A STUDY OF RESEARCH AND DEVELOPMENT MANAGEMENT SYSTEM

by

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INTRODUCTION

The purpose of this report is to study and understand the research and development management system and its dynamic behavior. The report is mainly based on the Ph.D thesis done by Roberts (3) from M.I.T. . An attempt is made to summarize the mathematical model developed by Roberts. Some modifications are made in the flow diagrams for each activity in order to simplify the model and to simulate the possible structure for failures of R and D management.

Roberts (3) used a quantitative approach to represent the life cycle of R and D organization. He used the Industrial Dynamics approach to study R and D systems. Throughout his simulation work Roberts used DYNAMO language. The model consists of about 200 variables, 40 initial conditions and approximately 70 constants. To understand the details of Roberts' model his simulation results are reproduced. Also some changes are made in the structure of R and D to simulate the reasons for failures of R and D management.

Much of the literature available on R and D systems deals with qualitative rather than quantitative approaches for R and D management systems.

Hamberg (21) in his book' R & D Essays on the Economics of Research and Development' described the statistical analysis of the determinants of the research and development in industry. Howard (22) gave a descriptive approach to R and D organizations in his book. His approach is mainly concerned to those people in the organization who actually perform the work of managing the establishment. Marschak, Glennan, and

Summers (23) studied the strategy of a development project and the procedure for allocating and re-allocating the project resources among various learning possibilities as the project unfolds and information accumulates. Gerstenfled (24) investigated the relationship between marketing and R and D by examining the outcomes of 91 R and D projects.

In a collection of papers published by American Management Association (25), the utilization of unused technology was described. Shannon (26) in his Ph.D thesis described more about the crucial management decisions of the project selection, evaluation, and allocation of resources to them. Souder (28) developed a model to evaluate the suitability of the various existing R and D models. He developed a list of 36 operationally defined characteristics within five criteria for evaluating management science model. Based on these characteristics and criteria, Souder evaluated the suitability of using the 41 existing operations research models in risky investment planning and decision making.

Most of the works cited above give descriptive approaches to the R and D systems. Some of them give quantitative approaches to certain activities like resource allocations, progress control etc., but not the entire activities together. Dean (27) edited '<u>Operations Research in Research and Development</u>' which is a collection of papers on problems of management systems such as measurement of value of scientific information, measurement of scientific research and development and related activities etc..

Chapter 1 in this report describes some of the structures used by the PERT and PERT/COST approaches and possible reasons for failures of systems based on such structures. Also Roberts' (3) Industrial Dynamics approach to study R and D project life cycle is described and the various activities that are taking place in the project life are summarized. The various activities in the project life are 1) perception of product value by both firm and customer, 2) estimation of effort and cost by both firm and customer, 3) funding of the project, 4) acquisition and utilization of man-power and 5) control of R and D progress.

Chapter 2 describes the various factors that are influencing the activities of R and D project life cycle.

Chapters 3,4,5,6, and 7 describe the flow diagrams and DYNAMO equations for the above activities respectively. The various modifications made in the flow diagrams are explained at the end of each chapter. For understanding the diagram symbols and notations used in equations in these Chapters, the author suggests the reader to go through Chapter 1, part 1 of reference 3 or Chapters 1 through 10 of reference 18 or Chapter 2 of reference 17.

Chapter 8 presents the results and discussion of the modified model and a comparison of the results from that of Roberts' model.

CHAPTER 1

STRUCTURE OF RESEARCH AND DEVELOPMENT ORGANIZATIONS

In this chapter, the basic structures used by PERT and PERT/COST approaches to represent the Research and Development organizations are explained and the possible reasons for failure of R and D organizations based on such structure are pointed out. Later in this chapter, the structure used by Roberts (3) to represent the dynamic system of R and D organizations is described and the various activities that are taking place in R and D organizations are summarized.

Before an insight is made into the structure of R and D organizations, it is very much essential to know the basic structure of any organization as viewed by the Industrial Dynamics. Industrial Dynamics treats any organization as a control system. In general, every organization will have definite goals to achieve and they adopt certain policies and procedures to achieve these goals. Each organization consists of smaller control systems. Either this organization or its component control system can be represented by a single feed back process as shown in Figure 1.1 (2).

There are four main features that are noteworthy of this feed back process and they are explained below.

1) Decision Transformation process
2) Distinction between real and apparent achievements
3) Decision making process
4) Recognition of the continuous feed back process of this loop.

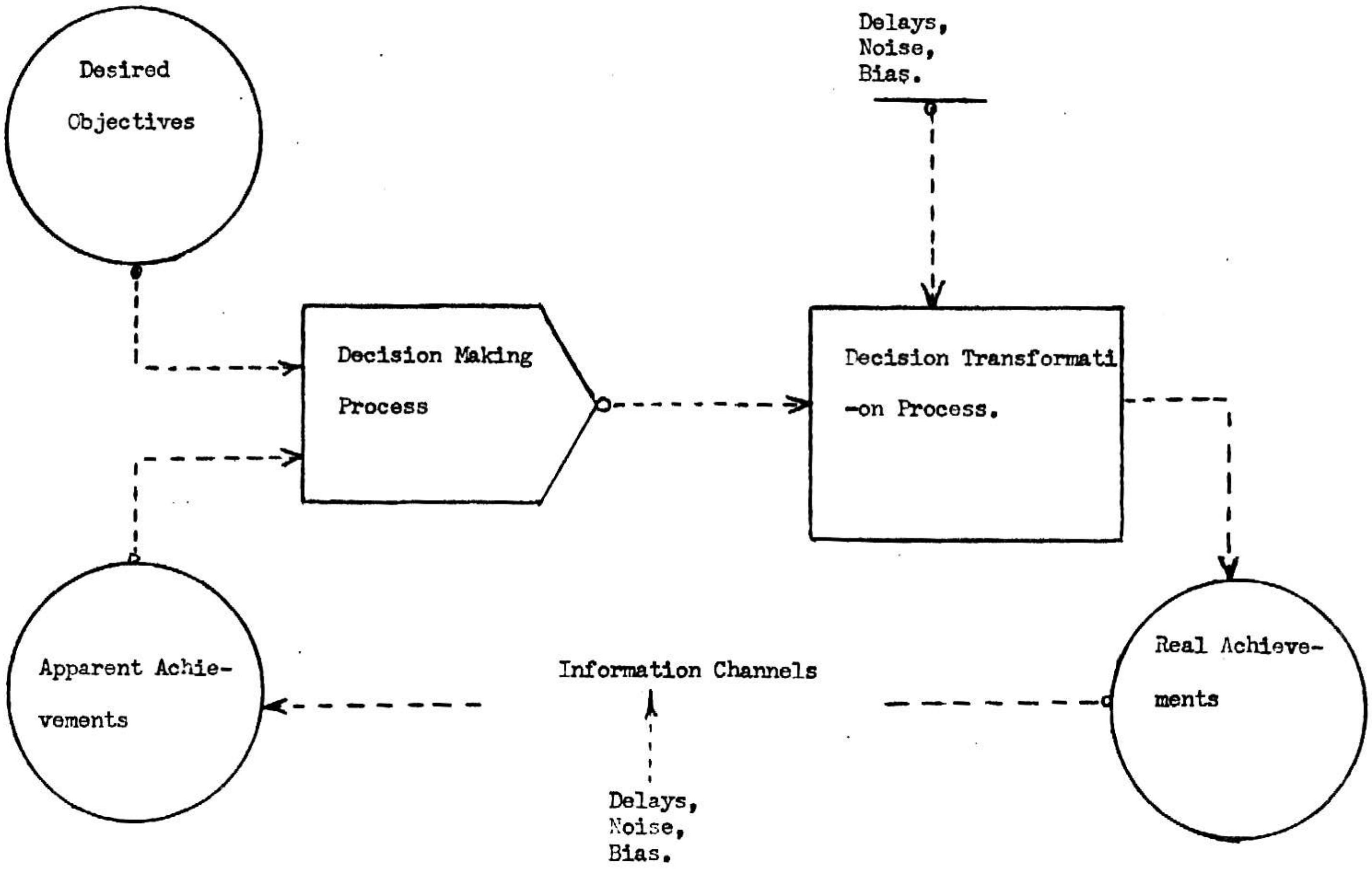


Figure 1.1 Control system structure of organisation (2)

Transformation of decisions takes place through a complex process which includes the basic structure of organizational, human and market-relation-ships. The decision transformation process is affected by delays, noise, bias etc. The real achievements are transformed into apparent achievements through information channels which contain noise and bias. The second aspect of this feedback process is to distinguish these two achievements from one another.

Decision making process is the response to the gap between desired objectives of the organization and the apparent progress towards those objectives. Though it is difficult to measure these objectives, each organization will have its own means of measuring their objectives. Karger and Albert (1) have suggested some methods of measuring professional work in their paper published in I.E. Journal. The final feature of this loop is its continuous feed back path of Decision-Results-Measurements-Evaluation-Decision. Due consideration should be given to these four features while designing any control system.

