)(MIRP.K-MPC.K)                              PL0170
12A   MPC.K=(A5)(EPWP.K)                                        PL0171
C     A5=0.5                                                    DB2000
12A   MIRPD.K=(DMPP)(MRFPA.K)                                   PL0839
```

```
NOTE   MESB      MARK. EFFORT IN SOLICITING BUS.                DB2084
18A    MESBF.K=(ACMEB)(MESBT.K-MESB.K)                            DB1084
51A    MESBT.K=CLIP(MF1.K,0,1.0,MF2.K)                            DB0085
7A     MF1.K=1.0-MF2.K                                            DB0086
44A    MF2.K=(AMS)(PEUMR.K)/PNUM.K                                DB3084
C       ACMEB=0.05                                                DB0099
C       APCC=0                                                    DB4975
C       AEPCC=0.04                                                DB3075
C       APP1=0.25                                                 PL0182
C       DPCC=1.0                                                  DB0100
C       AMS=0.25                                                  DB0262
C       MESB1=0.75                                                DB5230
C       TCAP=6                                                    DB6230
C       TCAC=6
NOTE
NOTE
NOTE
NOTE   INITIAL CONDITIONS FOR MARKETING SECTOR
NOTE
NOTE
NOTE                                                              DB1250
6N     MRFPA=MRFPE                                                DB4084
6N     MESB=MESB1                                                 PL0285
12N    MIRP=(DMPP)(MRFPE)                                         DB0975
6N     MPRC=0
NOTE
NOTE
NOTE
NOTE   EQUATIONS FOR ENGINEERING SECTOR
NOTE
NOTE
NOTE                                                              PL0166
51R    EPRE.KL=CLIP(MNP.K,MAP.K,MAP.K,MNP.K)                      PL0183
51R    ECAED.KL=CLIP(MND.K,MAD.K,MAD.K,MND.K)                     PL0191
51R    ECAER.KL=CLIP(MNR.K,MAM.K,MAM.K,MNR.K)                     PL0205
51R    ECIP.KL=CLIP(MNC.K,MAC.K,MAC.K,MNC.K)                      PL0164
40A    MNP.K=MRFPA.K+(1/DPA)(MIRP.K-MIRPD.K)                      PL0176
40A    MND.K=MCADA.K+(1/DD)(EICD.K-EICDD.K)                       PL0184
40A    MNR.K=MCARA.K+(1/DR)(EICR.K-EICRD.K)                       PL0192
12A    MNC.K=(ICW.K)(CIWN.K)                                      PL0165
```

```
                                                                        PL0177
3L    MCADA.K=MCADA.J+(DT)(1/TCAD)(MCAED.JK-MCADA.J)                    PL0178
C     TCAD=6                                                            PL0185
3L    MCARA.K=MCARA.J+(DT)(1/TCAR)(MCAER.JK-MCARA.J)                    PL0186
C     TCAR=6                                                            PL0180
1L    EICD.K=EICD.J+(DT)(MCAED.JK-ECAED.JK)                             PL0181
12A   EICDD.K=(DMPC)(MCADA.K)                                           PL0188
1L    EICR.K=EICR.J+(DT)(MCAER.JK-ECAER.JK)                             PL0189
12A   EICRD.K=(DMPG)(MCARA.K)                                           PL0779
1L    MAP.K=MAP.J+(DT)(TIP.JK-TOP.JK)                                   PL0780
1L    MAD.K=MAD.J+(DT)(TID.JK-TOD.JK)                                   PL0781
1L    MAM.K=MAM.J+(DT)(TIR.JK-TOR.JK)                                   PL0782
1L    MAC.K=MAC.J+(DT)(TIC.JK-TOC.JK)                                   PL0118
7A    DIFP.K=MNP.K-MAP.K                                                PL0119
7A    DIFD.K=MND.K-MAD.K                                                PL0120
7A    DIFR.K=MNR.K-MAM.K                                                PL0121
7A    DIFC.K=MNC.K-MAC.K                                                PL0122
20A   PDP.K=DIFP.K/MNP.K                                                PL0125
20A   PDD.K=DIFD.K/MND.K                                                PL0128
20A   PDR.K=DIFR.K/MNR.K                                                PL0131
20A   PDC.K=DIFC.K/MNC.K                                                PL0123
51A   PDEP1.K=CLIP(1.0,PDP.K,PDP.K,1.0)                                 PL0124
51A   PDEP.K=CLIP(PDEP1.K,-1.0,PDEP1.K,-1.0)                            PL0126
51A   PDED1.K=CLIP(1.0,PDD.K,PDD.K,1.0)                                 PL0127
51A   PDED.K=CLIP(PDED1.K,-1.0,PDED1.K,-1.0)                            PL0129
51A   PDER1.K=CLIP(1.0,PDR.K,PDR.K,1.0)                                 PL0130
51A   PDER.K=CLIP(PDER1.K,-1.0,PDER1.K,-1.0)                            PL0132
51A   PDEC1.K=CLIP(1.0,PDC.K,PDC.K,1.0)                                 PL0133
51A   PDEC.K=CLIP(PDEC1.K,-1.0,PDEC1.K,-1.0)                            PL0134
59A   PMDP.K=TABLE(TPP,PDEP.K,-1,+1,0.1)                                PL0135
59A   PMDD.K=TABLE(TPD,PDED.K,-1,+1,0.1)                                PL0136
59A   PMDR.K=TABLE(TPR,PDER.K,-1,+1,0.1)                                PL0137
59A   PMDC.K=TABLE(TPC,PDEC.K,-1,+1,0.1)                                PL0139
C     TPP*=-0.56/-0.55/-0.52/-0.49/-0.46/-0.42/-0.37/-0.30/-0.23/-0.13/0 PL0139
X1    .0/0.13/0.24/0.33/0.40/0.46/0.50/0.53/0.56/0.59/0.60              PL0140
C     TPD*=-1.0/-0.97/-0.92/-0.83/-0.70/-0.54/-0.37/-0.22/-0.12/-0.04/0. PL0140
X1    0/0.04/0.12/0.22/0.37/0.54/0.70/0.83/0.92/0.97/1.0                PL0141
C     TPR*=-1.0/-0.97/-0.92/-0.83/-0.70/-0.54/-0.37/-0.22/-0.12/-0.04/0. PL0141
X1    0/0.04/0.12/0.22/0.37/0.54/0.70/0.83/0.92/0.97/1.0                PL0142
C     TPC*=-0.32/-0.31/-0.30/-0.29/-0.28/-0.26/-0.24/-0.20/-0.16/-0.10/0 PL0142
X1    .0/0.17/0.26/0.33/0.36/0.38/0.39/0.40/0.41/0.41/0.42              PL0143
C     ITPP*=-1E20/-1E20/-1E20/-7.00/-1.20/-.71/-.46/-.29/-.16/-.07/0/.08 PL0143
```

```
        0.0/0.20/0.29/0.36/0.42/0.47/0.53/0.59/0.67/0.77/1.00                PL0144
X1      0.0/0.20/0.29/0.36/0.42/0.47/0.53/0.59/0.67/0.77/1.00/-0.47/-0.42/-0.36/-0.29/-0.20/   PL0145
C       ITPR*=-1.00/-0.77/-0.67/-0.59/-0.53/-0.47/-0.42/-0.36/-0.29/-0.20/   PL0145
X1      0.0/0.20/0.29/0.36/0.42/0.47/0.53/0.59/0.67/0.77/1.00                PL0146
C       ITPC*=-1E20/-1E20/-1E20/-1E20/-1E20/-1E20/-3.00/-.80/-.29/-.10/0/.   PL0146
X1      05/.13/.25/.70/10.00/1E20/1E20/1E20/1E20/1E20                        PL0138
24A     OP.K=(1/4)(PMDP.K+PMDD.K+PMDR.K+PMDC.K+0+0)                          PL0386
51A     OPE.K=CLIP(1.0,OP.K,OP.K,1.0)                                        PL0387
51A     AP.K=CLIP(-1.0,OPE.K,-1.0,OPE.K)                                     PL0147
59A     DPDP.K=TABLE(ITPP,AP.K,-1,+1,0.1)                                    PL0148
59A     DPDD.K=TABLE(ITPD,AP.K,-1,+1,0.1)                                    PL0149
59A     DPDR.K=TABLE(ITPR,AP.K,-1,+1,0.1)                                    PL0150
59A     DPDC.K=TABLE(ITPC,AP.K,-1,+1,0.1)                                    PL0114
12A     DDP.K=(DPDP.K)(MNP.K)                                                PL0115
12A     DDD.K=(DPDD.K)(MND.K)                                                PL0116
12A     DDR.K=(DPDR.K)(MNR.K)                                                PL0117
12A     DDC.K=(DPDC.K)(MNC.K)                                                PL0870
7A      DTPP.K=DIFP.K-DDP.K                                                  PL0871
7A      DTPD.K=DIFD.K-DDD.K                                                  PL0872
7A      DTPR.K=DIFR.K-DDR.K                                                  PL0873
7A      DTPC.K-DIFC.K-DDC.K                                                  PL0878
20A     OUTP.K-DTPP.K/TDTP                                                   PL0880
20A     OUTD.K-DTPD.K/TDTP                                                   PL0881
20A     OUTR.K-DTPR.K/TDTP                                                   PL0882
20A     OUTC.K=DTPC.K/TDTP                                                   PL0431
C       TDTP=2                                                               PL0472
7R      TOT.KL=PTO1.JK-PELT.JK                                               PL0471
7R      PTO1.KL=PTO.JK+PELE.JK                                               PL0470
9R      PTO.KL=TOP.JK+TOD.JK+TOR.JK+TOC.JK                                   PL0874
51R     TOP.KL=CLIP(0,-OUTP.K,DTPP.K,0)                                      PL0875
51R     TOD.KL=CLIP(0,-OUTD.K,DTPD.K,0)                                      PL0876
51R     TOR.KL=CLIP(0,-OUTR.K,DTPR.K,0)                                      PL0877
51R     TOC.KL-CLIP(0,-OUTC.K,DTPC.K,0)                                      PL0887
12R     TIP.KL-(PROP.K)(TOT.JK)                                              PL0888
12R     TID.KL-(PROD.K)(TOT.JK)                                              PL0889
12R     TIR.KL=(PROR.K)(TOT.JK)                                              PL0890
12R     TIC.KL-(PROC.K)(TOT.JK)                                              PL0766
51A     PROP.K-CLIP(0,PROP1.K,MSPDT,SPDT.K)                                  PL0767
51A     PROD.K-CLIP(0,PROD1.K,MSPDT,SPDT.K)                                  PL0768
51A     PROR.K=CLIP(0,PROR1.K,MSPDT,SPDT.K)                                  PL0769
51A     PROC.K=CLIP(0,PROC1.K,MSPDT,SPDT.K)                                  PL0770
        PROP1.  =PDTPP.K/SPDT.K                                              PL0771
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20A   PROC1.K=PDTPC.K/[illegible]                                              PL0774
51A   PDTPP.K=CLIP(DTPP.K,1E-10,DTPP.K,1E-10)                                  PL0762
51A   PDTPD.K=CLIP(DTPD.K,1E-10,DTPD.K,1E-10)                                  PL0763
51A   PDTPR.K=CLIP(DTPR.K,1E-10,DTPR.K,1E-10)                                  PL0764
51A   PDTPC.K=CLIP(DTPC.K,1E-10,DTPC.K,1E-10)                                  PL0765
9A    SPDT.K=PDTPP.K+PDTPD.K+PDTPR.K+PDTPC.K                                   PL0754
9N    MSPDT=1E-10+1E-10+1E-10+1E-10                                            PL0772