Before going into the Industrial Dynamics approach used by Roberts (2) to study the R and D control system, let us see the approaches used by others to study the R and D control system. Out of all approaches that are used to study R and D control systems, PERT and PERT/COST approaches are more recent ones. Most of these approaches use a single feed back loop system as shown in Figure 1.2 to describe the basic structure of R and D organization.

As can be seen from the diagram, the difference between forecast completion date and desired completion date causes decisions to change the magnitude or allocation of project resources (man-power, facilities,

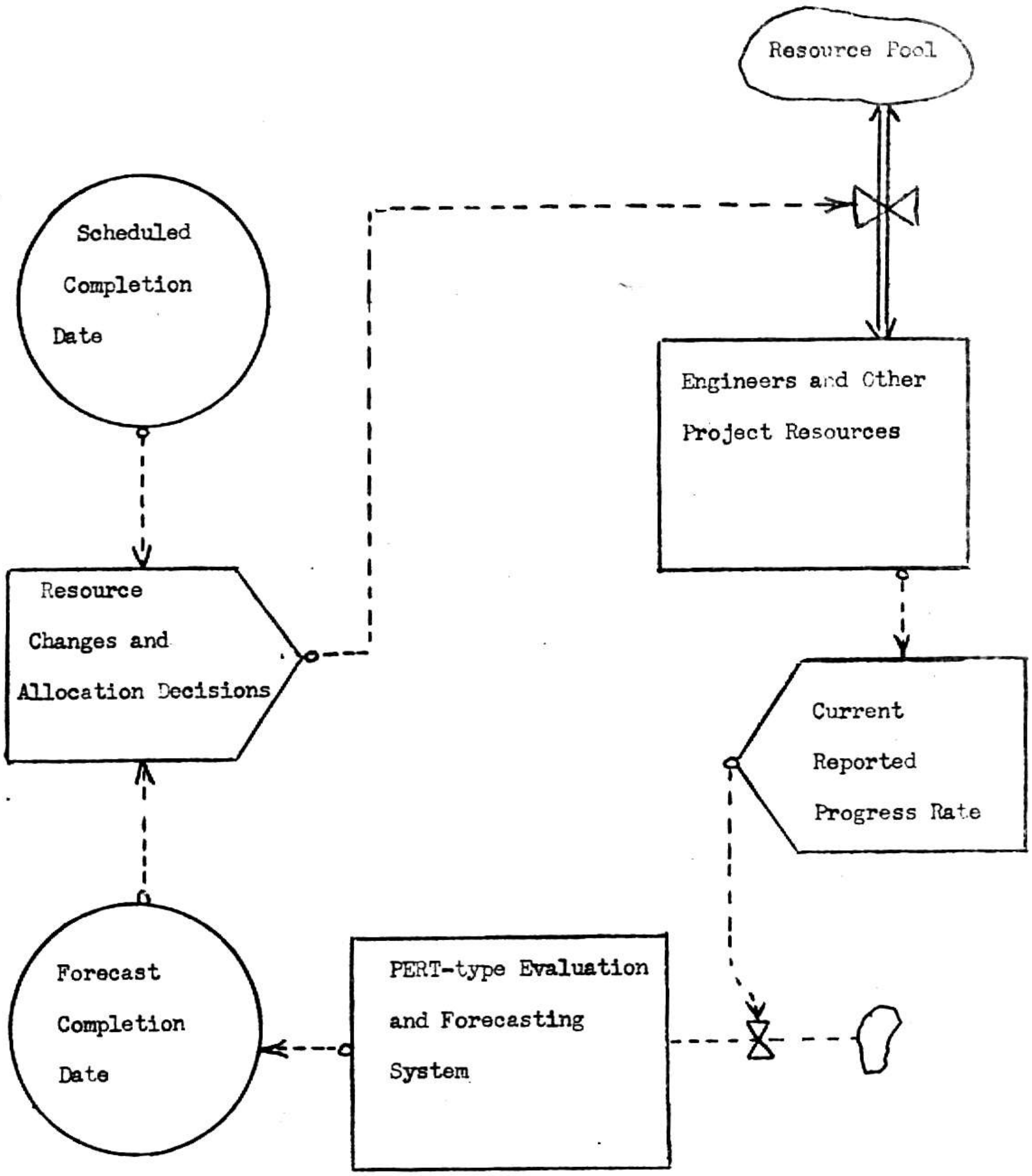


Figure 1.2 Assumed basis of current R and D project control (2)

equipment, priorities). As these resources are employed, they are assumed to produce the progress that is reported during the project. These reports are processed through PERT type of evaluation and forecasting system to create the forecasting completion date. Thus the cycle restarts again due to the gap between desired completion date and forecast completion date.

The design of an R and D control system based on above structure will fail because two main factors have been ignored. They are 1) The tangible precise measurement source and 2) Human elements in the project actions and decisions. The first factor contributes much towards the error between real and apparent achievement in an organization. The second factor also plays an important role in the organizations progress. For example the attitudes and the motivations of engineers and managers, their knowledge of the schedules and the current estimates in the project, the believed penalty reward structure-all effect the progress in the organization (2).

"In a study of research managers, scientists, and engineers engaged in large-scale research projects at major companies, Barnes Research Associates found that three basic conditions exist in discouraging productivity in industrial laboratories- an unstimulating employment environment, lack of financial incentives and strong personal motivation...... For example, Deutsch Shea Inc., a New York agency specializing in technical recruitment, has found that the financial considerations, including special monetary awards and the recognition are the two incentives engineers consider the most helpful in encouraging productive efforts..... Similar findings were revealed in a University of Michigan study in which more than 400 supervisors, scientists, and executives indicated that the reward most desired is recognition of professional achievement. Conversely, the failure of management to recognize individuals for their accomplishments is the most cited source of dissatisfaction" (26).

From above findings it is obvious that human elements play an important role in R and D organizations. Figure 1.3 (2) incorporates these two factors. Here again the difference between the desired completion date and forecast completion date create decisions to change resource allocations. Once the resources are obtained, the firm hires engineers and supporting man-power. These people produce progress. The firm perceives the cumulative progress rate which is reported for further analysis to create a forecast completion date. In this diagram it is shown that the progress rate in organization and the rate of reporting the organization's progress are dependent on engineer motivations.

Figure 1.3 does not represent fully the complex structure of the R and D organization. In any R and D organization three main things are involved. They are 1) The product, 2) The customer, and 3) The firm. So any structure which represents R and D organization should include the characteristics of the product, the customer and the firm. Figure 1.3 does not include these factors. The main characteristics of the product, the customer and the firm are enumerated below.

CHARACTERISTICS OF PRODUCT:

a) Intinsic product value

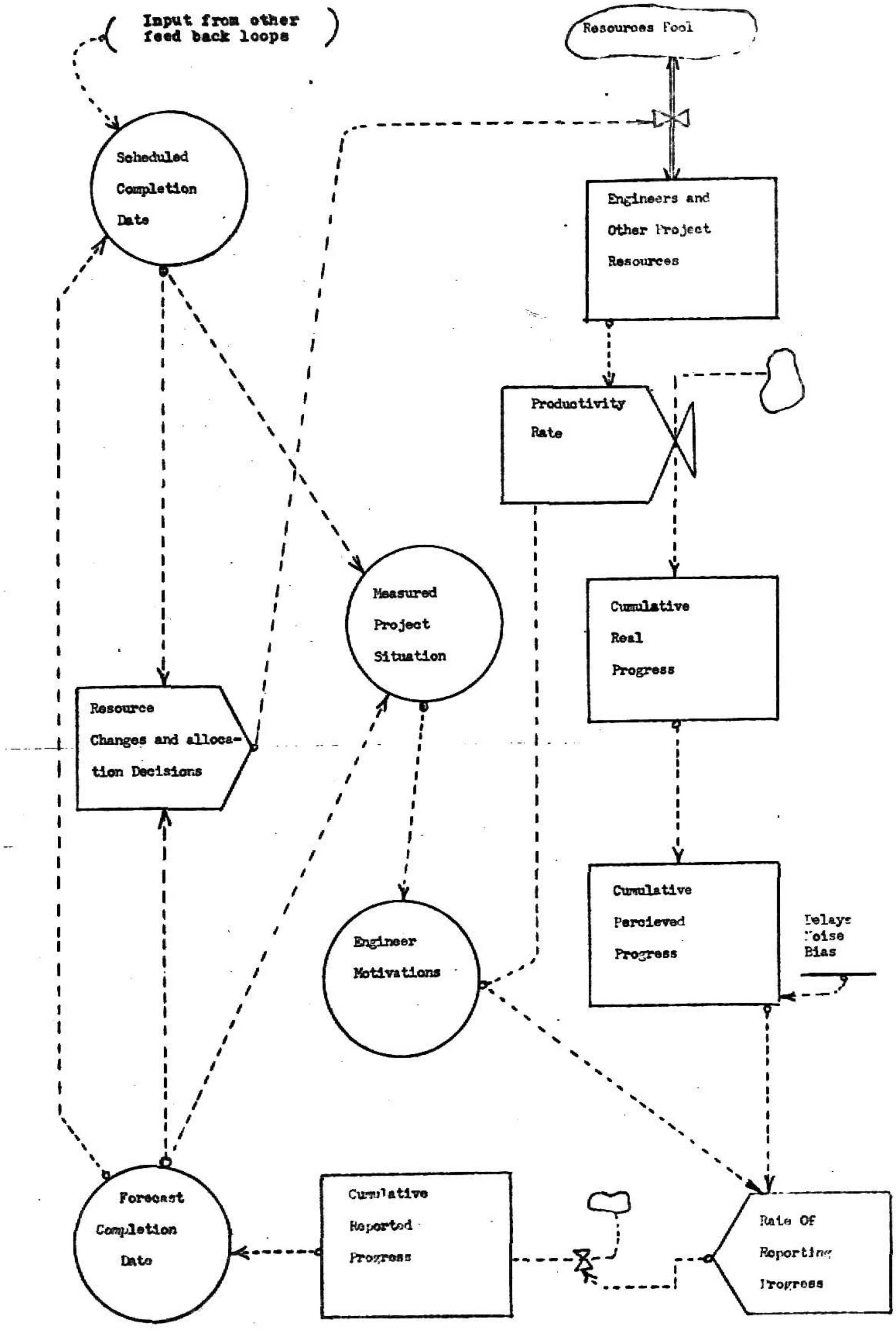


Figure 1.3 More complete representation of R and D system (2)

b) Intrinsic size of the job

c) Change in the growth of technology in the product development

CHARACTERISTICS OF THE FIRM:

a) Managerial and technical ability

b) Willingness to accept risks

c) Previous job size experience

d) Integrity

e) Criteria for project selection

f) Availability of funds

CHARACTERISTICS OF THE CUSTOMER:

a) Confidence in the firm

b) to g) All those factors listed in firm's characteristics

A complex system like R and D must include all these characteristics. Figure 1.4 represent the basic structure of R and D life cycle which incorporates all the above characteristics of the product, the customer and the firm. The various activities that are taking place in an R and D life cycle are explained below.

The life cycle of an R and D project starts when both customer and the firm percieve the need for a product and try to estimate the potential value of the product. This perception process happens due to the increasing need for a new product.

Both the customer and the firm will consider the technological feasibility of the product development and try to estimate the effort needed to develop the product in terms of man-power. Based on this effort estimate, both the customer and the firm will estimate the total

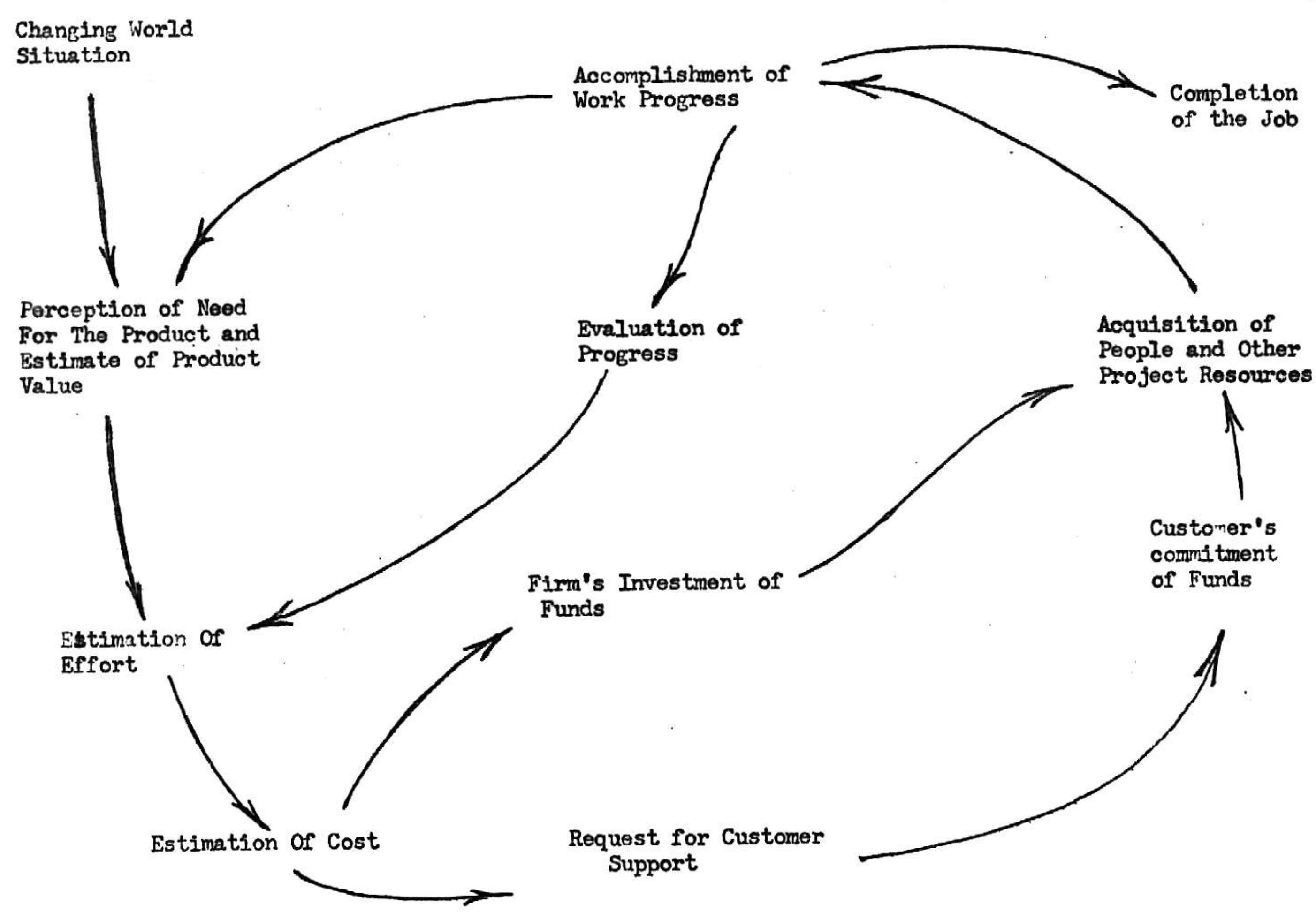


Figure 1.4 Dynamic system underlying project life cycle (3)

cost of the project.

At this point the firm has two parallel paths for obtaining funds. The firm can submit a request to the customer for financial support. The customer will compare the estimated product value to the estimated cost to complete the project. If this value is favourable to him, he will commit funds to the firm after a long budgetary delay.

Alternately, the firm can take a decision to invest its own money in the project. This decision of the firm will involve risk because the firm is investing its funds even before the customer commits. Both these paths will provide the firm with funds.

Once the funds are obtained the firm acquires engineers and necessary personnel to assist them. These personnel accomplish progress on the job. Both the customer and the firm will try to asses the progress. They evaluate the state of job completion by comparing their current interpretations of the results accomplished to date with their current interpretations of the end results desired. Continuous progress evaluation creates new estimate of work yet to be done on the project. This estimate is fed back to the closed-loop process described just now.

This continuing cycle of activities take place through out the project life and will lead to completion of the project or cancellation of the project at some point prior to full completion.

From Figure 1.4 it can be seen that there are five major activities that are taking place in the project life. They are 1) Perception of product value by both the customer and the firm, 2) Estimation of effort and cost by both of them, 3) Funding of the project, 4) Acquiring and using the engineering man-power, and 5) Control of project activities.

There are many factors which influence these activities of R and D life cycle and these factors and their influences are elaborately explained in Chapter 2.

CHAPTER 2

FACTORS INFLUENCING THE ACTIVITIES OF R AND D LIFE CYCLE

It is observed in Chapter 1 that there are five major activities that are taking place in R and D life cycle. They are

1) Perception of product value
2) Estimation of effort and cost
3) Funding of R and D project
4) Acquisition of engineering man power and progress rate by them and
5) Control of R and D progress

The various factors influencing each activity are enumerated in this chapter and the flow diagrams and DYNAMO equations for each activity are given in Chapters 3,4,5,6, and 7.

PERCEPTION OF PRODUCT VALUE:

The life cycle of R and D starts with the perception process. Perception of product value by the firm (or customer) is mainly dependent on two factors: 1) The current value of the product which in-turn depends on intrinsic product value and 2) The estimate of future product value of the product under consideration.

People place different values to different products depending on the need of the product. They will pay certain amount of money, which they think the product is worth, to buy that product, otherwise they do not make a buy, if the product is not worth that much. The amount which the people pay to buy a product is known as the intrinsic product value and it is a characteristic of a product. The intrinsic product value (IPV) varies over time as shown in Figure 2.1. Prior to some point in time, there may not be any value to the product, but its value increases as time passes and reaches its peak and stays constant for some time and then the value decreases and reaches zero after a long time. This kind of behavior is characteristic of all product life cycles (3).