12A   CIWN.K=(APEC)(PETA.K)                                                    PL0193
59A   ICW.K=TABLE(TIFC,ECHAN.K,-1.0,1.0,0.1)                                   PL0195
C     TIFC*=4.0/3.9/3.7/3.4/3.1/2.6/2.2/1.9/1.5/1.2/1.0/0.8/0.7/0.6/0.5/       PL0196
X1    0.5/0.4/0.4/0.4/0.3/0.3                                                  PL0196
51A   ECHAN.K=CLIP(1.0,CHAN.K,CHAN.K,1.0)                                      PL0197
51A   CHAN.K=CLIP(CHANG.K,-1.0,CHANG.K,-1.0)                                   PL0198
44A   CHANG.K=(12)(PERCH.K)/TPDIF                                              PL0199
21A   PERCH.K=(1/WAV5.K)(WAV1.K-WAV5.K)                                        PL0190
3L    WAV5.K=WAV5.J+(DT)(1/DTP)(MCAE.JK-WAV5.J)                                PL0200
C     DTP=60                                                                   PL0201
3L    WAV1.K=WAV1.J+(DT)(1/RTP)(MCAE.JK-WAV1.J)                                PL0202
C     RTP=12                                                                   PL0203
51A   ROT.K=CLIP(AP.K,0,AP.K,0)                                                PL0206
59A   WWL.K=TABLE(TWWL,ROT.K,0,1,0.05)                                         PL0207
C     TWWL*=40/40/41/45/49/55/59/63/66/69/72/74/76/78/80/81/82/83/84/84/       PL0208
X1    84                                                                       PL0208
7A    MUL.K=1+V.K                                                              PL0209
18A   V.K=(0.64)(1-U.K)                                                        PL0210
28A   U.K=(1.0)EXP(Q.K)                                                        PL0211
18A   Q.K=(1.5)(1-R.K)                                                         PL0212
20A   R.K=WWL.K/40                                                             PL0213
1L    EPWP.K=EPWP.J+(DT)(EPRE.JK-EPC2.JK)                                      PL0227
1L    EDWP.K=EDWP.J+(DT)(ECAED.JK-EDWC.JK)                                     PL0228
1L    ERWP.K=ERWP.J+(DT)(ECAER.JK-ERWC.JK)                                     PL0229
1L    ECWP.K=ECWP.J+(DT)(ECIP.JK-EPC1.JK)                                      PL0230
39R   EP2.KL=DELAY3(EPRE.JK,DCP)                                               PL0231
39R   EDW.KL=DELAY3(ECAED.JK,DCD)                                              PL0232
39R   ERW.KL=DELAY3(ECAER.JK,DCR)                                              PL0233
39R   EPC1.KL=DELAY3(ECIP.JK,DCC)                                              PL0234
C     DCP=1.5                                                                  PL0235
C     DCD=12                                                                   PL0236
C     DCR=18                                                                   PL0237
C     DCC=24                                                                   PL0238
12R   EPC2.KL=(MUL.K)(EP2.JK)                                                  PL0324
                                                                               PL0325
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7R     ECWS.KL=PSE.JK+PCS.JK                                          PL0476
12R    PSE.KL=(ACSS)(EDW.JK)                                          PL0482
C      ACSS=0.05                                                      PL0477
12R    PCS.KL=(CAS)(PCA.JK)                                           PL0478
6R     PCA.KL=800000                                                  PL0479
C      CAS=75.825E-6                                                  PL0239
3L     ECWCA.K=ECWCA.J+(DT)(1/TCWC)(EDWC.JK-ECWCA.J)
NOTE   ECWCA   ENGINEERING CONTRACT WORK AVERAGE LEVEL                PL0240
3L     EGRCA.K=EGRCA.J+(DT)(1/TGRC)(ERWC.JK-EGRCA.J)
NOTE   EGRCA  ENGINEERING GENERAL RESEARCH WORK AVERAGE LEVEL         PL0241
3L     ESRCA.K=ESRCA.J+(DT)(1/TSRC)(EPC1.JK-ESRCA.J)
NOTE   ESRCA  ENGINEERING SPECIAL RESEARCH WORK AVERAGE LEVEL         DB0114
37B    ETC1=BOXLIN(8,12)
NOTE   ETC1  ENGINEERING TECHNICAL COMPETENCE, PAST CONTRACT WORK     DB0116
37B    ETC2=BOXLIN(8,12)
NOTE   ETC2  ENGINEERING TECHNICAL COMPETENCE, PAST GENERAL RES. WORK DB0118
37B    ETC3=BOXLIN(8,12)
NOTE   ETC3 ENGINEERING TECHNICAL COMPETENCE, PAST CO. INITIATED WORK DB0115
6A     ETC1*1.K=ECWCA.K                                               DB0117
6A     ETC2*1.K=EGRCA.K                                               DB0119
6A     ETC3*1.K=ESRCA.K                                               PL0327
55A    ETC1S.K=SUM2(8,W1A,ETC1)                                       PL0328
55A    ETC2S.K=SUM2(8,W2A,ETC2)                                       PL0329
55A    ETC3S.K=SUM2(8,W3A,ETC3)                                       PL0330
20A    ETC1W.K=ETC1S.K/WFD                                            PL0331
20A    ETC2W.K=ETC2S.K/WFD                                            PL0332
20A    ETC3W.K=ETC3S.K/WFD                                            PL0334
3L     CICMA.K=CICMA.J+(DT)(1/CIP)(CICM.JK-CICMA.J)                   PL0335
C      CIP=24                                                         PL0337
8A     ETCT.K=ETC1W.K+ETC2W.K+ETC3W.K                                 PL0338
20A    ETCR.K=ETCT.K/RELF.K                                           PL0842
46A    RELF.K=(AAPO)(CPPOT)(CICMA.K)/((NF)(1)(1))                     PL0846
C      NF=28                                                          PL0340
1L     ETTC.K=ETTC.J+(DT)(ETCI.J+0)
NOTE   ETTC.K ENGINEERING TOTAL TECHNICAL COMPETENCE                  PL0341
18A    ETCI.K=(INC)(ETCR.K-ETTC.K)                                    PL0342
C      INC=0.01                                                       DB0138
7A     TAUW.K=EAUW.K+FAUW.K                                           DB0134
1L     EAUW.K=EAUW.J+(DT)(EAUWF.J+0)
NOTE   EAUW ENGINEERING ABILITY TO UNDERTAKE WORK                     DB1134
59A    FAUWT.K=TABLE(EWA,ETEI1.K,0,17,0.5)                            DB0132
       ... .1/0.14/0.09/0.05/0.03/.02/.0
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                                                              DB2134
18A   LAUWF.K=(ACEAW)(LAUWT.K-LAUW.K)                         DB3134
C     ACEAW=0.05                                              PL0083
42A   ETEI.K=MTBL.K/((PETA.K)(ADPMS))
NOTE  ETEI  ENGINEERING TIMES TO EXHAUST WORK INVENTORY       PL0257
9A    MTBL.K=MIRPD.K+EICDD.K+EICRD.K+MNCD.K                   DB0130
51A   ETEI1.K=CLIP(ETEI.K,17,17,ETEI.K)                       DB0155
C     TSRC=12                                                 DB0157
C     TCWC=12                                                 DB0158
C     TGRC=12                                                 PL0082
C     ADPMS=2                                                 PL0289
C     PLANP=0.75                                              PL0290
C     PLAND=3                                                 PL0291
C     PLANR=3                                                 PL0282
C     PLANC=1                                                 DB7100
C     DMPC=3                                                  DB7300
C     DMPG=3                                                  PL0004
C     DMPS=1                                                  PL0362
C     W1A*=0/3/2.5/2/1.5/0.5/0.5/0.0                          PL0361
C     W2A*=0/2/4.5/6/3.5/2/1/1                                PL0360
C     W3A*=0/1/2/4/7/9/5/2                                    PL0833
C     WFD=60                                                  PL0760
C     ETC1*=404/404/404/404/404/404/404/404                   PL0761
C     ETC2*=71/71/71/71/71/71/71/71                           PL0752
C     ETC3*=15/15/15/15/15/15/15/15                           PL0890
NOTE  EQUATIONS FOR ENGINEERING PERSONNEL FOLLOW              DB0226
1L    PETA.K=PETA.J+(DT)(PELE.JK-PELT.JK)
NOTE  PETA PERSONNEL ENGINEERING TOTAL AVAILABLE              PL0244
9R    PEMRT.KL=MRFPE.JK+MCAED.JK+MCAER.JK+MNC.K
NOTE  PEMRT PERSONNEL ENGINEERING MANPOWER REQUESTS TOTAL     PL0252
3L    MNCA.K=MNCA.J+(DT)(1/TCAC)(MNC.J-MNCA.J)                PL0253
12A   MNCD.K=(DMPS)(MNCA.K)                                   PL0305
7A    PNUM.K=PNUMP.K+NBUW.K                                   PL0245
16A   PNUMP.K=(DCP)(MRFPA.K)+(DCD)(MCADA.K)+(DCR)(MCARA.K)+(DCC)(MNCA.K)   PL0245
X1                                                            PL0259
16A   NBUW.K=(PLANP)(MRFPA.K)+(PLAND)(MCADA.K)+(PLANR)(MCARA.K)+(PLANC)(   PL0259
X1    MNCA.K)                                                 DB0230
3L    PEMRA.K=PEMRA.J+(DT)(1/DAMP)(PEMRT.JK-PEMRA.J)
NOTE  PEMRA PERSONNEL ENGINEERING MANPOWER REQUESTS AVERAGE   DB0229
1L    PEUMR.K=PEUMR.J+(DT)(PEMRT.JK-ETWC.J)
NOTE  PEUMR PERSONNEL ENGINEERING UNFILLED MANPOWER REQUESTS  PL0225
9A    ETWC.K=EPC1.JK+EPC2.JK+EDWC.JK+ERWC.JK
      ... TOTAL WORK COMPLETION RATE
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9A      PEMD.K=PEPWD.K+PECWD.K+PESWD.K+PEGWD.K                              [illegible]
NOTE    PEMD PERSONNEL ENGINEERING MANPOWER DESIRED
7A      PEPWD.K=PEPW1.K+PEPW2.K                                             DB6000
20A     PEPW1.K=MRFPA.K/AEPF                                                DB7000
20A     PEPW2.K=PEPW3.K/AEPF                                                DB6043
21A     PEPW3.K=(1/DAPB)(MIRP.K-MIRPD.K)                                    DB9000
7A      PECWD.K=PECW1.K+PECW2.K                                             DB3100
20A     PECW1.K=MCADA.K/AEPF                                                PL0246
20A     PECW2.K=PECW3.K/AEPF                                                DB5100
21A     PECW3.K=(1/DAPC)(EICD.K-EICDD.K)                                    PL0247
7A      PEGWD.K=PEGW1.K+PEGW2.K                                             DB3300
20A     PEGW1.K=MCARA.K/AEPF                                                PL0248