For example, if we consider the product life cycle of an automobile (of any make and model) in America, the value of the automobile is zero when it is not in existence, but its value keeps on increasing when the manufacture continues and reaches its maximum value when it comes to market, and this maximum value remains constant for one year and then drops slowly and reaches negligible value after some time. This kind of behavior is true with all kinds of products.

Based on the intrinsic product value, the firm will be able to estimate the current value of the product. The firm needs a certain amount of time delay to notice changes in the value of the product and this delay time will be different for one company to other and it mainly depends on the technical know-how of the firm.

Firm's (or customer's) perception of product value is dependent not only on the current value of the product but also on the estimate of its future value. This future value of the product depends mainly on the time period over which the firm (or customer) wants to project the current product value. The time period over which the firm wants to project the value of the product is termed as projection horizon of the firm.

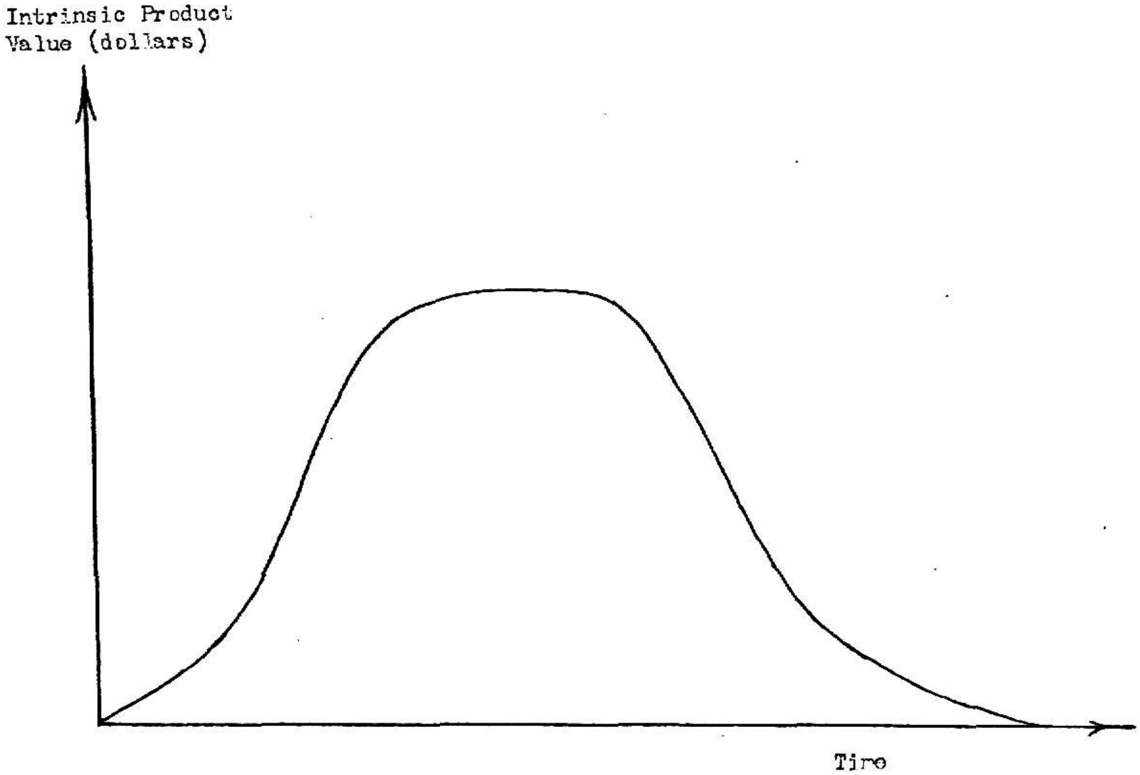


Figure 2.1 Time path of the underlying need for a product (3)

Therefore we can say that the perception process of the firm (or customer) depends on 1) The current value of the product which in turn depends on the intrinsic product value and 2) The estimate of the future value of the product which depends on firms projection horizon, and its current value of the product.

ESTIMATION OF EFFORT AND COST:

The second major activity in R and D life cycle is the firm's (or customer's) estimation of effort and cost needed to complete the project. This process can be divided further into two phases. 1) Estimation of effort needed to develop the product and 2) Estimation of total cost to complete the project.

Firm's (or customer's) estimation of effort depends on the estimates of 1) Job size, and 2) Future technical effectiveness of the firm's engineers. Firm's job size estimate depends on the 1) Intrinsic size of the job, 2) The relationship of the previous job size experience, 3) Firm's over all tendency to under estimation and 4) Firm's over all technical and managerial ability. The amount of fully effective effort needed to translate the existing technical know-how into a complicated equipment design is termed as the intrinsic size of the job and it is the major factor affecting the job size estimation of the firm. Firm with previous experience on the job will have tendency to over estimate or under estimate the job size depending on whether the size of the jobs the firm completed previously are smaller or larger respectively. Firms usually try to show the job to be smaller in order to obtain contracts. This kind of under estimation of job size is a common behavior in all firms. But the amount of under estimation of the job size mainly depends on the quality of the firm.

Firm's estimation of future technical effectiveness mainly depends on its current technical effectiveness of the engineers, the changes in the technological effectiveness available to the firm and expected time over which the changes in the available technology are expected to continue.

The firm will estimate the effort needed to complete the project with the help of the job size estimate and future technical effectiveness. Estimation of cost by the firm mainly depends on the effort needed to develop the product and firm's engineering and over head costs.

FUNDING OF R AND D PROJECT:

The third major activity of R and D life cycle is funding of the project. This activity mainly consists of three phases. They are 1) Firm's bid for financial support, 2) Customer's evaluation of firm's fund request and commitment of funds and 3) Firm's investment of funds in the project.

There are three main factors which influence the firm's request for financial support. They are 1) The estimated future value of the product, 2) The estimated total cost of the project and 3) Firm's integrity. Based on the estimates of future value of the product, total cost of the project and return on investment criterion, the firm estimates the expenditure rate on the project. The firm requests a fraction of the expenditure rate from the customer and this fraction depends mainly on the integrity of the firm. Firms with highest integrity will request full expenditure rate from the customer.

Customer's commitment of funds depends on the relationship of the future value of the product and total cost to complete the project and also his return on investment criterion and his confidence in the firm's estimates. The final factor which influence the customer's commitment of funds is the availability of funds to him.

Firm's investment decision depends on its willingness to participate in the project, its expected profit rate on the project and the amount of funds available to the firm.

ACQUISITION AND UTILIZATION OF ENGINEERING MANPOWER:

The fourth activity in R and D life cycle is acquiring of engineering man power and accomplishment of work progress. This activity can be conveniently divided into two sub-activities. 1) Acquiring of engineering man power and 2) Accomplishment of work progress on the job.

There are three policies of the firm which influence the rate of acquisition of engineering man power. These policies are 1) acquisition policy, 2) training policy and 3) transfer policy. Firm's acquisition policy determines the number of engineers to be hired in the project and it depends on the available expenditure rate to the firm. Firm's hiring rate of engineers is limited by the number of recruiting personnel in the personnel department and also by the fully trained engineers in firm. Firm's training policy determines the number of engineers in training and engineering trainers in the firm. Both are dependent on the number of fully experienced engineers in the firm. Firm's transfer policy affects the number of engineers in the project. When the project nears completion, the firm would like to transfer some or all of its engineers to different projects or fire the engineers. But some firms would hesitate to fire experienced engineers and continue to maintain a certain amount of stable work force level. So this kind of policies will affect the firm's acquisition of new engineering man power.

The accomplishment of work progress by the engineers mainly depends on six factors. They are

1) Firm's technical knowledge in the product development area
2) Experience of engineers on the job
3) The quality of the management
4) Catagories of engineering employees
5) Size of engineering work force
6) Ability of the engineering managers

Firm's technical knowledge that can be applied to the product development, mainly depends on the available technical effectiveness at the firm and its ability in utilizing the available technical effectiveness. The later factor depends on firm's technical and managerial ability. Experience of engineers on the job also influence the productivity of the engineers to a great extent. The more experienced engineers are likely to accomplish the job in lesser time than those of the inexperienced engineers.

The various categories of engineering employees will also influence the productivity of the engineers. There are four kinds of engineers in the R and D project. 1) Engineers in training, 2) Engineering trainers, 3) Fully experienced engineers and 4) Engineers leaving the firm either voluntarily or non-voluntarily. Fully experienced engineers are considered to be standard for productivity measurement. The productivity rate of engineers in training will be considered low compared to the productivity rate of fully experienced engineers because they are new to the project. Engineering trainers are once upon a time fully experienced engineers, but their contribution toward the product development will be less because most of their time is used in training new engineers. Their efficiency shows up in the number of engineers they train. Lastly the productivity rate of engineers leaving the firm (voluntarily or non voluntarily) will be very low due to complete immoralization and their dissatisfaction with the job.

The quality of the engineering management contributes to great extent to the productivity of the engineers. An organization with poor management might result in hiring of less competent people, lack of proper use of technological developments and decreased technical effectiveness of the firm. A good quality management will influence the productivity of the engineers in many respects. It will try to establish penalty-reward structure to improve the productivity of the firm. It will encourage initiative and creativity of the engineers through the penalty reward structure. It provides workers with motivations derived from pride and involvement in the work group.

The size of the engineering work force directly affects the productivity of the engineers. Above a certain level of engineers, the additional amount of engineers will cause reduction in productivity due to the communication delays (4). An organization with a tight position in engineering personnel may accomplish the job efficiently and in much shorter time. Examples are Sidewinder Missile project (5,3) and Vangaurd Satellite launching by Von Braun group.

The ability of the engineering manager also influences the productivity of the engineers. His improper decision of employing more number of talented engineers on a job which can be done by a fewer and less talented engineers will cause a wastage of engineering man power. More important waste comes from poor management decisions that provide engineering resources to a high percentage on projects which never result in satisfactory finished products. In the same way the engineering manager's allocation of his time can have a great effect on the work productivity of his group.

CONTROL OF R AND D PROGRESS:

The final activity of R and D life cycle is control of its progress. This acitvity consists of four processes. They are

1) Establishing a criteria for progress measurement
2) Observing the criteria during the project life
3) Evaluating the observed criteria with estimated values and
4) Taking action in response to the gap between process 2 and 3.

Establishing a criteria in R and D project is quite difficult due to intangible and imprecise measurements and uncertain nature of technological developments in the product development area. In any company, manufacturing and accounting divisions can have tangible and precise measurements about their progress rate. Counting the daily out put in a manufacturing division or looking at the financial statements in an accounting division, the firm can obtain tangible and precise measurements but it is difficult to measure the progress of R and D as the definition of progress in R and D is not clear. In the past many schemes have been tried for keeping track of R and D progress including Gantt Charts, project milestone schedules, sophisticated computer reporting techniques etc., but these processes depend on subjective judgement. Peter V. Norden (6) stated in his article in IRE transactions that it is easier to specify to a greater accuracy of the nature and measure of outcomes in a manufacturing division and in basic research, it is impossible to specify. Nelson (7) has pointed out that there will be considerable uncertainty as to the outcome of R and D program and the uncertainty is related to the degree of knowledge in the relevant fields and to the advance sought in the programs. It is obvious from above that establishing criteria for project measurement is quite difficult because of intangible, imprecise measurements and uncertain behavior of the technological developments in product development.

In R and D project, both customer and firm will aim at the development of an end product. So the main objective in measuring the R and D progress would be to see how far the product has been completed. It was pointed out earlier in this chapter that the ability to recognize specific job size requirements depends on the general managerial and technical skills of the firm and the customer and how they use these capabilities. Also it was pointed out in this chapter (estimation of effort and cost) that both firm and the customer would try to estimate the effort needed to develop the product based on the considerations of the believed job size and the assessments of the technological effectiveness of the company's engineers. The progress on a research and development job is defined as the accumulation over the period of time of the project of the effective man-hours contributed by the engineering work force. As the effective effort is applied over time by the engineer, the job will be completed, but there is no correct measure for the engineering effectiveness. Therefore it is difficult to control R and D progress.

In the past some defense contractors have used some kind of plans for establishing a criteria for measuring and controlling the progress of their projects. Bendix Corporation has used project schedule charts (8), Silvania has used schedules with appropriate mile stones (9) and General Electric Company has divided the plan into certain operations and each operation is expressed in terms of lead time to complete that operation (10). But it is very difficult to use this kind of proceedures in R and D project control. It is clear from literature (11,12,13,14,15 and 16) that the R and D managers are lacking the ability to estimate properly the time and effort needed to complete the R and D jobs. RAND corporation study (11) shows that 2 out of 22 R and D firms estimated the project costs correctly. Another report (12) by RAND corporation revealed the slippages in development schedules of aircraft engines. An informal talk by a former chief scientist of the U.S. Air Force revealed that one out of 300 contractors completed the job in the estimated time (13). The data collected by Harvard Business School Weapons Acquisition Research Project confirms above findings (14). The incorrect estimate of project effort is still a current problem in all R and D projects and it is revealed in the study of R and D contracting experiences by NASA recently (15). From these evidences, it can be said that it is difficult to establish a meaningful criteria for measuring progress in R and D efforts. Project performance can be evaluated, only if it is measurable, to see whether the job is on schedule or not. Apart from completion of the job, there are other factors like elapsed time and cumulative cost in which the project managers are interested in. Some managers used the above three factors for measuring the progress of R and D. All these methods explained so far neglected inclusion of human factors. R and D progress, measurement and control are strongly dependent on human factors and it was pointed in chapter 1 that R and D organization will fail due to ignoring of human factors. Measurement and evaluation of criteria is mainly effected by the human factors which is neglected in PERT and PERT/COST analyses used in studying R and D organization's progress. The current methods used for measuring R and D progress by one of the departments of General Electric Company is to divide the project into six distinct phases of engineering development. At the end of each phase, they review the situation, observe the short comings and correct them (16). Haine and Lob (17) indicate that there are many short comings when the progress of R and D is expressed in percent completion of the project. In order to curcumvent this difficulty the project has been divided into small bits of tasks which allowed them to prepare more accurate estimates of progress evaluation.

Karger and Albrecht (1) suggest that in a company the measurement of progress of research and engineering personnel can be achieved by establishing goals for the organization as a whole, for each subunit of the organization and for each professional in the organization. However they have not suggested any mathematical formulation of progress measurement.

Taking corrective action is the final aspect of the control of R and D progress activity, over optimistic companies respond less frequently to the gaps or error signals in the progress. This kind of behavior of the firm will cause either failure or serious difficulities in the project. Some companies respond very quickly to the minor error signals in the progress. This might result in over expansion and wasteful haste in the job performance and it might result in unncessarily large and ultra-expensive project, much greater than is really required by the basic situation. Company's response to error signals depends on its own previous job size experience, its attitude and upon the insight and ability of its management to understand the under lying project situation.

CHAPTER 3

PERCEPTION OF PRODUCT VALUE

INTRODUCTION

In chapter 2, the factors influencing each activity of R and D life cycle have been enumerated. In this chapter, flow diagrams and equations for firm's (and customer's) perception process are given.

The perception process by the firm (or customer) is affected by 1) the estimate of current product value and 2) the estimate of future product value. Firm's revision of current product value estimate depends on the changes in intrinsic product value (IPV) and delay in recognizing these changes in product value (DRPVF). This delay mainly depends on the firm's technical know-how. In order to initiate the perception process, two exogenous input values are fed in, they are intrinsic product values over time and delay time to recognize the product value variations which depends on the know-how level of the firm.

FLOW DIAGRAM FOR FIRM'S PERCEPTION PROCESS

Figure 3.1 shows the flow diagram for the firm's perception process. The numbers in diagram symbols represent equations. The exogenous input values are shown on the top of the diagram. The input values for IPV are assumed to vary with time as shown in Figure 2.1. The delay in recognizing the product value is assumed to have an exponential relationship as shown in Figure 3.2. In the initial stages, when the firm's technical know-how is very low then the delay in recognizing the product value will be very high at 66 months and the delay will have a