20A     PEGW2.K=PEGW3.K/AEPF                                                DB5300
21A     PEGW3.K=(1/DAPG)(EICR.K-EICRD.K)                                    PL0249
7A      PESWD.K=PESW1.K+PESW2.K                                             DB3200
20A     PESW1.K=MNC.K/AEPF                                                  PL0250
20A     PESW2.K=PESW3.K/AEPF                                                DB5200
21A     PESW3.K=(1/DAPS)(MNC.K-MNCD.K)                                      PL0251
39R     PEHP.KL=DELAY3(PERP.JK,DELH)                                        PL0472
NOTE    PEHP PERSONNEL ENGINEERING HIRING POLICY
C       DELH=6                                                              PL0473
51R     PERP.KL=CLIP(PECP.K,0,PECP.K,PECP2.K)                               PL0474
21A     PECP.K=(1/DT)(PECP1.K-MAR.K)                                        PL0475
NOTE    PECP PERSONNEL ENGINEERING CHANGE POLICY
7A      PECP1.K=PEMD.K-PETAT.K                                              DB0237
44A     PECP2.K=(0.01)(PETA.K)/DT                                           PL0476
1L      PELP.K=PELP.J+(DT)(PERP.JK-PELE.JK)                                 PL0477
NOTE    PELP PERSONNEL ENGINEERING ENTERING LABOR IN PROCESS
39R     PELE.KL=DELAY3(PEHP.JK,DFRP)                                        DB0241
NOTE    PELE PERSONNEL ENGINEERING LABOR ENTERING
51R     PELT.KL=CLIP(PELT1.K,0,MAR.K,AETH)                                  DB0238
NOTE    PELT PERSONNEL ENGINEERING LABOR TERMINATIONS
17A     PELT1.K=(0.5)(APTE)(MARC*1.K)+(1)(APTE)(MARC*2.K)+(2)(APTE)(MARC*3  DB9876
X1      .K)                                                                 DB9876
51A     MAR.K=CLIP(MARN.K,0,MARN.K,0)                                       PL0245
NOTE    MAR MANPOWER AVAILABLE FOR REASSIGNMENT
10A     MARN.K=PETA.K-EPRE.JK-ECAED.JK-ECAER.JK-ECIP.JK+0                   PL0216
37B     MARC=BOXLIN(3,1)                                                    DB1239
1L      MARC*1.K=MARC*1.J+(DT)(MARF.J+0)                                    DB2259
18A     MARF.K=(ACMAR)(MAR.K-MARC*1.K)                                      DB3259
C       ACMAR=0.50                                                          DB5259
                                                                            DB0245
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C       DAPB=3                                      PL0470
C       DAPC=3                                      DB8100
C       DAPG=3                                      DB8500
C       DAPS=3                                      PL0471
C       AETH=5                                      DB0242
C       APTE=0.10                                   DB0249
C       DAMP=6                                      DB0244
C       TPCP=3                                      DB0247
C       DFRP=1                                      PL0475
NOTE
NOTE
NOTE
NOTE    INITIAL CONDITIONS FOR ENGINEERING SECTOR
NOTE
NOTE
NOTE
6N      EAUW=0.52                                   PL0855
6N      MCAED=MAD                                   PL0224
6N      MCAER=MAM                                   PL0225
6N      MNC=MAC                                     PL0226
6N      CICMA=CICM                                  PL0336
6N      MAP=10.1                                    PL0783
6N      MAD=404                                     PL0784
6N      MAM=71                                      PL0785
6N      MAC=15                                      PL0786
6N      TOP=0                                       PL0264
6N      TOD=0                                       PL0265
6N      TOR=0                                       PL0266
6N      TOC=0                                       PL0267
6N      TIP=0                                       PL0268
6N      TID=0                                       PL0269
6N      TIR=0                                       PL0270
6N      TIC=0                                       PL0271
6N      EPRE=MRFPE                                  PL0272
6N      WAV5=MCAE                                   PL0273
6N      WAV1=MCAE                                   PL0274
12N     EICD=(MCAED)(DMPC)                          PL0275
6N      ECAED=MND                                   PL0276
6N      MND=MCADA                                   PL0277
12N     EICR=(MCAER)(DMPG)                          PL0278
6N      ECAER=MNR                                   PL0279
                                                    PL0280
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6N    MCADA=MCAED                                                  PL0283
6N    MCARA=MCAER                                                  PL0284
21N   TPDIF=(1/2)(DTP-RIP)                                         PL0204
12N   EPWP=(DCP)(EPRE)                                             PL0286
12N   EDWP=(DCD)(ECAED)                                            PL0287
12N   ERWP=(DCR)(ECAER)                                            PL0288
12N   ECWP=(DCC)(ECIP)                                             PL0258
6N    EPC2=EP2                                                     PL0076
6N    EDWC=EDW                                                     PL0077
6N    ERWC=ERW                                                     PL0078
6N    ECWCA=EDWC                                                   PL0293
6N    EGRCA=ERWC                                                   PL0294
6N    ESRCA=EPC1                                                   PL0295
6N    MNCA=MNC                                                     PL0297
20N   ETCR=ETCT/RELF                                               PL0343
8N    ETCT=ETC1W+ETC2W+ETC3W                                       PL0344
20N   ETC1W=ETC1S/WFD                                              PL0346
20N   ETC2W=ETC2S/WFD                                              PL0347
20N   ETC3W=ETC3S/WFD                                              PL0348
55N   ETC1S=SUM2(8,W1A,ETC1)                                       PL0349
55N   ETC2S=SUM2(8,W2A,ETC2)                                       PL0350
55N   ETC3S=SUM2(8,W3A,ETC3)                                       PL0351
6N    ETTC=ETCR                                                    PL0355
46N   RELF=(AAPO)(CPPOT)(CICM)/((NF)(1)(1))                        PL0850
6N    TOT=0                                                        PL0454
6N    PTO=0                                                        PL0473
6N    PTO1=0                                                       PL0474
7N    ECWS=PSE+PCS                                                 PL0485
12N   PSE=(ACSS)(EDW)                                              PL0483
12N   PCS=(CAS)(PCA)                                               PL0484
6N    PCA=800000                                                   PL0480
NOTE  INITIAL CONDITIONS FOR ENGINEERING PERSONNEL FOLLOW          PL0892
6N    PETA=PEMRT                                                   DB0250
6N    PEMRA=PEMRT                                                  DB0255
9N    PEMRT=MRFPE+MCAED+MCAER+MNC                                  PL0254
10N   PEUMR=MIRP+EICD+EICR+MNC+PNWP1+0                             PL0255
16N   PNWP1=(DCP)(MRFPA)+(DCD)(MCADA)+(DCR)(MCARA)+(DCC)(MNCA)     PL0256
6N    PERP=0                                                       PL0478
6N    PELT=0                                                       DB0252
12N   PELP=(DFRP)(PEHP)                                            DB0253
NOTE
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NOTE   EQUATIONS FOR FACTORY SECTOR
NOTE
NOTE
NOTE                                                                         DB0176
1L     FSEP.K=FSEP.J+(DT)(ECWS.JK-FSRP.JK)
NOTE   FSEP FACTORY SPECIFICATIONS FROM ENGINEERING IN PROCESS
39R    FSRP.KL=DELAY3(ECWS.JK,DSPF)                                          DB0177
NOTE   FSRP FACTORY SPECIFICATION READY FOR PRODUCTION
3L     FSRPA.K=FSRPA.J+(DT)(1/TSPA)(FSRP.JK-FSRPA.J)                         DB0178
NOTE   FSRPA FACTORY SPECIFICATION READY FOR PRODUCTION, AVERAGE
1L     FUPS.K=FUPS.J+(DT)(FSRP.JK-FPRD.JK)                                   DB0179
NOTE   FUPS FACTORY UNORDERED PRODUCTION SPECIFICATIONS
1L     FUEO.K=FUEO.J+(DT)(FSRP.JK-FECE.JK)                                   DB0180
NOTE   FUEO FACTORY UNFILLED EQUIPMETN ORDERS
51R    FPRD.KL=CLIP(FPRDD.K,FPRM.K,FPRM.K,FPRDD.K)                           PL0759
NOTE   FPRD FACTORY PRODUCTION RATE DECISION
51A    FPRDD.K=CLIP(FSRP.JK,FPRB.K,FUPSD.K,FUPS.K)                           PL0756
40A    FPRB.K=FSRP.JK+(1/DFBA)(FUPS.K-FUPSD.K)                               PL0757
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
NOTE   FEPM FACTORY EQUIPMENT IN PROCESS OF MANUFACTURING
39R    FECE.KL=DELAY3(FPRD.JK,DFPM)                                          DB0189
NOTE   FECE FACTORY EQUIPMENTS COMPLETED AND SHIPPED
3L     FECEA.K=FECEA.J+(DT)(1/TFEA)(FECE.JK-FECEA.J)                         DB0190
NOTE   FECEA FACTORY EQUIPMENT COMPLETED AVERAGE
1L     FAUW.K=FAUW.J+(DT)(FAUWF.J+0)                                         DB0155
NOTE   FAUW  FACTORY ABILITY TO UNDERTAKE WORK
59A    FAUWT.K=TABLE(FWA,FTEI1.K,0,17,0.5)                                   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     27.02/.02/.01/.01/.01/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0/0             DB0135
51A    FTEI1.K=CLIP(FTEI.K,17,17,FTEI.K)                                     DB0151
46A    FTEI.K=(1)(1)(FUPSD.K)/((DNPF)(PFMP.K)(APLF))                         DB0131
NOTE   FTEI FACTORY TIMES TO EXHAUST INVENTORY
18A    FAUWF.K=(ACFAW)(FAUWT.K-FAUW.K)                                       DB2135
C      ACFAW=0.05                                                            DB3135
C      APLF=0.04                                                             PL0838