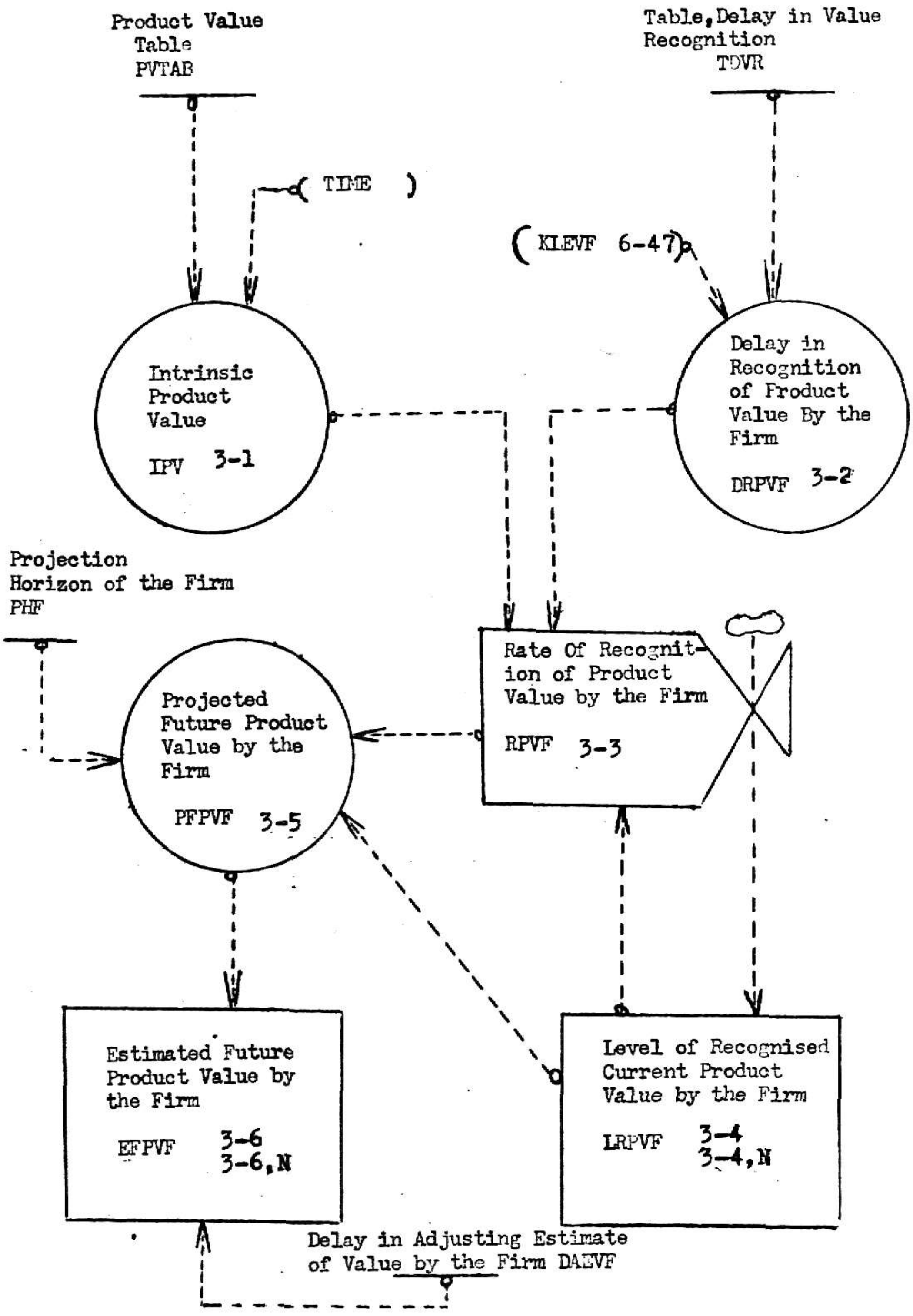


Figure 3.1 Firm's perception process

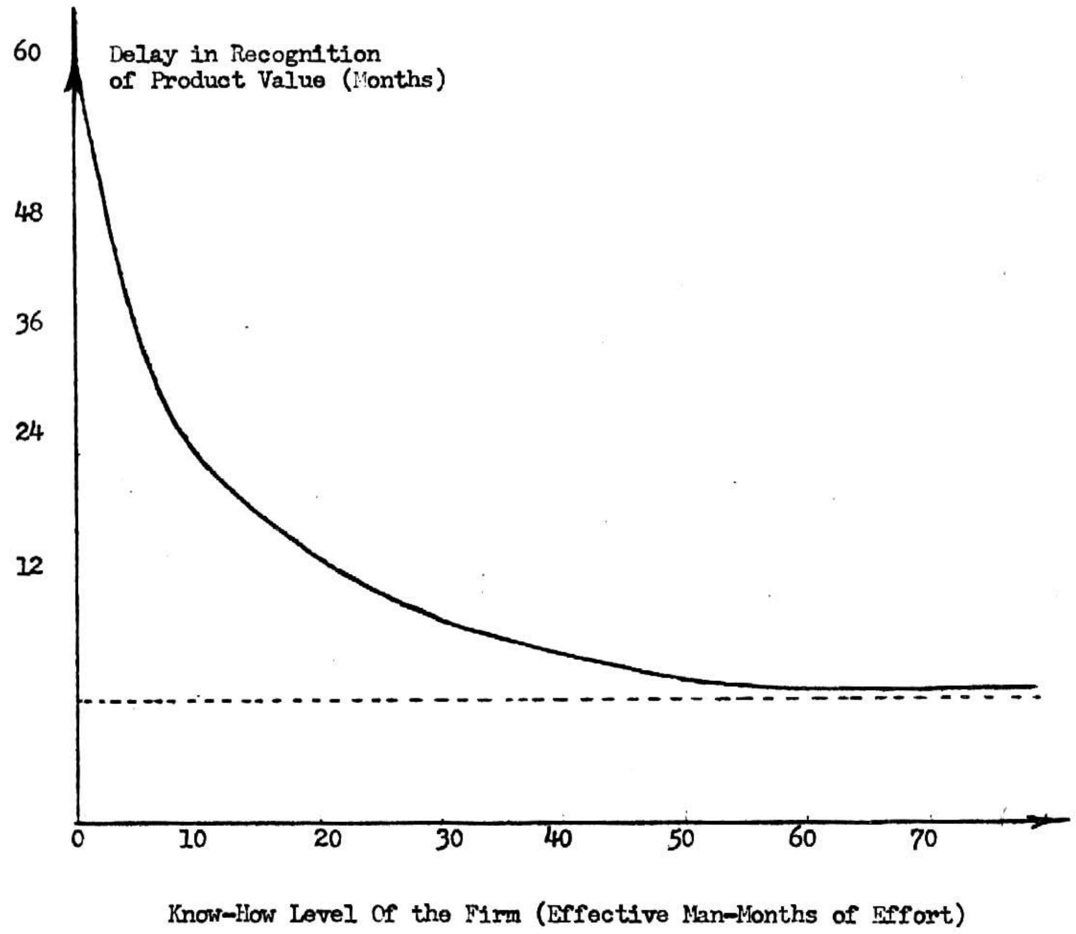


Figure 3.2 Delay in recognition of product value at the firm (3)

minimum value of 6 months irrespective of how high the firm's know how will be in the future.

The rate of recognized product value depends on the IPV values and delay in recognizing these IPV values. As the firm obtains information about the product, it accumulates a level of the current value of the product. Based on the rate of change of product value and current estimate of the product value, the firm tries to project the value into future (which depends on the projection horizon of the firm) and tries to estimate the future value of the product. Firm will revise its estimates about the future value of the product whenever it notices changes in the projected value of the product, and it revises the estimate after certain time delay. In perception process, the aim of the firm is to estimate future value of the product.

EQUATIONS FOR FIRM'S PERCEPTION PROCESS

The equations for input values of IPV and delay in recognizing the product values (DRPVF) are given below

IPV.K = TABLE (PVTAB, TIME.K, 0, 180, 6) (3-1,A)

IPV - Intrinsic Product Value (dollars)

PVTAB - Product Value TABle, the name of the table of input values for IPV (dollars), in which values have been inserted at six-month intervals from TIME = 0 to TIME = 180 months.

TIME - Simulated project time (months)

DRPVF.K = TABHL (TDVR, KLEVF.K, 0, 60, 5) (3-2,A)

DRPVF - Delay in Recognition of Product Value by the Firm (months)

TDVR - Table, Delay in Value Recognition, a table of numbers that gives an appropriate value of DRPVF for each value of KLEVF

KLEVF - Know-how LEVel of the Firm (effective man-months of effort)

The rate of recognition of product value (RPVF) is given by

$$RPVF.KL = \frac{IPV.K - LRPVF.K}{DRPVF.K} \qquad (3\text{-}3,R)$$

RPVF - Rate of recognition of Product Value by the Firm (dollars per month)

IPV - Intrinsic Product Value (dollars)

LRPVF - Level of Recognized Current Product Value by the Firm (dollars)

DRPVF - Delay in Recognition of Product Value by the Firm (months)

The level of recognized current product value (LRPVF) is a continuous summation of the changes in product value (RPVF)

$$LRPVF.K = LRPVF.J + (DT)\ (RPVF.JK) \qquad (3\text{-}4,L)$$

$$LRPVF = 0 \qquad (3\text{-}4,N)$$

LRPVF - Level of Recognized Product Value by the Firm (dollars)

DT - Delta Time (months), the time interval between computer solutions of the equations.

RPVF - Rate of recognition of Product Value by the Firm (dollars per month)

Projected future product value (PFPVF) depends on RPVF, LRPVF, and PHF, the projection horizon of the firm

$$PFPVF.K = LRPVF.K + (PHF)(RPVF.JK) \qquad (3.5,A)$$

PHF = 48

PFPVF - Projected Future Product Value by the Firm (dollars)

PHF - Projection Horizon of the Firm (months)

LRPVF - Level of Recognized Current Product Value by the Firm (dollars)

RPVF - Rate of recognition of Product Value by the Firm (dollars per month)

The firm revises its estimates of future product value (EFPVF) when ever it observes changes in projected future product value (PFPVF) and its previous estimate of future product value (EFPVF). The firm revises these estimates after certain amount of time delay, DAEVF. The equation for firm's estimate of future product value (EFPVF) is given by

$$EFPVF.K = EFPVF.J + \left(\frac{DT}{DAEVF}\right)(PFPVF.J-EFPVF.J) \qquad (3\text{-}6,L)$$

$$EFPVF = 0 \qquad (3\text{-}6,N)$$

DAEVF = 6 months

EFPVF - Estimated Future Product Value by the Firm (dollars)

DAEVF - Delay in Adjusting Estimate of Value by the Firm (months)

PFPVF - Projected Future Product Value by the Firm (dollars)

In the model only positive values are considered for projected future product value (PFPVF) and this is accomplished by replacing equation (3-5) by the following equations.

$$TFPVF.K = LRPVF.K + (PHF)(RPVF.JK) \qquad (3\text{-}5a,A)$$

$$PFPVF.K = MAX(TFPVF.K,\ 0) \qquad (3\text{-}5b,A)$$

FLOW DIAGRAM AND EQUATIONS FOR CUSTOMER'S PERCEPTION PROCESS

Figure 3.3 shows the flow diagram for customer's perception process. The flow diagram is similar to firm's diagram since the perception process is common to both. In this diagram, the constants are assumed to be different from the values of the firm, but rest of the equations are similar to that of firm's equations.

Customer's rate of recognition of product value (RPVC) is given in equation (3-7)

$$RPVC.KL = \frac{IPV.K - LRPVC.K}{DRPVC.K} \qquad (3\text{-}7,R)$$

RPVC - Rate of recognition of Product Value by the Customer (dollars per month)

IPV - Intrinsic Product Value (dollars)

DRPVC - Delay in Recognition of Product Value by the Customer (months)

LRPVC - Level of Recognized Current Product Value by the Customer (dollars)

Customer's level of recognized current product value (LRPVC) is given by

$$LRPVC.K = LRPVC.J + (DT)(RPVC.JK) \qquad (3\text{-}8,L)$$

$$LRPVC = 0 \qquad (3\text{-}8,N)$$

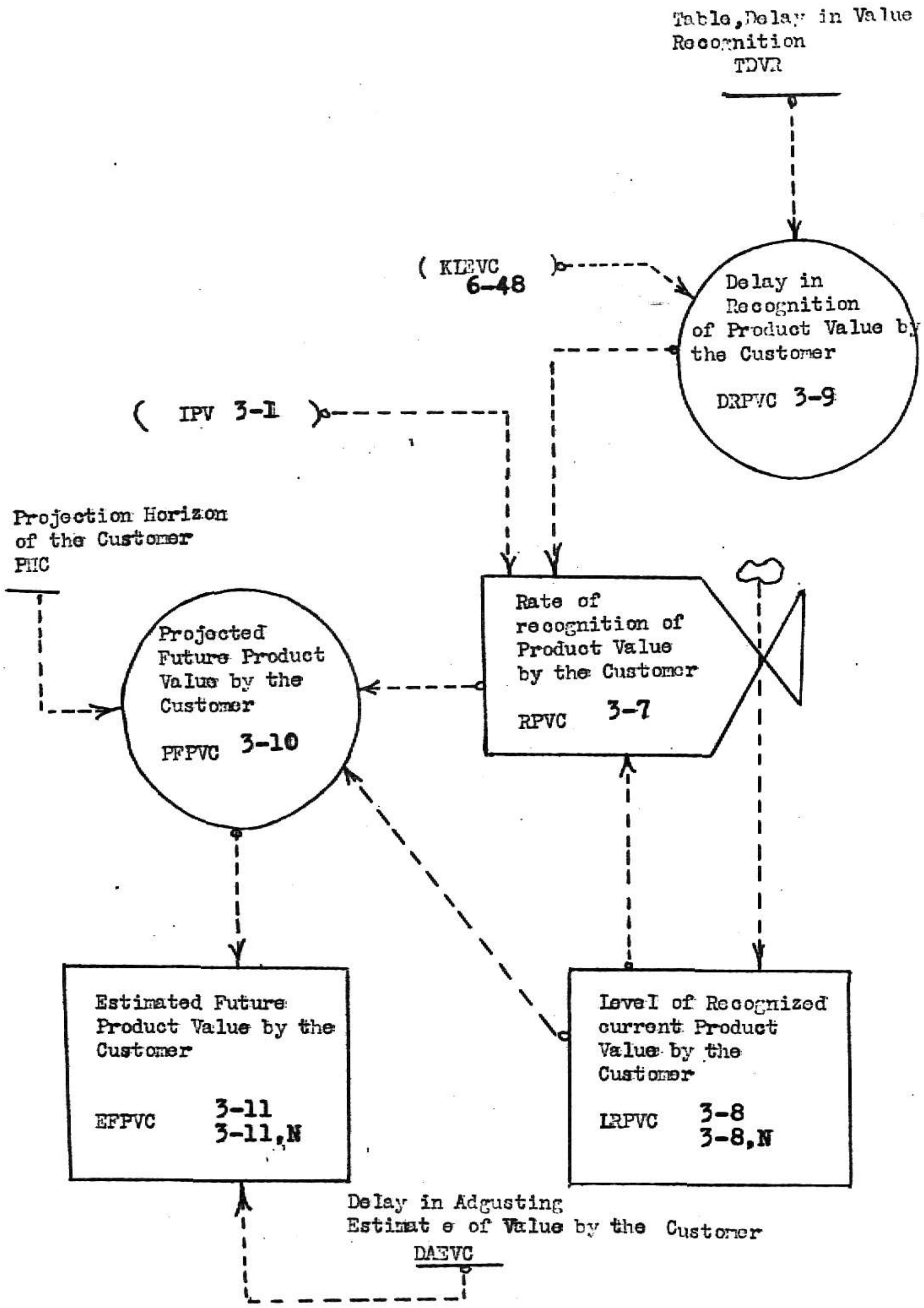


Figure 3.3 Customer's perception process

LRPVC - Level of Recognized Current Product Value by the Customer (dollars)

RPVC - Rate of recognition of Product Value by the Costomer (dollars per month)

Customer's delay in recognizing the product value (DRPVC) is a function of his technical know-how (KLEVC) and is given by

DRPVC.K = TABHL (TDVR, KLEVC.K, 0, 60, 5) (3-9,A)

DRPVC - Delay in Recognition of Product Value by the Customer (months)

TDVR - Table, Delay in Value Recognition, a table of numbers that gives an appropriate value of DRPVC for each value of KLEVC.

KLEVC - Know-how LEVel of the Customer (effective man-months of effort)

Customer's projected future product value (PFPVC) depends on LRPVC, RPVC, and customer's projection horizon, PHC.

PFPVC.K = LRPVC.K + (PHC)(RPVC.JK) (3-10,A)

PHC = 36 months

PFPVC - Projected Future Product Value by the Customer (dollars)

LRPVC - Level of Recognized Current Product Value by the Customer (dollars)

PHC - Projection Hoarizon of the Customer (months)

RPVC - Rate of recognition of Product Value by the Customer. (dollars per month)

The estimated future product value (EFPVC) of the customer is given as

$$EFPVC.K = EFPVC.J + \left(\frac{DT}{DAEVC}\right)(PFPVC.J - EFPVC.J) \qquad (3\text{-}11,L)$$

$$EFPVC = 0 \qquad (3\text{-}11,N)$$

DAEVC = 8 month

EFPVC - Estimated Future Product Value by the Customer (dollars)

DAEVC - Delay in Adjusting the Estimate of Value by the Customer (months)

AFPVC - Projected Future Product Value by the Customer (dollars)

As done in the case of the firm, only positive values are considered in the model for projected future value of the product (PFPVC) and this is accomplished by replacing equations 3-10 by the following equations.

$$TFPVC.K = LRPVC.K + (PHC)(RPVC.JK) \qquad (3\text{-}10a,A)$$

$$PFPVC.K = MAX\ (TFPVC.K,0) \qquad (3\text{-}10b,A)$$

This completes the specification of DYNAMO equations for perception process of customer and firm.

MODIFICATION MADE IN FLOW DIAGRAMS 3.1 AND 3.3

The estimated value of the projected future product value is assumed to depend on the current product value, rate of change in product value, and the projection horizon of the firm (or customer). Roberts used an exponentially smoothed value for the rate of change of product value to estimate the projected future product value. The author used the actual changes in product value between solution time intervals to estimate the projected future product value. This modification is shown in figures 3.1 and 3.3 by indicating the projected future product value being influenced directly by the rate of change in product value.

Roberts has shown that the projected future product value depends on the exponentially smoothed value of the rate of change of product value. This modification is done to see whether there will be any change in the estimate of future product value.

CHAPTER 4

ESTIMATION OF EFFORT AND COST

INTRODUCTION

In this chapter, the flow diagrams and DYNAMO equations for firm's (and customer's) estimation of effort and cost are given. Firm's process of estimation of effort and cost is divided into the following three phases.

1) Firm's estimation of job size
2) Firm's estimation of technical effectiveness and
3) Firm's estimation of a effort and cost.