C      DSPF=1                                                                DB0194
NOTE   DSPF DELAY IN SPECIFICATIONS PROCESS AT FACTORY
C      TSPA=6                                                                DB0195
C      DNPF=3                                                                DB0192
NOTE   DNPF DELAY, NORMAL PLANNING AT FACTORY
```

```
NOTE   DFPM DELAY IN FACTORY PROCESS OF MANUFACTURING
C      TFEA=12                                                    DB0199
NOTE   EQUATIONS FOR FACTORY PERSONNEL FOLLOW                     PL0891
1L     PFMP.K=PFMP.J+(DT)(PFLE.JK-PFLT.JK)                        DB0276
NOTE   PFMP PERSONNEL FACTORY MAN POWER
7A     PFLD.K=PFLD1.K+PFLD2.K                                     DB0277
NOTE   PFLD PERSONNEL FACTORY LABOR DESIRED
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
NOTE   PFCP PERSONNEL FACTORY CHANGE POLICY
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
NOTE   PFLT PERSONNEL FACTORY LABOR TERMINATIONS
1L     PFLP.K=PFLP.J+(DT)(PFHP.JK-PFLE.JK)                        DB0281
NOTE   PFLP PERSONNEL FACTORY LABOR IN PROCESS
39R    PFLE.KL=DELAY3(PFHP.JK,DPFT)                               DB0282
NOTE   PFLE PERSONNEL FACTORY LABOR ENTERING
C      AFTH=50                                                    DB1287
C      AFTH1=5                                                    DB0287
C      DPFT=3                                                     DB0289
NOTE   DPFT DELAY, PERSONNEL FACTORY TRAINING AND RECRUITING
C      TPFR=3                                                     DB0288
C      DFBA=3                                                     DB1288
NOTE   DFBA DELAY FACTORY BACKLOG ADJUSTMENT
NOTE
NOTE
NOTE
NOTE   INITIAL CONDITIONS FOR FACTORY SECTOR
NOTE
NOTE
NOTE
6N     FAUW=0.37                                                  DB4135
12N    FSEP=(DSPF)(ECWS)                                          DB0204
12N    FUPS=(DNPF)(FSRPA)                                         PL0883
6N     FPRB=FSRP                                                  PL0758
```

```
6N     FECEA=FECE                                                        DB0206
NOTE   INITIAL CONDITIONS FOR FACTORY PERSONNEL FOLLOW                   PL0693
20N    PFMP=FSRPA/APLF                                                   DB0283
6N     PFHP=0                                                            DB0285
6N     PFLT=0                                                            DB0284
12N    PFLP=(DPFT)(PFHP)                                                 DB0290
NOTE
NOTE
NOTE
NOTE   EQUATIONS FOR FINANCIAL SECTOR
NOTE
NOTE
NOTE
51A    OCPC.K=CLIP(OCP.K,OCO.K,MAR.K,MPT.K)                              PL0217
NOTE   OCPC OPERATIONS CONTROL PRICE CONSTANT
7A     OCP.K=1-EMR.K                                                     PL0218
51A    MR.K=CLIP(MR1.K,0,MAR.K,MPT.K)                                    PL0912
21A    MR1.K=(1/PETA.K)(MAR.K-MPT.K)                                     PL0911
12A    MPT.K=(PPT)(PETA.K)                                               PL0913
C      PPT=0.02                                                          PL0914
51A    MP.K=CLIP(0.5,MR.K,MR.K,0.5)                                      PL0381
51A    EMR.K=CLIP(0,MP.K,0,MP.K)                                         PL0382
14A    OCO.K=1.3+(-AWR)(R.K)                                             PL0220
C      AWR=0.3                                                           PL0221
17A    OCIE.K=(AERP)(ARE)(CWC.K)+(ARE)(PWC.K)(1)+(0)(0)(0)               PL0222
NOTE   OCIE OPERATIONS CONTROL INCOME ENGINEERING
7A     CWC.K=EDWC.JK+ERWC.JK                                             PL0362
7A     PWC.K=EPC1.JK+EPC2.JK                                             PL0363
7R     OCIT.KL=OCIE.K+OCIF.K                                             PL0299
NOTE   OCIT OPERATIONS CONTROL INCOME TOTAL
7R     OCNPR.KL=OCRP.JK-OCPLT.JK                                         PL0300
NOTE   OCNPR OPERATIONS CONTROL NET PROFIT RATE
1L     OCPL.K=OCPL.J+(DT)(OCRP.JK-OCPLT.JK)                              PL0301
NOTE   OCPL OPERATIONS CONTROL PROFIT LEVDL
13A    OCIF.K=(FECE.K)(OCRPF.K)(ARFI)                                    DB0306
NOTE   OCIF OPERATIONS CONTROL INCOME FACTORY
14A    OCRPF.K=ARFP+(ARITC)(ETIC.K)                                      DB0307
NOTE   OCRPF OPERATIONS CONTROL RATE OF PROFIT FOR FACTORY
7R     OCET.KL=OCEF.K+OCEE.K                   O.C. EXP. TOTAL           DB0309
NOTE   OCET OPERATIONS CONTROL EXPENSES TOTAL
```

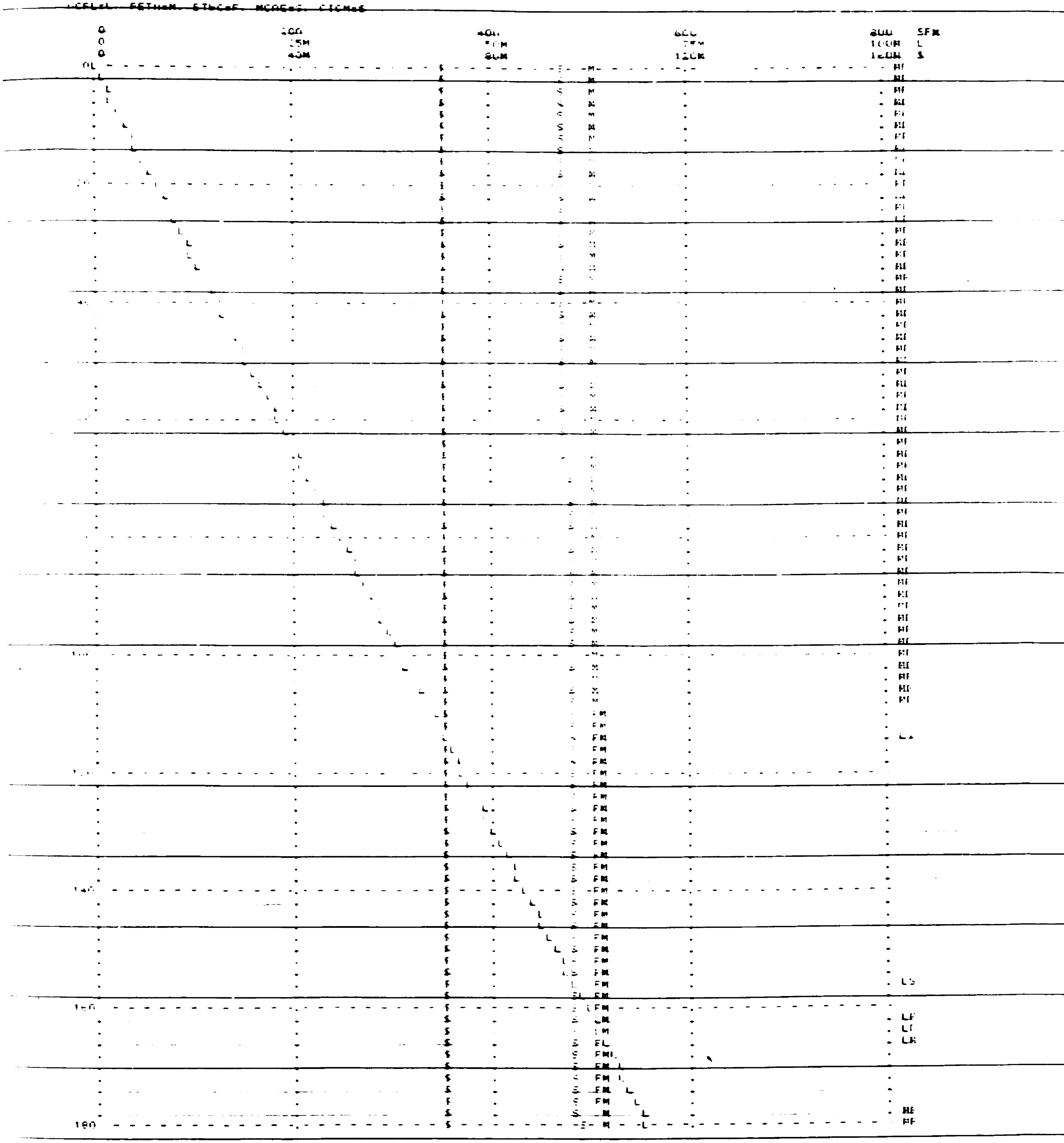
```
PLOT   OCPL=L(0,100E6)/PETA=M(0,800)/ETWC=T(0,600)/MCAE=S(0,800)/CICM=$(0   PL0490
X1     ,160E6)                                                              PL0490
PLOT   MRFPE=P(0,12)/MCAE1=J(0,800)/MCAE2=K(0,800)/EPC1=A(0,24)/EPC2=B(0,   PL0491
X1     24)/CICM=$(0,160E6)                                                  PL0491
PLOT   OCIT=I(0,16E6)/OCET=T(0,16E6)/OCPL=L(0,100E6)/OCIE=U(0,4E6)/OCIF=F   PL0492
X1     (0,16E6)/OCEE=V(0,4E6)/OCEF=D(0,16E6)                                PL0492
PLOT   CPPO=N(0.7,0.11)/OCPC=S(0.6,0.14)/TAUW=G(0.6,1.0)/MESB=H(0.6,0.8)/   PL0493
X1     ETTC=E(0.70,0.86)/EPW1=*(0.5,0.9)                                    PL0493
PLOT   MNP=T,MAPC=4,MNC=C,MACC=7(0,24)/OP=2(-0.1,0.1)/MND=U,MADC=5(0,800)   PL0063
X1     /MNR=V,MAMC=6(0,100)/PETA=M(0,800)                                   PL0063
PRINT  1)PURPT,MESB,MIRP,MPRC,EAUW,CMCO1,CMCO2,EPW1,EPW2,MCAE               PL0094
PRINT  2)ETWC,OCIE,OCIF,OCIT,OCPL,OCEE,OCEF,OCET,OCRP,OCNPR                 PL0095
PRINT  3)PEMRT,PEUMR,ETWC,PEHP,PELP,PELE,PETA,PELT,MAR,PNUM                 PL0096
PRINT  4)ECWS,FSEP,FSRP,FUEO,FUPS,FECE,FPRD,FEPM,FPRM,FAUW                  PL0097
PRINT  5)PFHP,PFLP,PFLE,PFLT,PFMP,PFLD,NDUW,PNUMP,EICD,EICR                 PL0098
PRINT  6)ETET,FTET,ETTC,TAUW,OCPC,ETC1,ETC2,ETC3,CICMA,RELF                 PL0357
PRINT  7)ECWCA,EGRCA,ESRCA,ETC1W,ETC2W,ETC3W,ETCT,ETCR,PERCH,ECHAN          PL0356
PRINT  8)MNP,MND,MNR,MNC,MAPC,MADC,MAMC,MACC,MR,CPPO                        PL0390
PRINT  9)MRFPE,CRFPO,EP2,EPC2,EPC1,EDW,EDWC,ERWC,CCPE1,CCPE2                PL0391
PRINT  10)OP,WWL,MUL,CWC,PWC,PURP,MCAED,MCAER,MARC*1,MARC*2                 PL0041
PRINT  11)ICW,MIRPD,EICDD,EICRD,MNCD,MIBL,EPRE,ECIP,ECAED,ECAER             PL0836
PRINT  12)DDP,DDD,DDR,DDC,DIFP,DIFD,DIFR,DIFC,TIP,TID                       PL0851
PRINT  13)TIR,TIC,TOP,TOD,TOR,TOC,DTPP,DTPD,DTPR,DTPC                       PL0852
PRINT  14)SPDT,TOT,TINP,TIND,TINR,TINC,PDP,PDD,PDR,PDC                      PL0853
NOTE
NOTE
NOTE
NOTE   INPUTS   ,
NOTE
NOTE
NOTE
16R    CICM.KL=(C1)(INP1.K)+(C2)(INP2.K)+(C3)(INP3.K)+(C4)(INP4.K)          DB0012
7A     INP1.K=CICMN+INSTP.K                                                 DB0025
7A     INP2.K=CICMN+INRMP.K                                                 DB0037
7A     INP3.K=CICMN+INIMP.K                                                 DB9038
7A     INP4.K=CICMN+RNDM.K                                                  DB0341
41A    INIMP.K=PULSE(140E6,12,60)                                           PL0904
7A     INRMP.K=INRM1.K+INRM2.K                                              PL0916
47A    INRM1.K=RAMP(700E3,12)                                               PL0903
47A    INRM2.K=RAMP(-700E3,24)                                              PL0915
45A    INSTP.K=STEP(7E6,12)                                                 PL0902
7A     RNDM.K=BIAS+RNDOM.K                                                  DB0342
```

```
C      BIAS=0                                                                              DB0544
NOTE   MANAGEMENT POLICIES (B)
C      TPP*=-0.75/-0.73/-0.68/-0.62/-0.55/-0.44/-0.32/-0.21/-0.12/-0.05/0             PL0600
X1     .00/0.05/0.12/0.21/0.32/0.44/0.55/0.62/0.68/0.73/0.75                          PL0600
C      TPD*=-1.00/-0.96/-0.92/-0.84/-0.75/-0.60/-0.44/-0.28/-0.16/-0.07/0             PL0601
X1     .00/0.07/0.16/0.28/0.44/0.60/0.75/0.84/0.92/0.96/1.00                          PL0601
C      TPR*=-1.00/-0.96/-0.92/-0.84/-0.75/-0.60/-0.44/-0.28/-0.16/-0.07/0             PL0602
X1     .00/0.07/0.16/0.28/0.44/0.60/0.75/0.84/0.92/0.96/1.00                          PL0602
C      TPC*=-0.50/-0.47/-0.44/-0.40/-0.35/-0.28/-0.20/-0.13/-0.08/-0.03/0             PL0603
X1     .00/0.03/0.08/0.13/0.20/0.28/0.35/0.40/0.44/0.47/0.50                          PL0603
C      ITPP*=-1E20/-1E20/-2.00/-0.74/-0.70/-0.59/-0.49/-0.40/-0.30/-0.18/            PL0604
X1     0.00/0.18/0.30/0.40/0.49/0.59/0.70/0.74/2.00/1E20/1E20                         PL0604
C      ITPD*=-1.00/-0.78/-0.65/-0.56/-0.50/-0.44/-0.38/-0.31/-0.23/-0.14/            PL0605
X1     0.00/0.14/0.23/0.31/0.38/0.44/0.50/0.56/0.65/0.78/1.00                         PL0605
C      ITPR*=-1.00/-0.78/-0.65/-0.56/-0.50/-0.44/-0.38/-0.31/-0.23/-0.14/            PL0606
X1     0.00/0.14/0.23/0.31/0.38/0.44/0.50/0.56/0.65/0.78/1.00                         PL0606
C      ITPC*=-1E20/-1E20/-1E20/-1E20/-1E20/-1.00/-0.70/-0.53/-0.40/-0.24/            PL0607
X1     0.00/0.24/0.40/0.53/0.70/1.00/1E20/1E20/1E20/1E20/1E20                         PL0607
                                                                                750

                                                                   TOTAL        750*
```

APPENDIX E

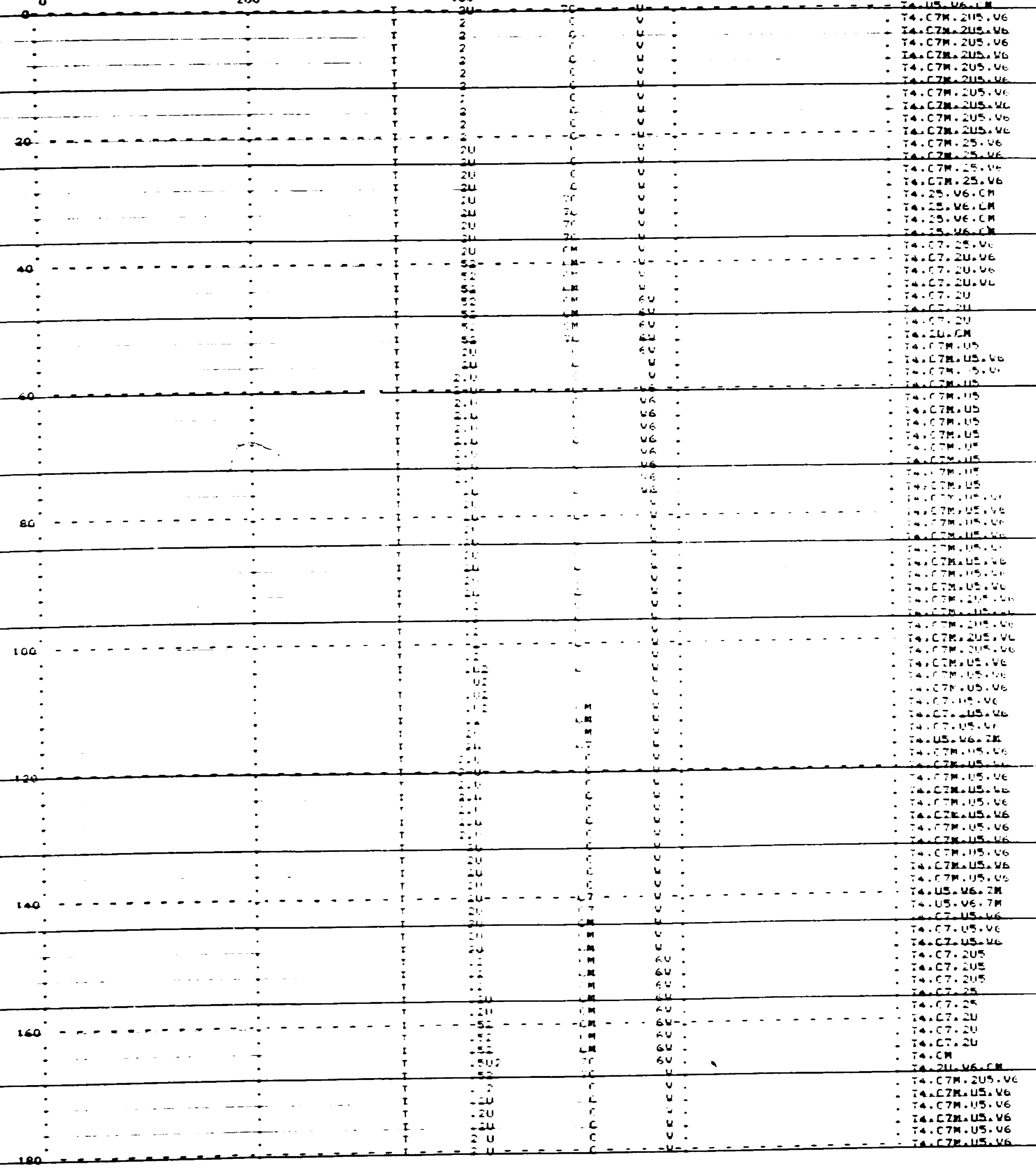
BEGAN PLOTTING AT ... = 2010.3 INDUSTRIAL DYNAMICS. RUN NUMBER 1...(A)



BEGAN PLOTTING AT 5/ 8 2011.2 INDUSTRIAL DYNAMICS. RUN NUMBER 1985PL(A)

MNP=T, MAPC=4, MNC=C, MACC=7, OP=2, MND=U, MADC=5, MNR=V, MAMC=6, BETA=M

-0.1	-0.05	0	0.05	0.1	2
0	6	12	18	24	7C4T
0	25	50	75	100	6U
0	200	400	600	800	M5U

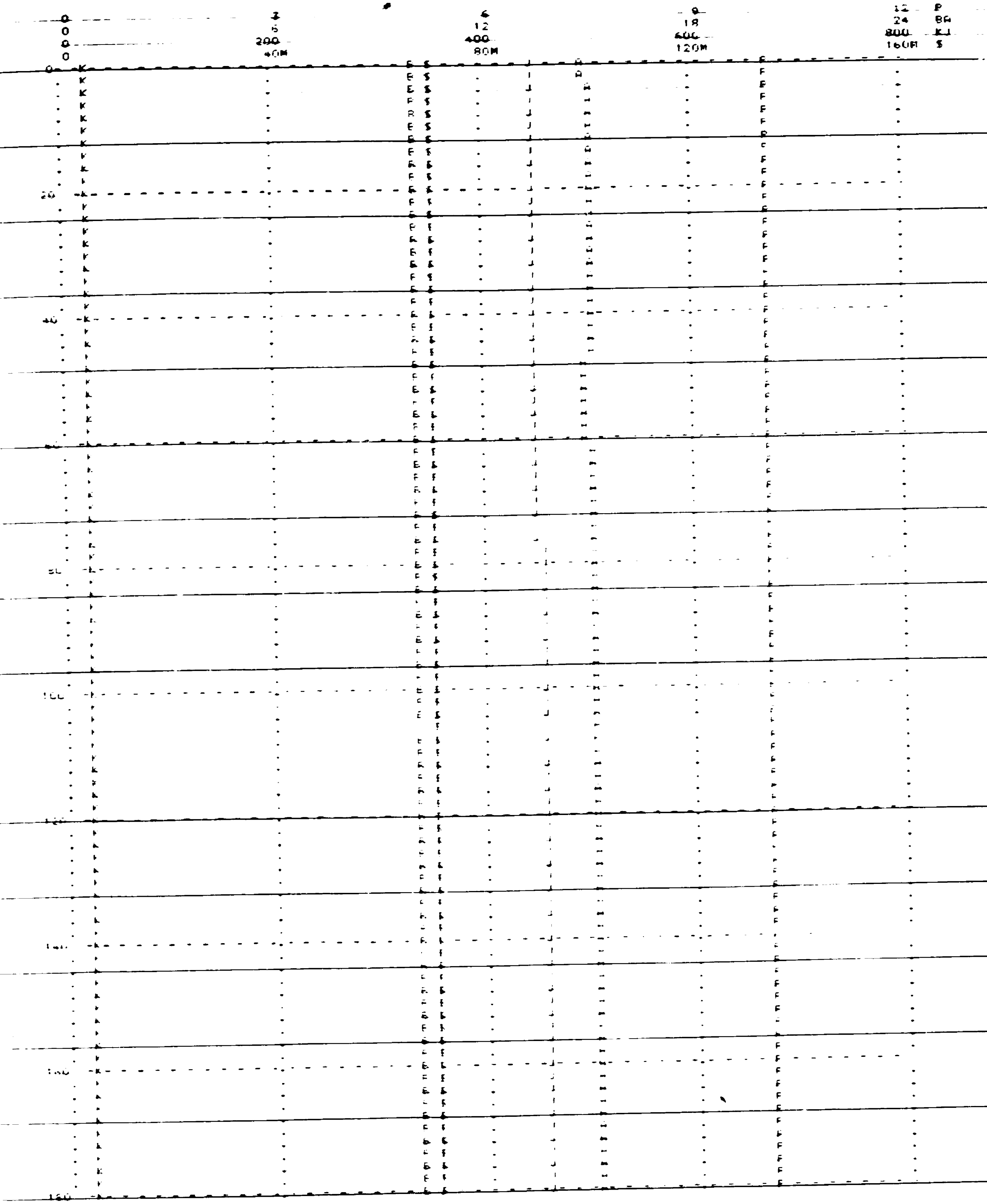


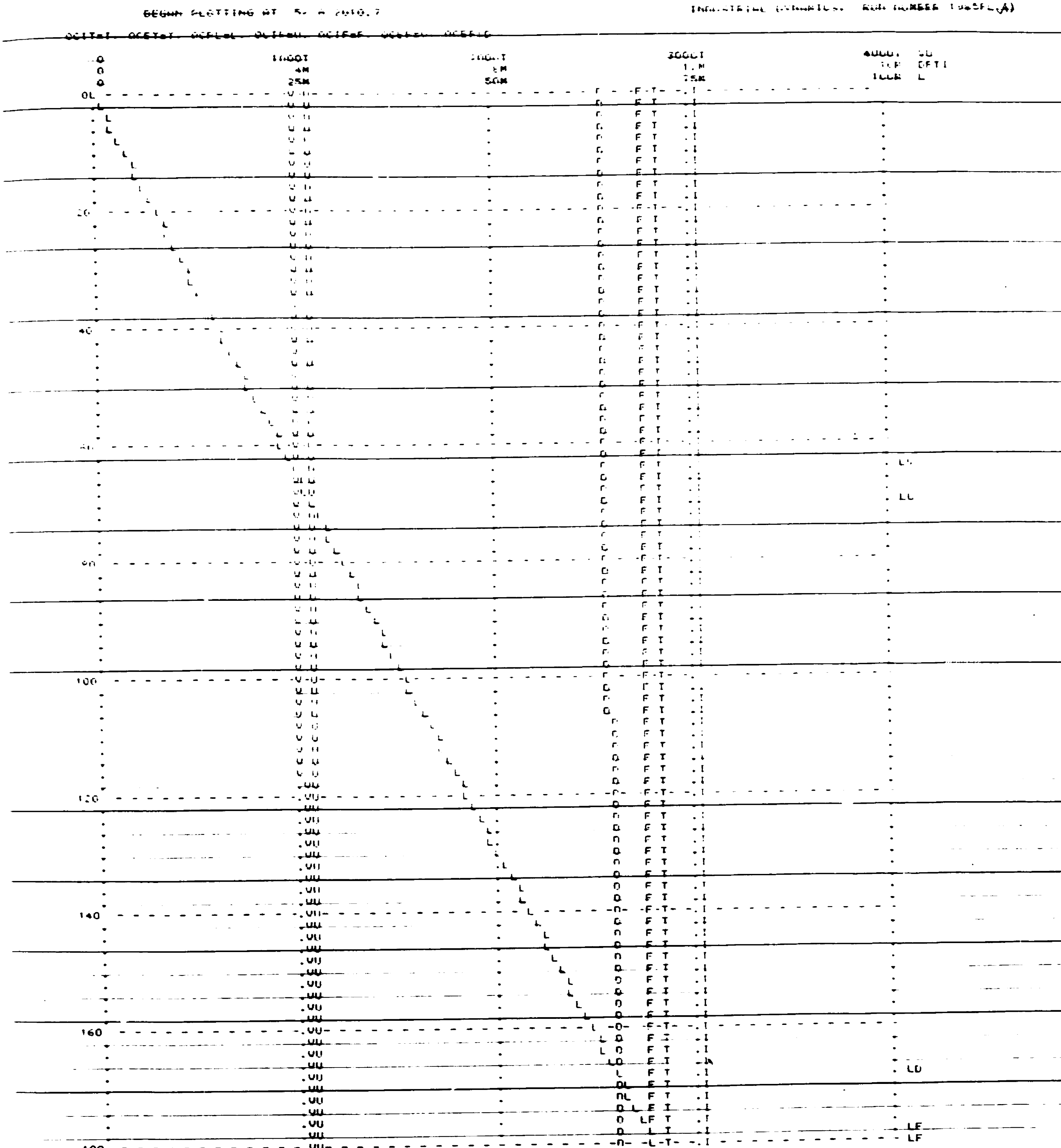
FINISHED RUNNING RUN NUMBER 1985PL AT 5. 8 2011.5

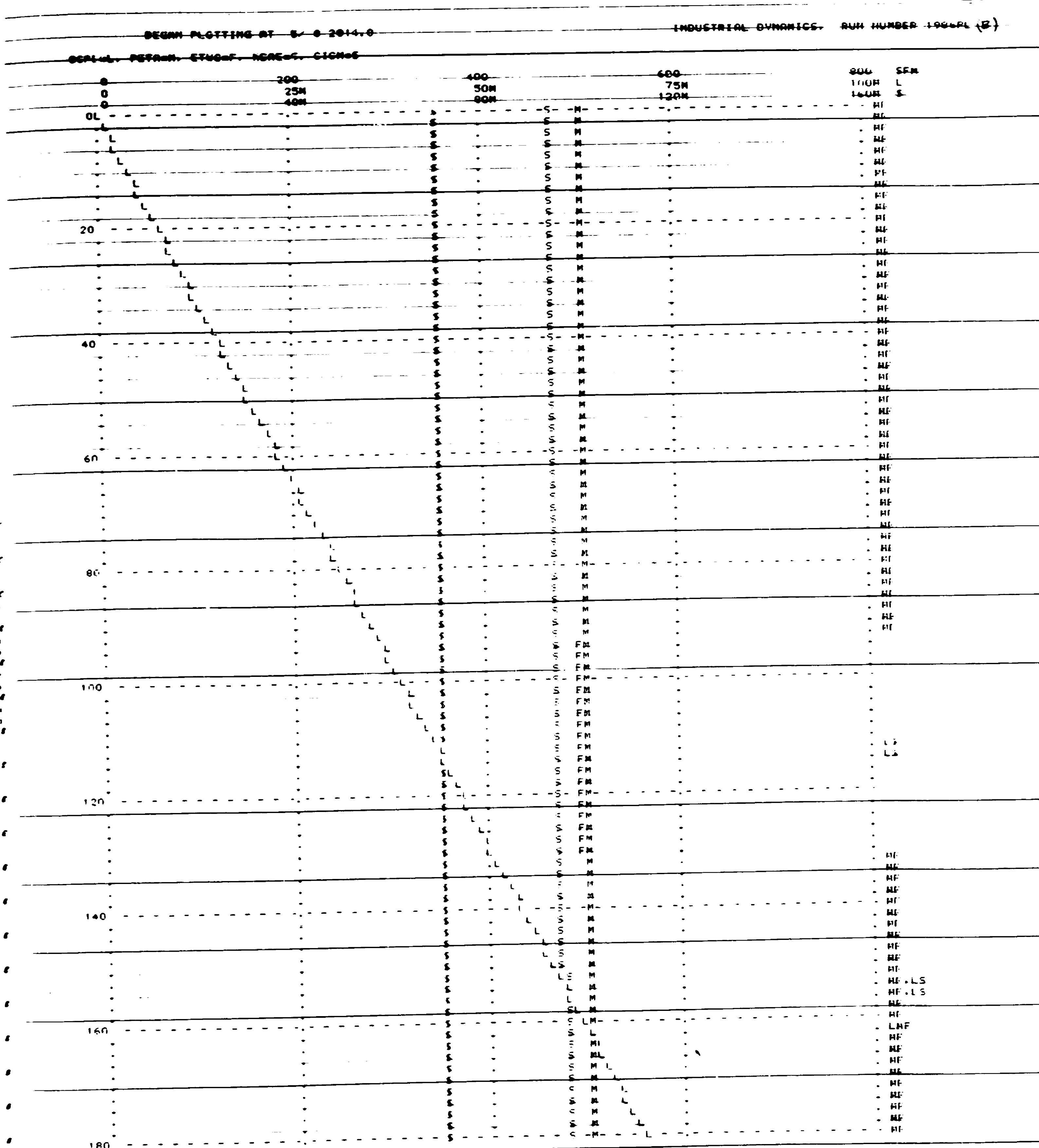
BEGUN PLOTTING AT 5- 6 2010.

INDUSTRIAL DYNAMICS. RUN NUMBER 1985FL A,

MRFPE=P, MCOE1=J, MCOE2=K, EPC1=A, EPC2=E, CICM=$



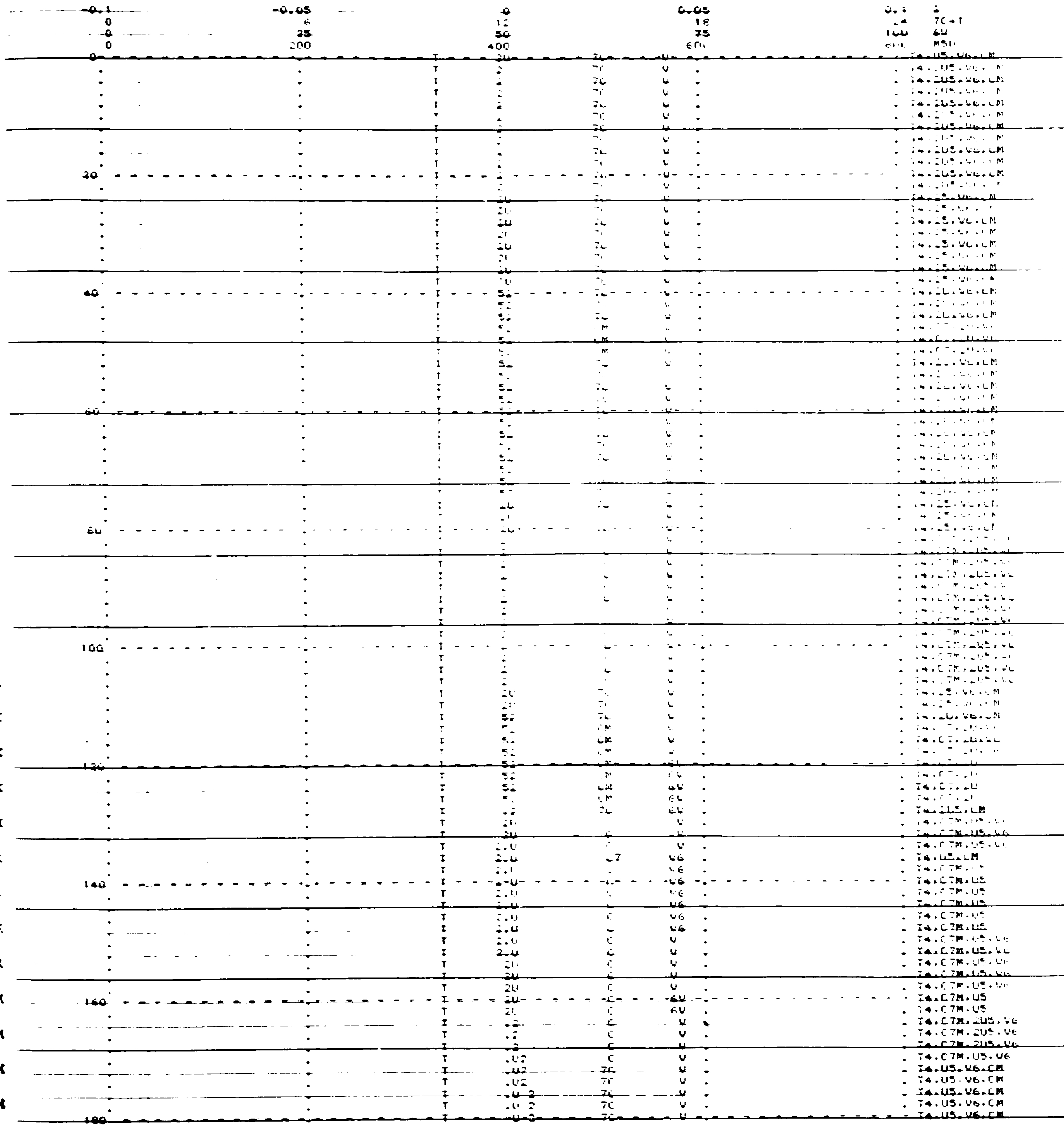

INDUSTRIAL DYNAMICS. RUN NUMBER 1065FL(A)
1000T
4M
25M
3000T
75M
0
20
40
100
120
140
160
180


BEGAN PLOTTING AT 5/ 0 2014.0
INDUSTRIAL DYNAMICS. RUN NUMBER 1964PL (B)
0 200 400 600 800 SFM
0 25M 50M 75M 100M L
0 40M 80M 120M 160M $
0L
20
40
60
80
100
120
140
160
180

BEGAN PLOTTING AT 5- 8 2014.9

INDUSTRIAL DYNAMICS- RUN NUMBER 1736PL (B)

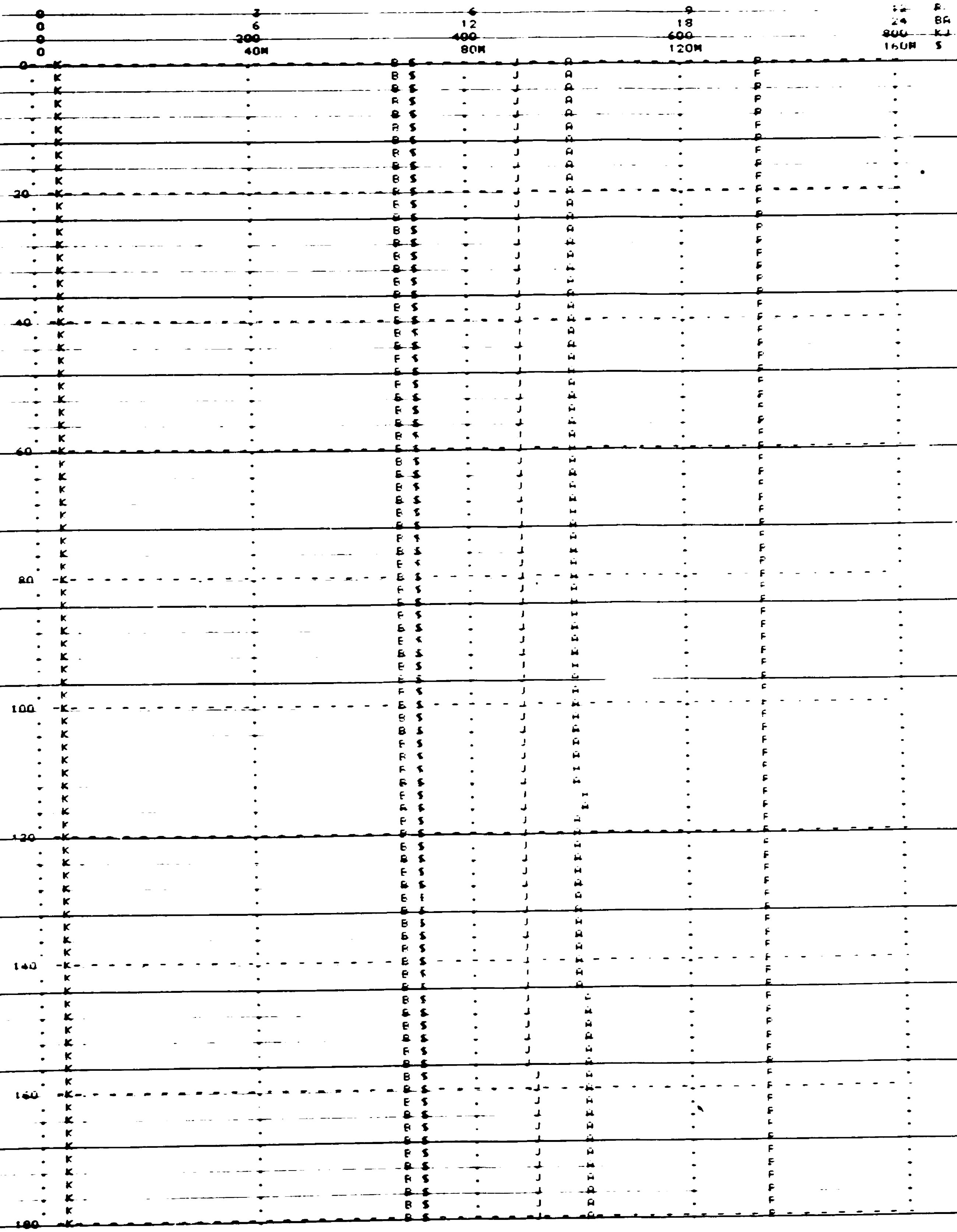
MNP=T, MAPC=4, MNC=C, MACC=7, OP=2, MNO=U, MADC=5, MNR=V, MANC=6, FETA=M



FINISHED RUNNING RUN NUMBER 1736PL AT 5- 8 2015.2

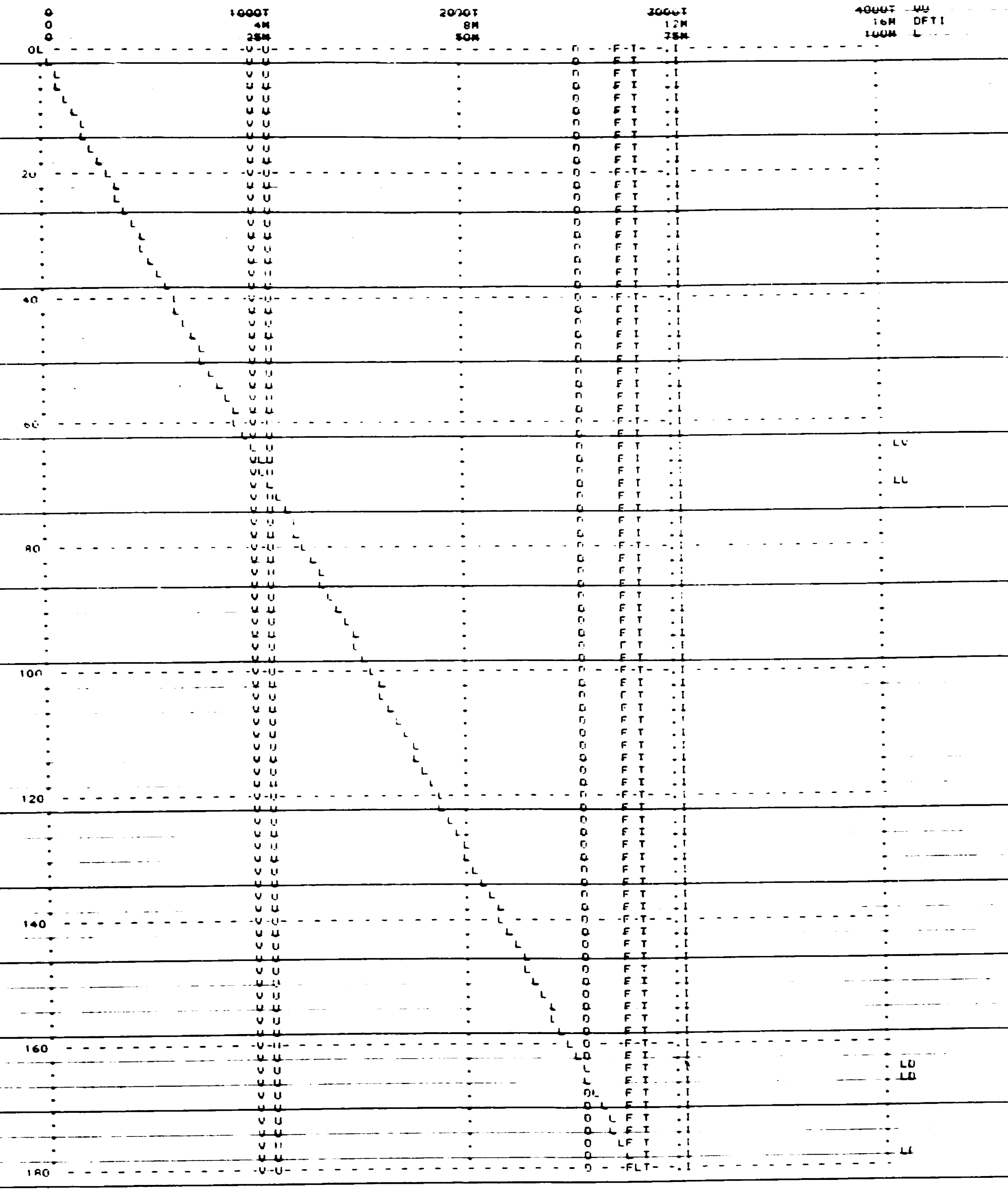
BEGAN PLOTTING AT 5/ 0 2014.2 INDUSTRIAL DYNAMICS, RUN NUMBER 1906PL (B)

MAFPE=P, MBAE1=J, MCAE2=K, EPC1=F, EPC2=B, CICM=$



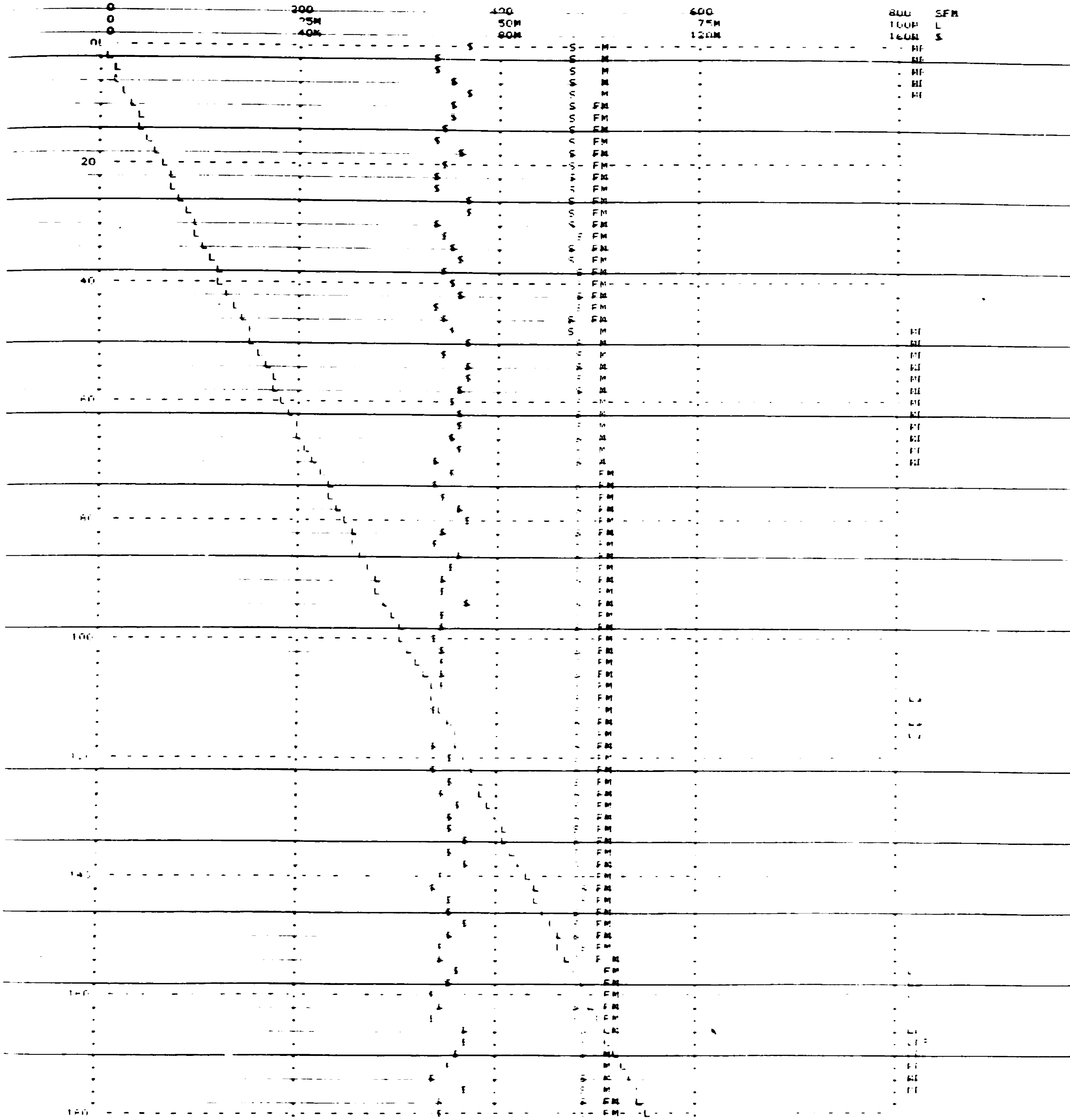
BEGAN PLOTTING AT 5- 0 2014.4

INDUSTRIAL DYNAMICS, RUN NUMBER 1906FL (B)



BEGAN PLOTTING AT 5- 0 2001.0

INDUSTRIAL G-MONTHS. RUN NUMBER 1965FL (A)



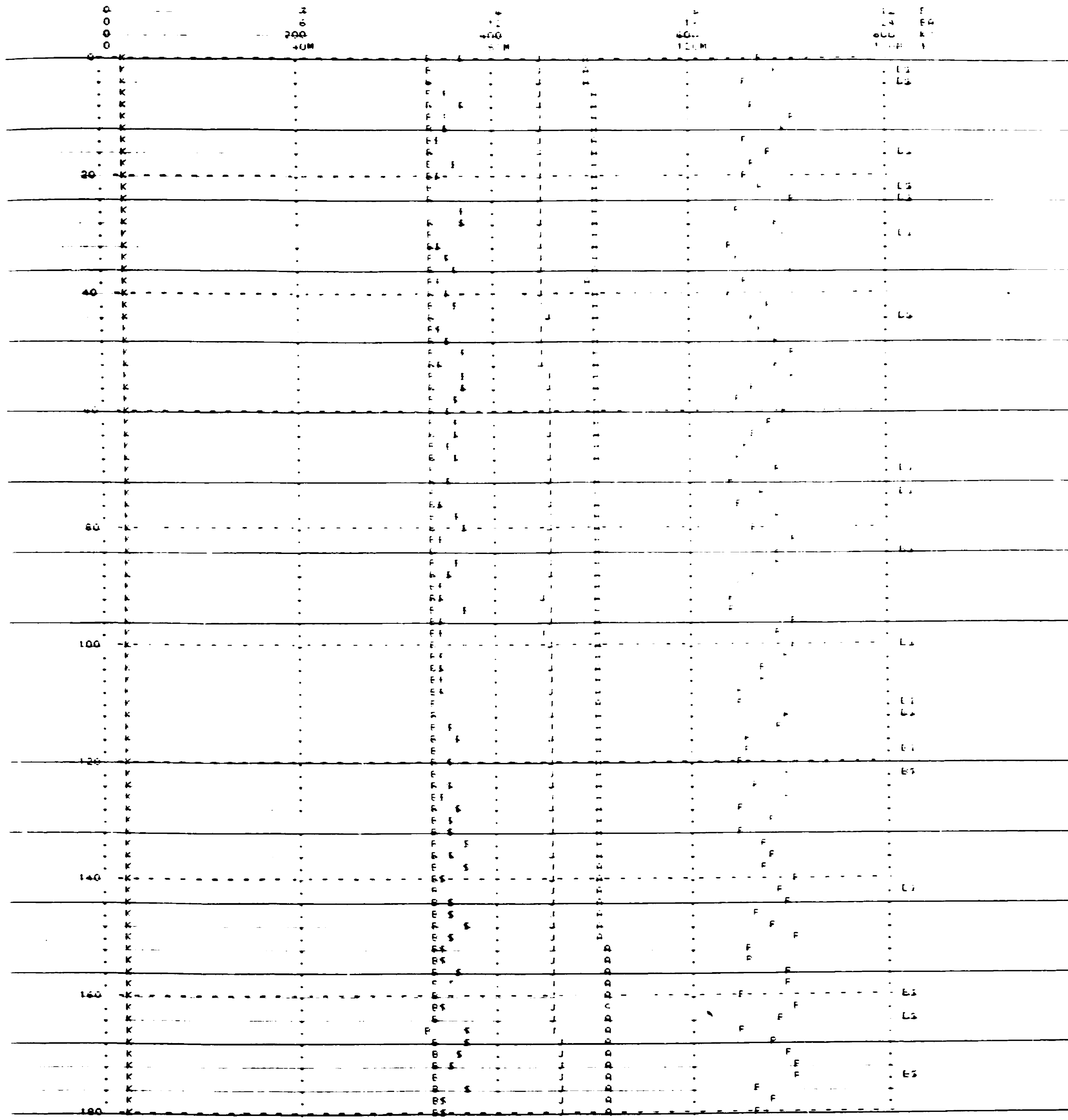
DESPM PLOTTING AT 5/ 8 2002.7 INDUSTRIAL DYNAMICS. RUN NUMBER 1909PL (A)

MNP=T, MRPC=4, MNC=C, MACC=7, OP=2, MNG=U, MSDC=5, MNR=V, MAMC=6, PSTA=M

```
-0.1            -0.05            0            0.05           0.1    2
 0               6               12           18             24     7C4T
 0               25              50           75             100    6U
 0               200             400          600            800    MSU
0 - - - - - - - - - - - - - - I - - 2U - - - 7C - - V - - - - - - - T4.U5.V6.CM
  .             .             T     2U       C     V  .             . T4.C7M.25.V6
  .             .             I     U2       C     V  .             . T4.C7M.U5.V6
  .             .             I     U2       C     V  .             . T4.C7M.U5.V6
  .             .             I     2        C     V  .             . T4.C7M.2U5.V6
  .             .             T     2       7C     V  .             . T4.2U5.V6.CM
  .             .             T     U2      7C     U  .             . T4.U5.V6.CM
  .             .             T     U2      7C     V  .             . T4.U5.V6.CM
  .             .             I     2U       C     U  .             . T4.C7M.25.V6
  .             .             T     52       C     V  .             . T4.C7M.2U.V6
20 - - - - - - - - - - - - - - I - - 2U - - - 7C - - V - - - - - - - T4.25.V6.CM
  .             .             T     U2      7C     V  .             . T4.U5.V6.CM
  .             .             T     25U      C     U  .             . T4.C7M.V6
  .             .             T     52       C     V  .             . T4.C7M.2U.V6
  .             .             T     52       C     U  .             . T4.C7M.2U.V6
  .             .             T     52      7C     6V .             . T4.2U.CM
  .             .             I     5U 2    7C     6U .             . T4.CM
  .             .             T     5U2     7C     6V .             . T4.CM
  .             .             T     52       C     6U .             . T4.C7M.2U
  .             .             T     .2       C     6V .             . T4.C7M.2U5
40 - - - - - - - - - - - - - - I - - .U2 - - - C - - U - - - - - - - T4.C7M.U5.V6
  .             .             T     2U       C     V  .             . T4.C7M.U5.V6
  .             .             T     .2       C     U  .             . T4.C7M.2U5.V6
  .             .             T     2.U      C     U                . T4.C7M.U5.V6
  .             .             T4    2.U      C     U                . C7M.U5.V6
  .             .             T     .U2      C     V  .             . T4.C7M.U5.V6
  .             .             T4    .U       C     U  .             . C7M.U5.V6
  .             .             T     2.U      C     V  .             . T4.C7M.U5.V6
  .             .             I     2.U      C     U  .             . T4.C7M.U5.V6
  .             .             T     2U       C     V  .             . T4.C7M.U5.V6
60 - - - - - - - - - - - - - - 4T - - .2 - - - C - - U - - - - - - - C7M.2U5.V6
  .             .              T    .2       C     V  .             . T4.C7M.2U5.V6
  .             .             T4    2U       C     U  .             . C7M.U5.V6
  .             .             T     .U2      C     6V .             . T4.C7M.U5
  .             .             4T    .5U2     C     6U .             . C7M
  .             .             4T    .5U 2    C     6V .             . C7M
  .             .             T     .2U     CM     6U .             . T4.C7.25
  .             .             T     .52     7C     6V .             . T4.2U.CM
  .             .             I     25U      C     V  .             . T4.C7M.V6
  .             .             T    2 .U5     C     V  .             . T4.C7M.V6
80 - - - - - - - - - - - - - - T4 - 2 .U - - - C - - U - - - - - - - C7M.U5.V6
  .             .             T    2.U       C     U  .             . T4.C7M.U5.V6
  .             .             T    2.U       C     U  .             . T4.C7M.U5.V6
  .             .             4T    .U    2  C     V  .             . C7M.U5.V6
  .             .             T42   .U      C7     U  .             . U5.V6.7M
  .             .             T   2 .U      C7     V  .             . T4.U5.V6.7M
  .             .             T4  2 .U      C7     U  .             . U5.V6.7M
  .             .             T    2.U      C7     V  .             . T4.U5.V6.7M
  .             .             T    2U        M     V  .             . T4.C7.U5.V6
  .             .             T4   2 .U     CM     V  .             . C7.U5.V6
100 - - - - - - - - - - - - - - I - - 2U - - - CM - - U - - - - - - - T4.C7.U5.V6
  .             .             T     2U      CM     V  .             . T4.C7.U5.V6
  .             .             T     2U      CM     V  .             . T4.C7.U5.V6
  .             .             T    2.U      CM     V  .             . T4.C7.U5.V6
  .             .             T     .2      CM     V  .             . T4.C7.2U5.V6
  .             .             T     .2      CM     V  .             . T4.C7.2U5.V6
  .             .             T     .2      CM     6U .             . T4.C7.2U5
  .             .             T     .U 2    CM     6V .             . T4.C7.U5
  .             .             T     .2U     CM     6U .             . T4.C7.25
  .             .             T     .52     CM     6V .             . T4.C7.2U
120 - - - - - - - - - - - - - - T - - .5U 2 - - CM - - 6U - - - - - - T4.C7
  .             .             T     .5U2    CM     6V .             . T4.C7
  .             .             T     .5U 2   CM     6U .             . T4.C7
  .             .             T     .2U     7C     6V .             . T4.25.CM
  .             .             T     .52     7C     6U .             . T4.2U.CM
  .             .             T     .5U2     C     6V .             . T4.C7M
  .             .             T     .52      C     6U .             . T4.C7M.2U
  .             .             T     .2U      C     V  .             . T4.C7M.25.V6
  .             .             T     .52      C     U  .             . T4.C7M.2U.V6
  .             .             T     .52      C     V  .             . T4.C7M.2U.V6
140 - - - - - - - - - - - - - - 4T - - .5U2 - - C - - 6U - - - - - - - C7M
  .             .             T4   2 .5U     C     6V .             . C7M
  .             .             T     .2U      C     6 U.             . T4.C7M.25
  .             .             T     .2U      C     6 V.             . T4.C7M.25
  .             .             I     .5U 2    C     6 U.             . T4.C7M
  .             .             T     .52      C      6V.             . T4.C7M.2U
  .             .             I     .52      C      6U.             . T4.C7M.2U
  .             .             T     .2U     CM      6V.             . T4.C7.U5
  .             .             T     .U2     CM      6U.             . T4.C7.U5
  .             .             T     2 U     CM      6V.             . T4.C7.U5
160 - - - - - - - - - - - - - - I - - 2U - - - CM - - 6U - - - - - - - T4.C7.U5
  .             .             T     2 U     CM     V  .             . T4.C7.U5.V6
  .             .             4T    .U   2  CM     U  .             . C7.U5.V6
  .             .             T    2.5U     CM     V  .             . T4.C7.V6
  .             .             T     .52      C     6U .             . T4.C7M.2U
  .             .             4T    .5U 2    C     6 V.             . C7M
  .             .             I     .5U  2   C     6 U.             . T4.C7M
  .             .             T     .5 U 2  7C     6  V             . T4.CM
  .             .             I     .5 U  2 7C     6  U             . T4.CM
  .             .             T     .5 2    CM     6 V              . T4.C7.2U
180 - - - - - - - - - - - - - - 4T - - 5U- 2 - - 7C - - 6 V - - - - - - CM
```

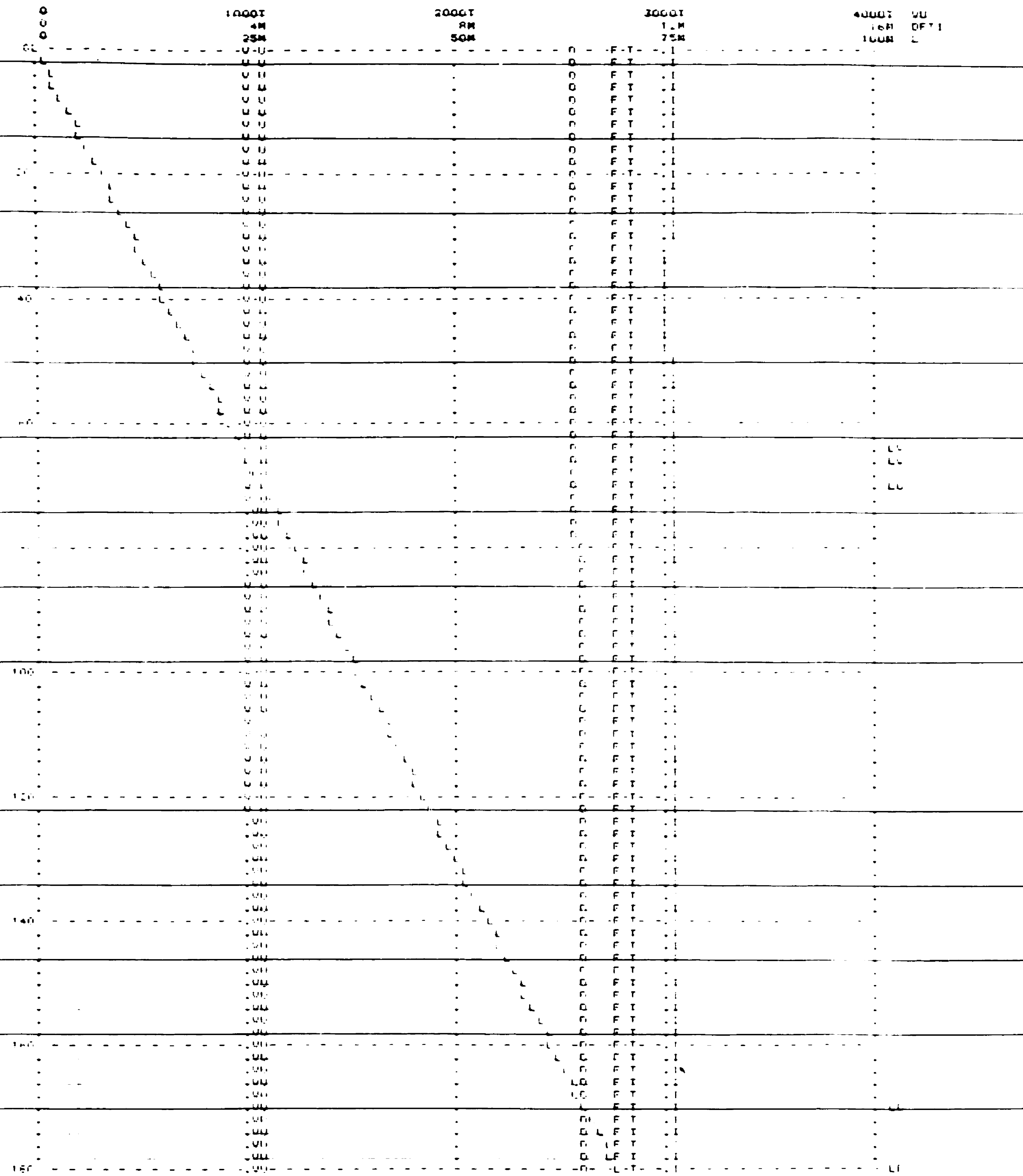
FINISHED RUNNING RUN NUMBER 1309PL AT 5/ 8 2003.0

BEGAN PLOTTING AT 5- 6 2002.0



BEGAN PLOTTING AT 5- 6 2001.3 INDUSTRIAL DYNAMICS. RUN NUMBER 1V6UPL(A)

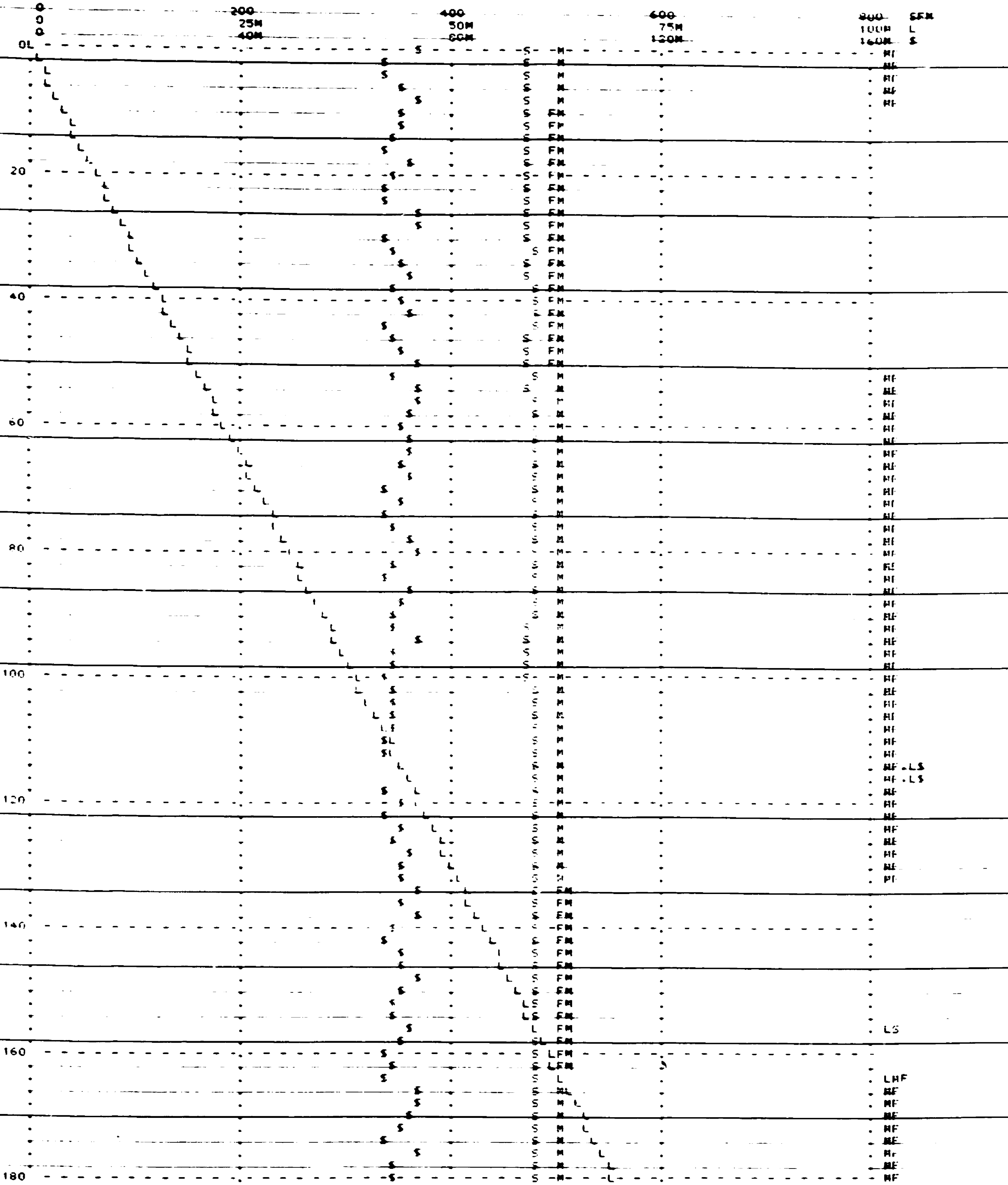
OCITS=I, OCFTS=T, OCPLS=L, OCIES=U, OCIFS=F, OCEES=L, OCEFS=D



BEGAN PLOTTING AT 5- 8 2006.6

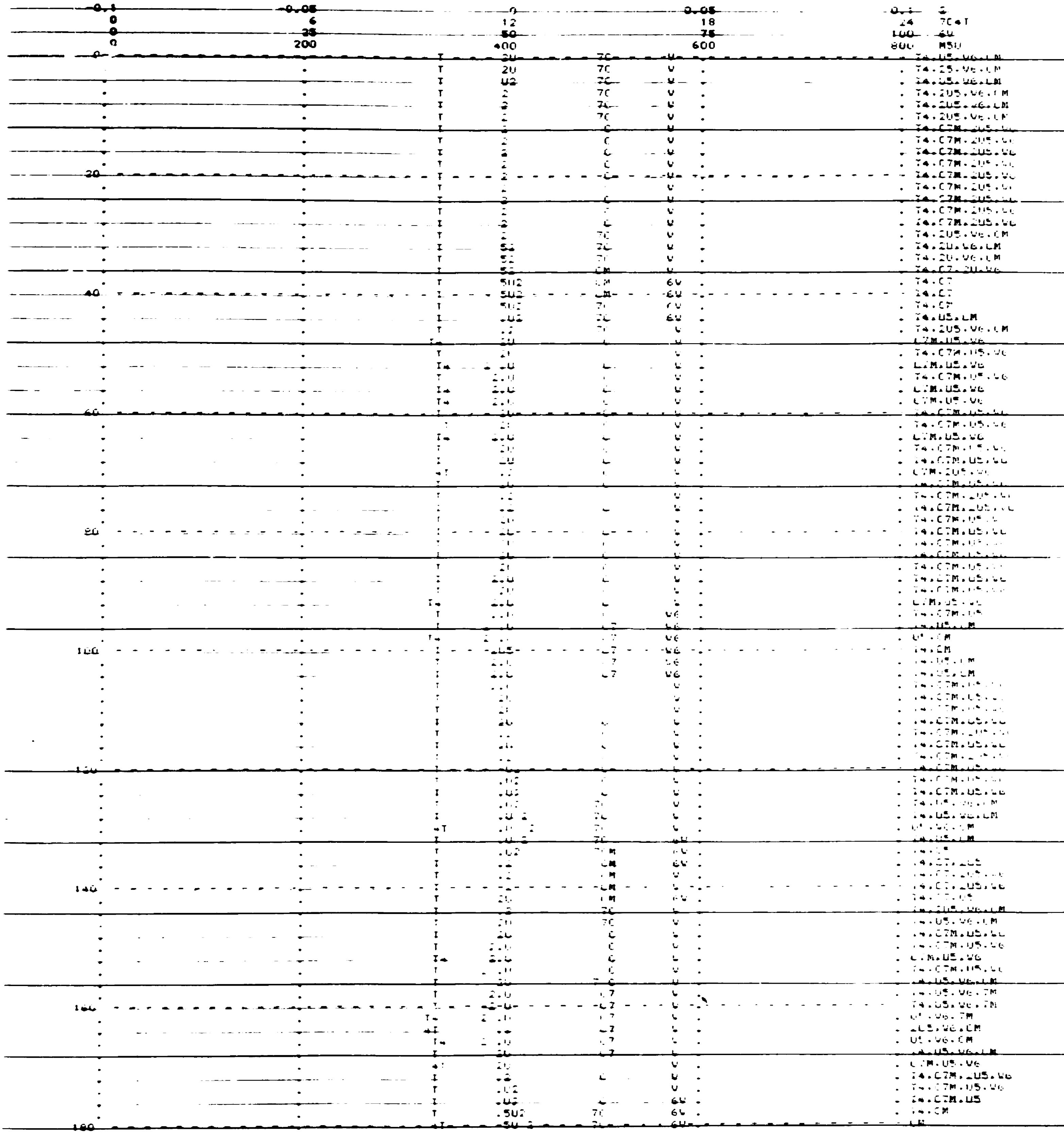
INDUSTRIAL DYNAMICS. RUN NUMBER 1990PL(B)

OCPL=L, PETA=M, ETNG=F, NCAE=S, CICN=$



BEGAN PLOTTING AT 5/ 8 2006.5 INDUSTRIAL DYNAMICS, RUN NUMBER 1990FL (B)

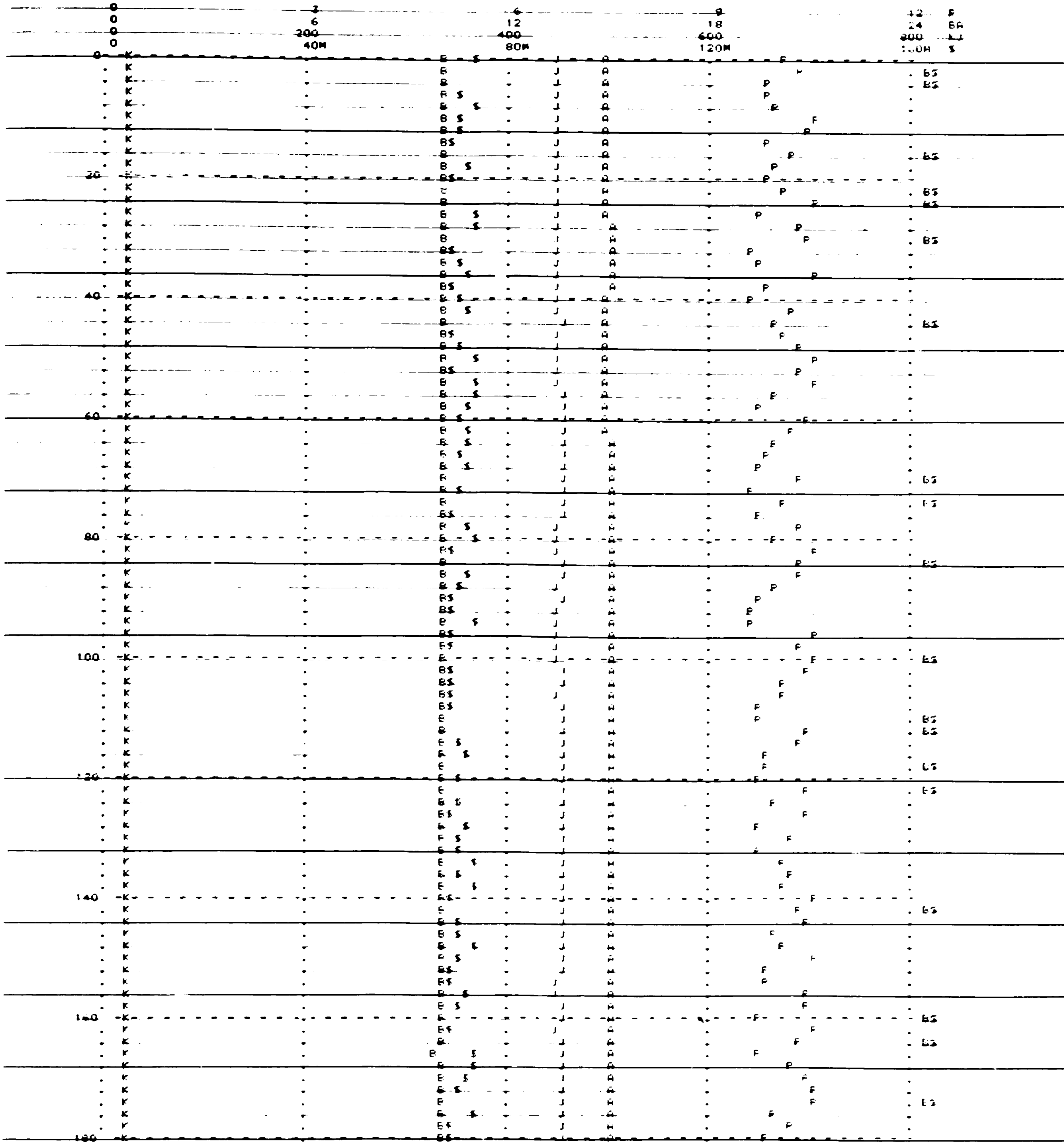
MNP=T, MAPC=1, MNC=C, MACC=7, OP=2, MND=L, MADC=5, MNR=V, MANC=, FETO=M



FINISHED RUNNING RUN NUMBER 1990FL AT 5/ 8 2006.6

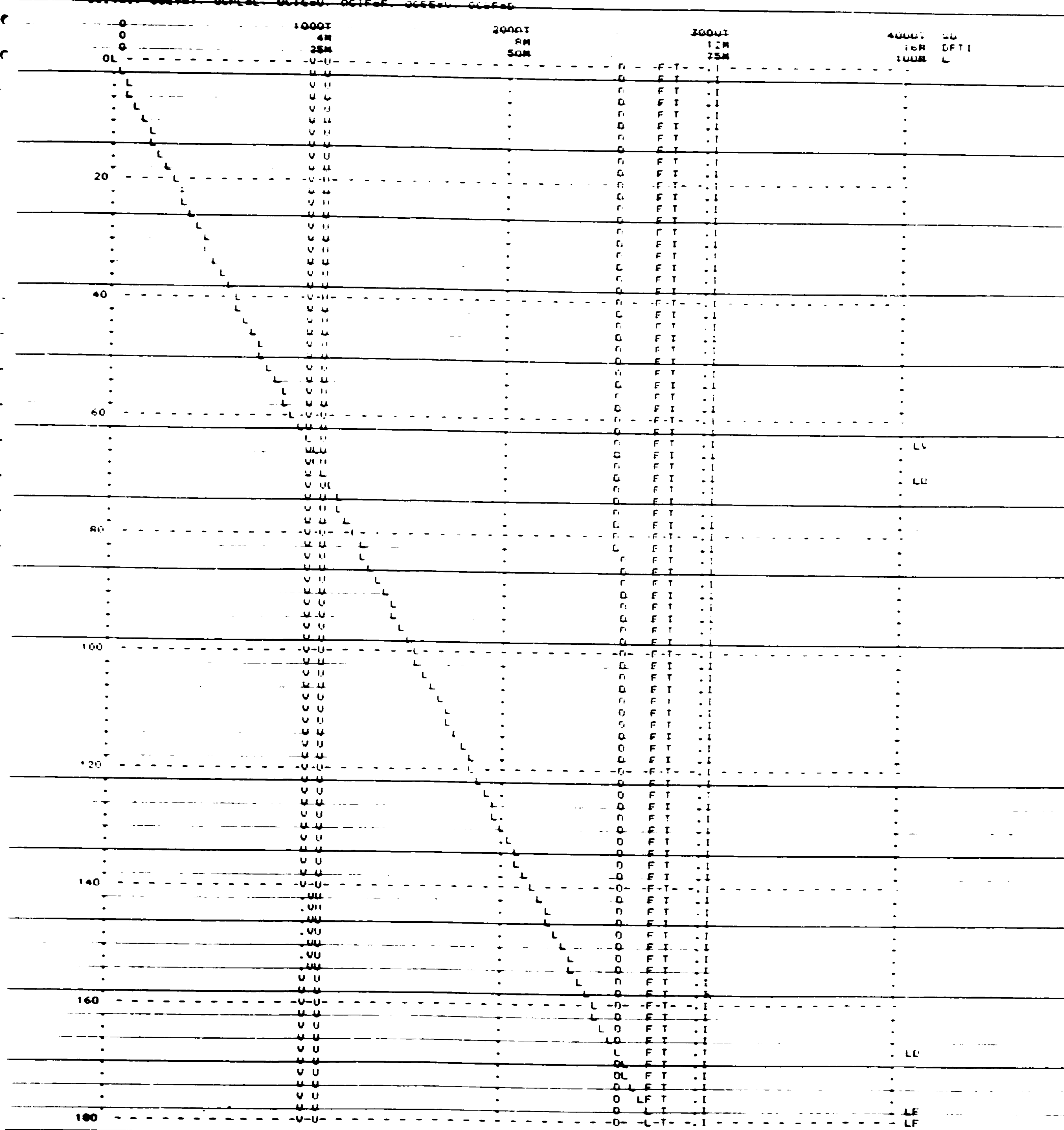
BEGAN PLOTTING AT 5/ 0 2005.0 — INDUSTRIAL DYNAMICS. RUN NUMBER 1940FL(B)

MRFPE=P, MCAE1=J, MCAE2=K, EPC1=A, EPC2=B, CICM=$



BEGAN PLOTTING AT 5- 0 2006.0

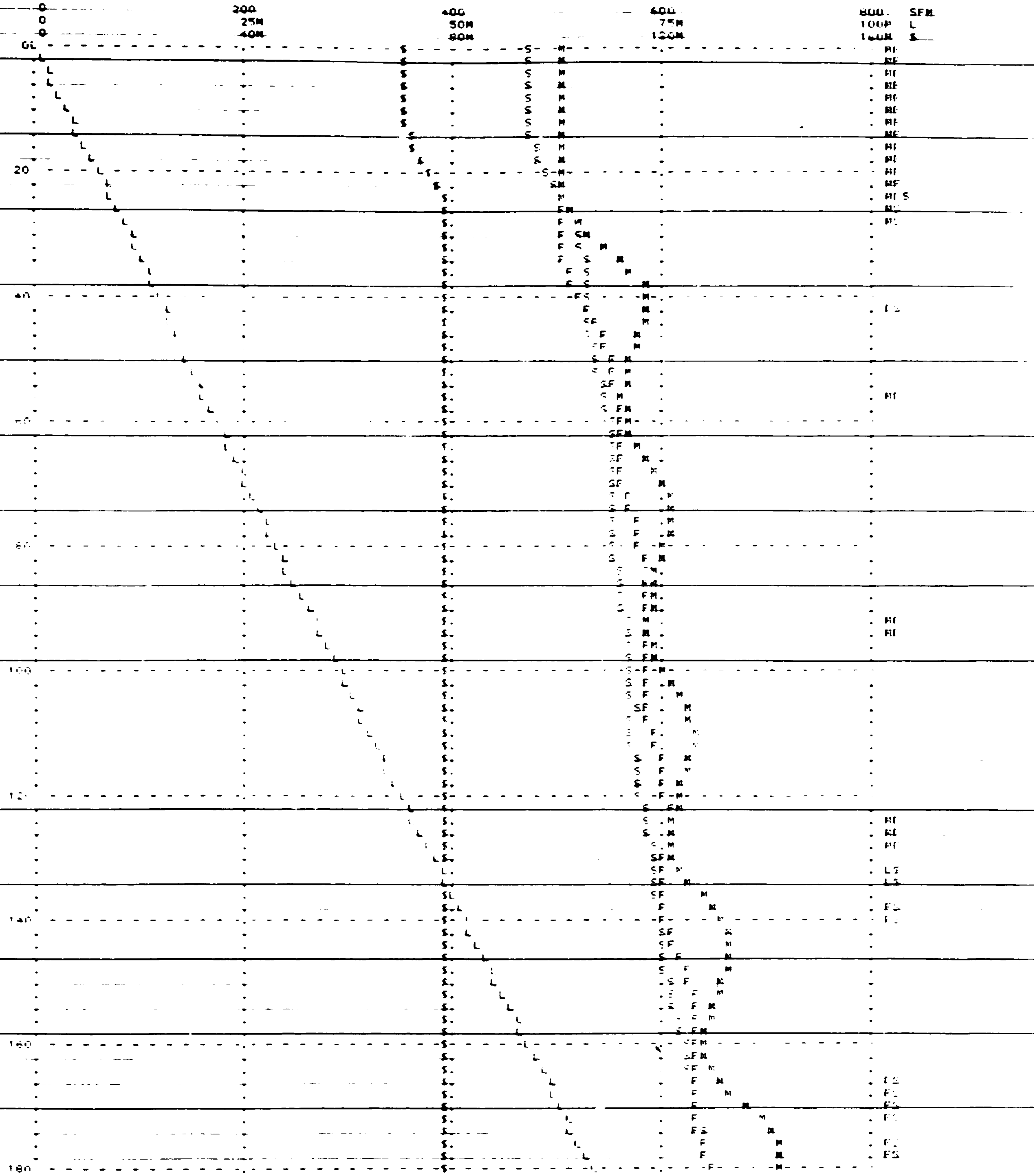
INDUSTRIAL DYNAMICS. RUN NUMBER (B)



BEGUN PLOTTING AT 5. 0 2016.7

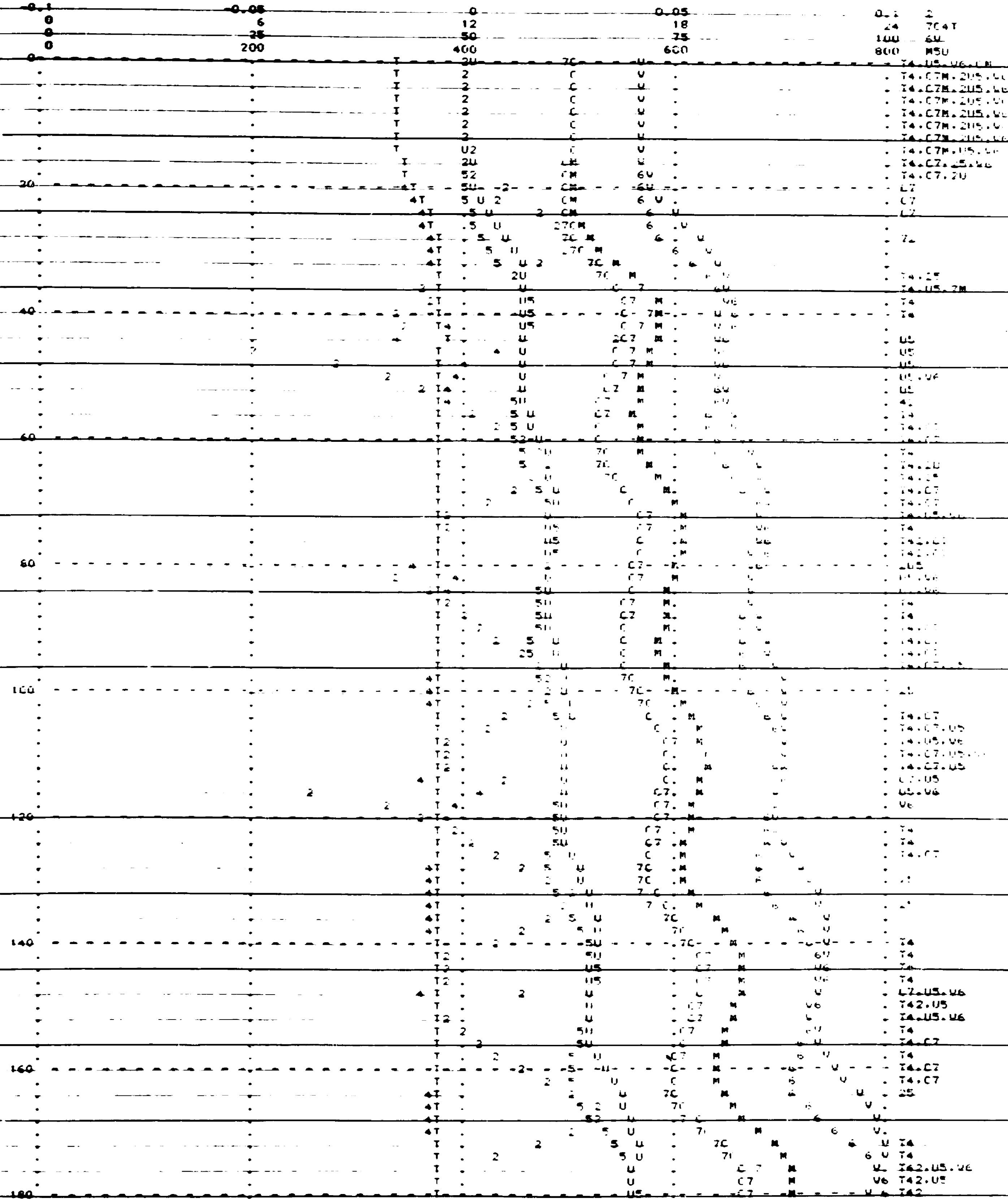
INDUSTRIAL DYNAMICS. RUN NUMBER 1967FL.A)

OCPL=L, BETA=M, ETWC=F, MCOE=S, CICM=$



BEGAN PLOTTING AT 5/ 8 2019.6 — INDUSTRIAL DYNAMICS. RUN NUMBER 1467RL (A)

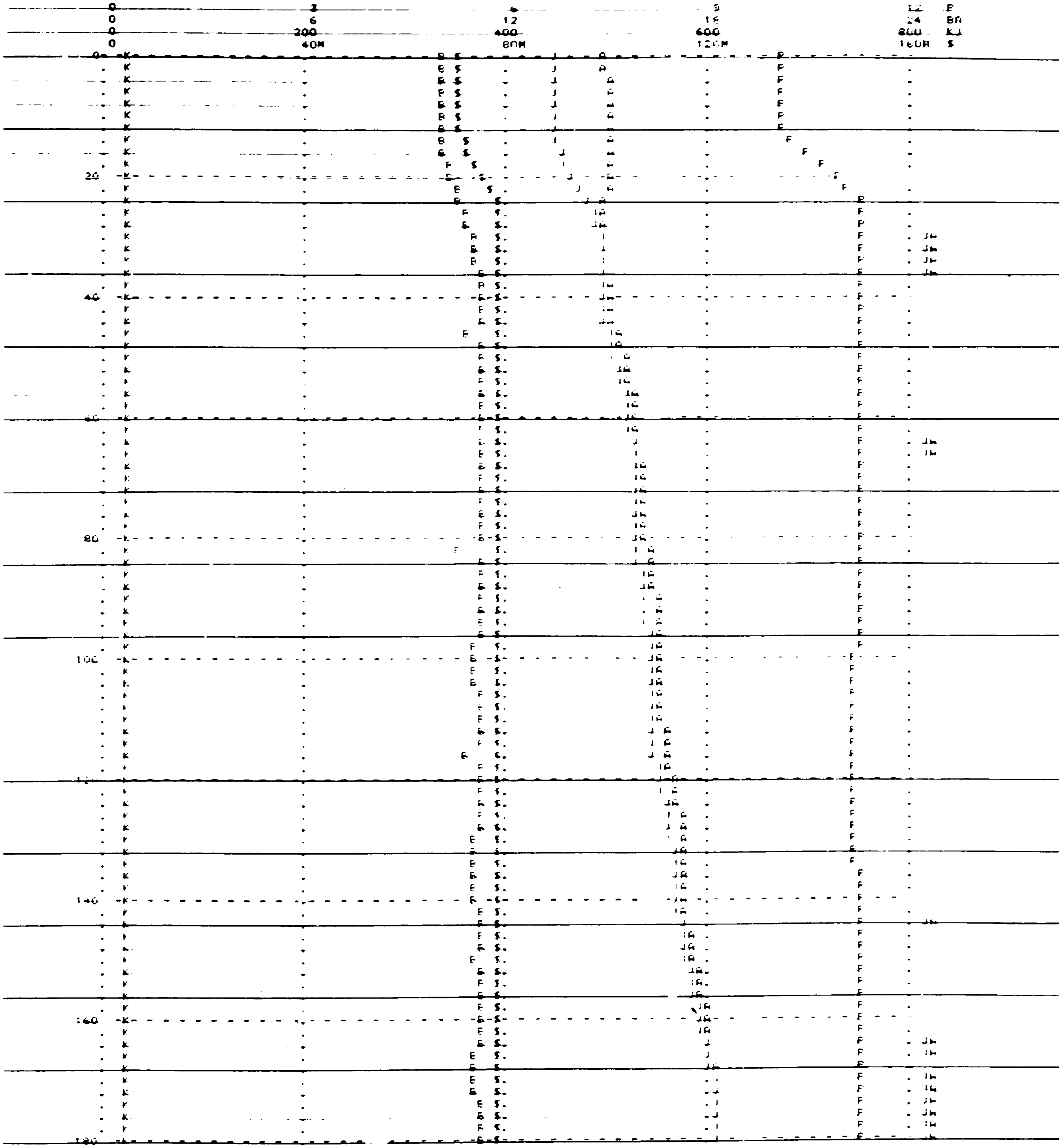
MNP=T, MAPC=4, MNC=C, MACC=7, OP=2, MND=J, MAPC=5, MNR=U, MAMC=6, PETA=M

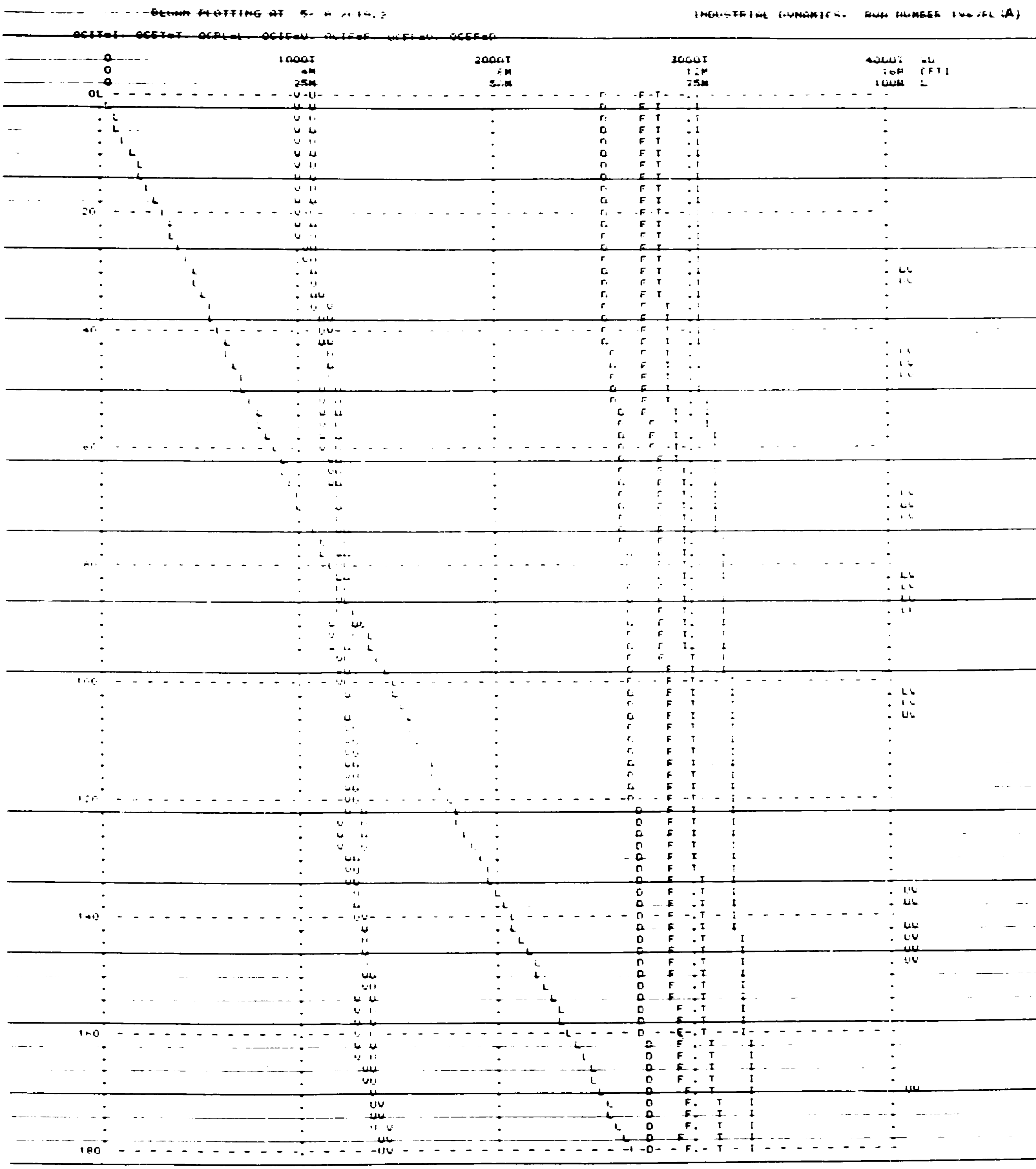


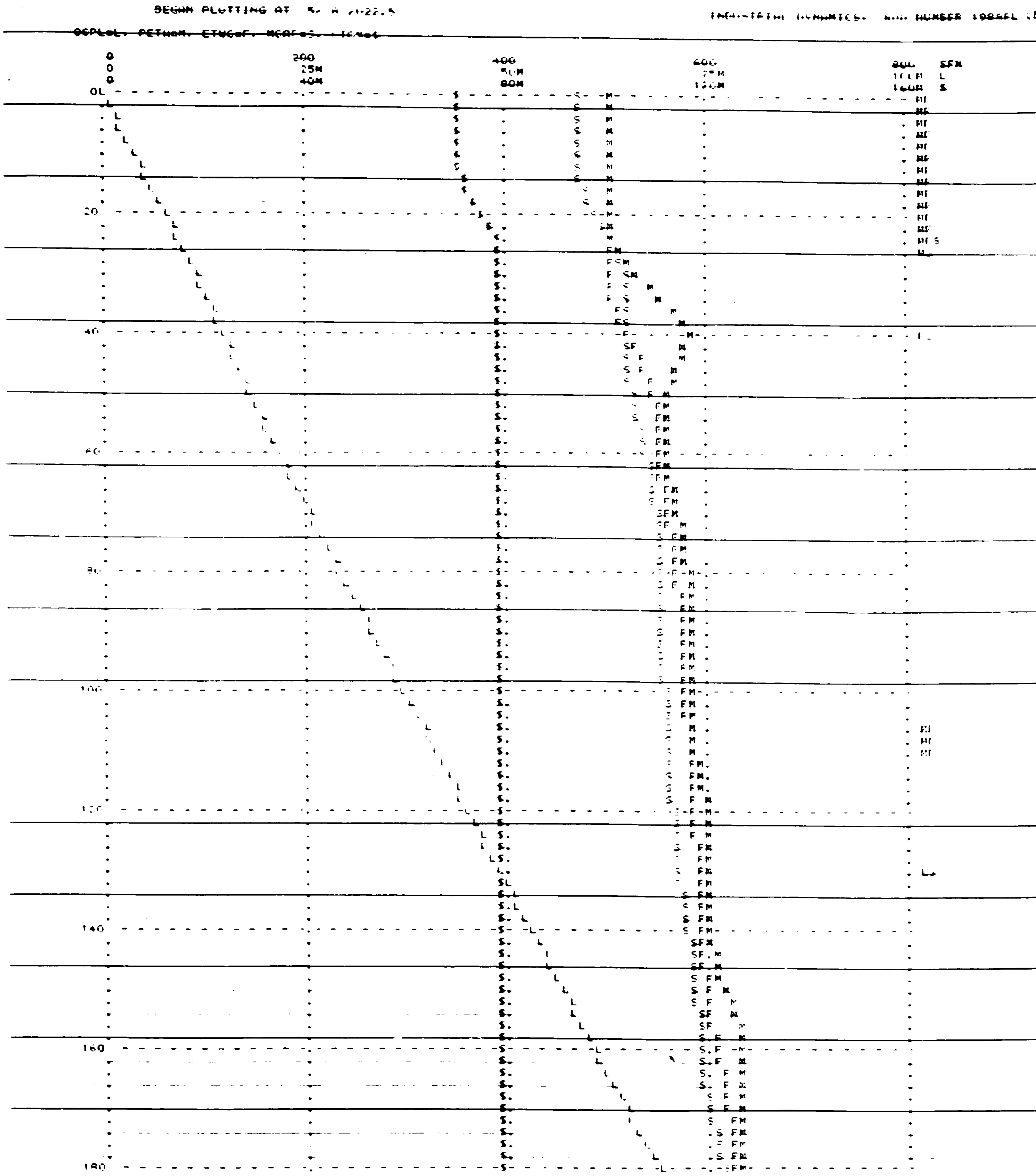
FINISHED RUNNING RUN NUMBER 1387RL AT 5/ 8 2019.9

BEGAN PLOTTING AT 5/ 8 2018.9 INDUSTRIAL DYNAMICS. RUN NUMBER 1982EL (A)

MRERE=R, MCAE1=J, MCAE2=K, EPC1=A, EPC2=E, CICM=$



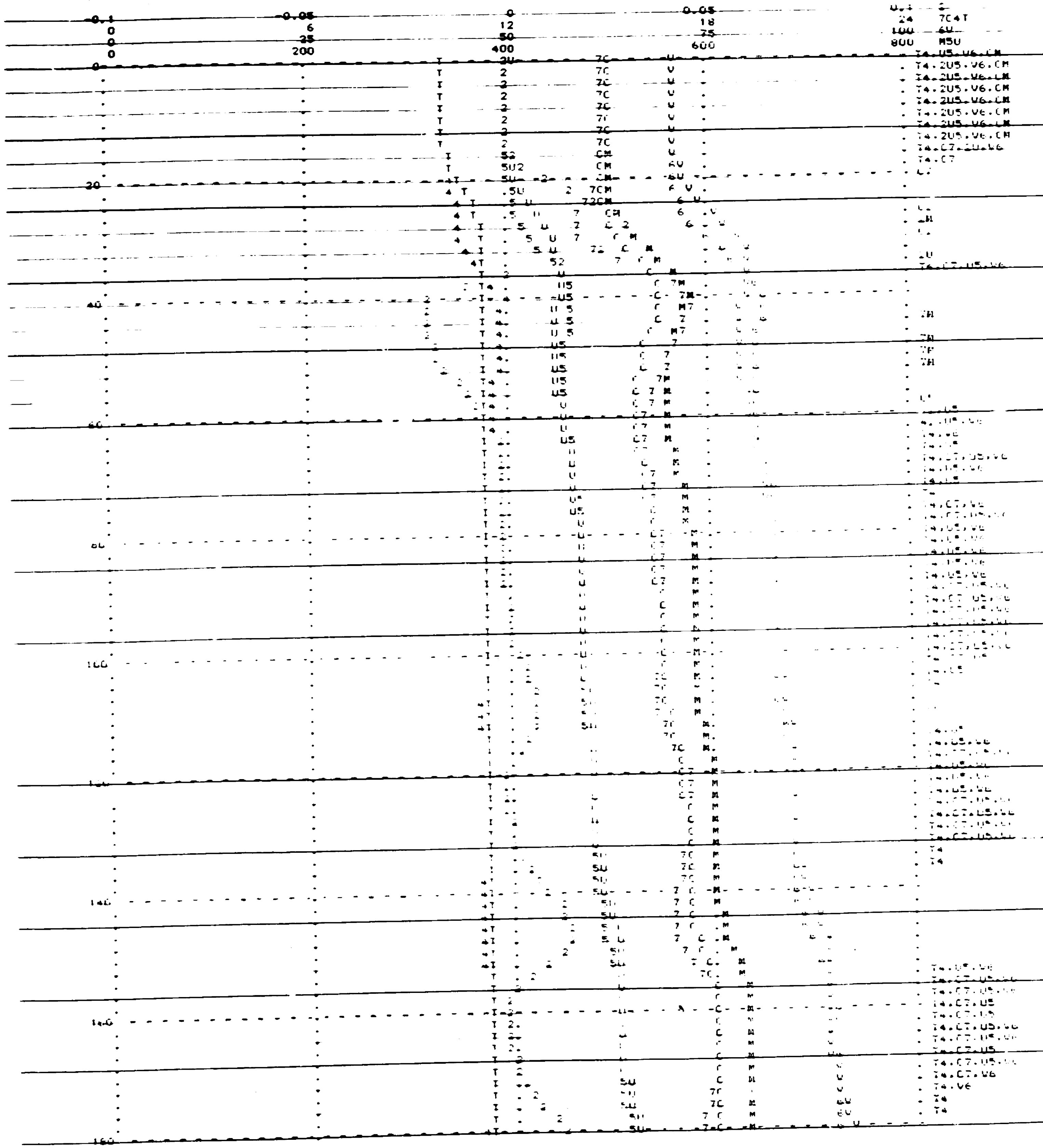

INDUSTRIAL DYNAMICS. RUN NUMBER (A)
0 1000T 2000T 3000T 4000T
0 4M 8M 12M 16M
0 25M 50M 75M 100M
0L
20
40
60
80
100
120
140
160
180


BEGAN PLOTTING AT
INDUSTRIAL DYNAMICS. RUN NUMBER
0
200
25M
40M
400
50M
80M
600
120M
800
SFM
L
$
20
40
60
80
100
140
160
180

BEGAN PLOTTING AT 5/ 8 2023.4

INDUSTRIAL DYNAMICS. RUN NUMBER 1966FL (B)

MNP=T, MAPC=4, MNC=C, MACC=7, OP=2, MND=U, MADC=5, MNR=V, MANC=6, PETA=M



FINISHED RUNNING RUN NUMBER 1966FL AT 5/ 8 2023.7