FLOW DIAGRAM FOR FIRM'S ESTIMATION OF JOB SIZE

Figure 4.1 shows the flow diagram for firm's job size estimzation. It was explained in chapter 2 that firm's job size estimation depends on 1) intrinsic size of the job, 2) the relationship of the previous job size experience and 3) firm's over estimation or under estimation of the job size which depends on the ability or quality of the firm. These three variables are used as input values to the estimation process and they are shown on the top of the diagram. The intrinsic size of the job is defined in Chapter 2 as the amount of fully effective effort needed to translate the existing technical know-how into a complicated equipment design. This intrinsic size of the job, denoted in the diagram as NLKP, the needed level of know-how for development of the product, is assumed to be 5500 man-months of effort. The firm is assumed to have handled 25% smaller jobs, hence the value, PDPEF, the percent deviation of past experience of the firm is set equal to -0.25, and firm is assumed to be extremely able in estimating the job size, hence the quality of the firm (QF) is assumed

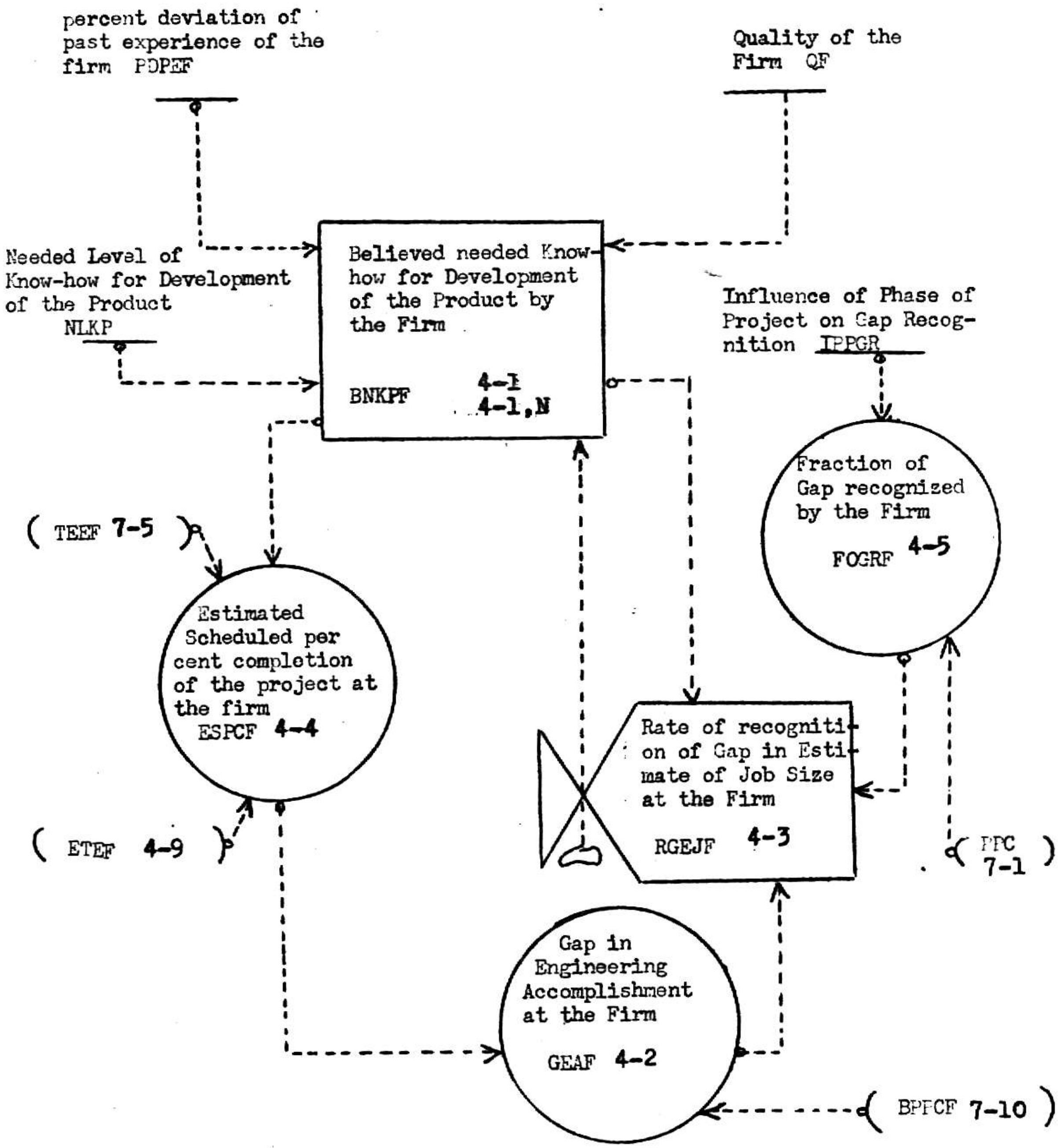


Figure 4.1 Firm's job size estimate.

to be 1.0 which means firm's estimates are 100% correct. These three factors are shown on the top of the diagram.

With these three input values, the firm estimates the initial size of the job, denoted by believed needed know-how for development of the product by the firm, (BNKPF). During the project life, these estimates are altered due to responses to gaps that the organization detects in the scheduled engineering accomplishment. These gaps exist between the scheduled percentage completion of the job and the organizations estimate of the percentage completion of the project to date. The fraction of this gap, which affects the changes in job size estimates, depends on the stage of project completion.

EQUATIONS FOR FIRM'S JOB SIZE ESTIMATION

The estimate for firm's job size (BNKPF) can be represented by a level equation

BNKPF.K = BNKPF.J + (DT)(RGEJF.JK) (4-1,L)

BNKPF - Believed Needed know-how for development of the Product by the Firm (effective man-months of effort)

RGEJF - Rate of recognition of Gap in Estimate of Job Size at the Firm (effective man-months per month)

Equation (4-1,L) says that the firm's present estimate of job size is equal to its previous estimate plus changes in the job size estimate from its previous estimate. Equation (4-1,N) gives the initial estimate of job size by the firm.

BNKPF = (NLKP)(1 + PDPEF) / (QF) (4-1,N)

NLKP - Needed Level of Know-how for development of the product (effective man-months of effort)

PDPEF - Percentage Deviation of Past Experience of the Firm (percentage)

QF - Quality of the Firm (percentage)

GEAF, the gap in engineering accomplishment is the percentage deviation between the estimated schedule (ESPCF) and the believed progress to date (BPPCF) in terms of percentage of project completion and is given by

$$GEAF.K = \frac{ESPCF.K - BPPCF.K}{BPPCF.K} \qquad (4\text{-}2,A)$$

GEAF - Gap in Engineering Accomplishment at the Firm (percentage error)

ESPCF - Estimated Scheduled Percentage Completion of the project at the Firm (percentage completion).

BPPCF - Believed Percentage of Project Completed by the Firm (percentage completed).

GEAF is multiplied by BNKPF to obtain the gap in man-months of effort which then is multiplied by fraction of gap recognized by firm (FOGRF) to obtain the rate of recognition of gap in job size estimate at the firm (RGEJF).

$$RGEJF.KL = (GEAF.K)(BNKPF.K)(FOGRF.K) \qquad (4\text{-}3,R)$$

RGEJF - Rate of recognition of Gap in Estimate of Job size at the Firm (effective man-months per month)

GEAF - Gap in Engineering Accomplishment at the Firm (percentage error)

BNKPF - Believed Needed Know-how for development of the Product by the Firm (effective man-months of effort)

FOGRF - Fraction Of Gap Recognized by the Firm (percentage of gap recognized per month)

Scheduled percentage of project completion (ESPCF) is a rate of the actual effective effort expended to the believed effective effort needed (BNKPF) to complete the job. Actual effective effort expended is a product of effort expanded to date (TEEF) and its believed effectiveness (ETEF).

$$ESPCF.K = \frac{(TEEF.K)(ETEF.K)}{(BNKPF.K)} \qquad (4\text{-}4,A)$$

ESPCF - Estimated Scheduled Percentage Completion of the project at the Firm (percentage completion).

TEEF - Total Engineering Effort at the Firm (man-months of effort)

ETEF - Estimate of Current Technical Effectiveness by the Firm (percentage effectiveness of engineers)

BNKPF - Believed Needed Know-how for development of the Product by the Firm (effective man-months of effort).

In the initial stages it is difficult for both firm and customer to detect gaps between real and apparent progress in the organization because the progress is very small. However, the firm would be able to detect this gap as it accomplishes continuous progress on the job. Hence it is assumed that the fraction of the gap recognized (FOGRF) by the firm to vary with stage of project completion (PPC).

FOGRF.K = TABLE (IPPGR,PPC.K, 0, 1, 0.1) (4-5,A)

FOGRF - Fraction Of Gap Recognized by the Firm (percentage of gap recognized per month)

IPPGR - Influence of Phase of Project on Gap Recognition, a table of numbers that indicates the value of FOGRF as a function of PPC

PPC - Percentage of Project Completion (percentage completion)

FLOW DIAGRAM FOR FIRM'S ESTIMATION OF TECHNICAL EFFECTIVENESS

Figure 4.2, shows the flow diagram for firm's estimation of future technical effectiveness. The changes in the state of art with time are assumed and fed as input values to this estimation process. The changes in state of art (TE) is assumed to follow the curve shown in Figure 4.3.

The technological effectiveness in the existing state of art is thus a time varying factor significant in all technical fields of product development (3).

Based on the technical effectiveness in the state of art, and delay in transmitting the changes in state of art the firm tries to estimate the rate of change of technical effectiveness available to the firm. Based on this rate of change in technical effectiveness available to the firm, it will try to estimate the level of technical effectiveness available to the firm. Firm's estimate of current technological effectiveness is a summation of changes in the current technical effectiveness. The difference between the firm's current technical effectiveness estimate and realized technical effectiveness will cause the firm to change its

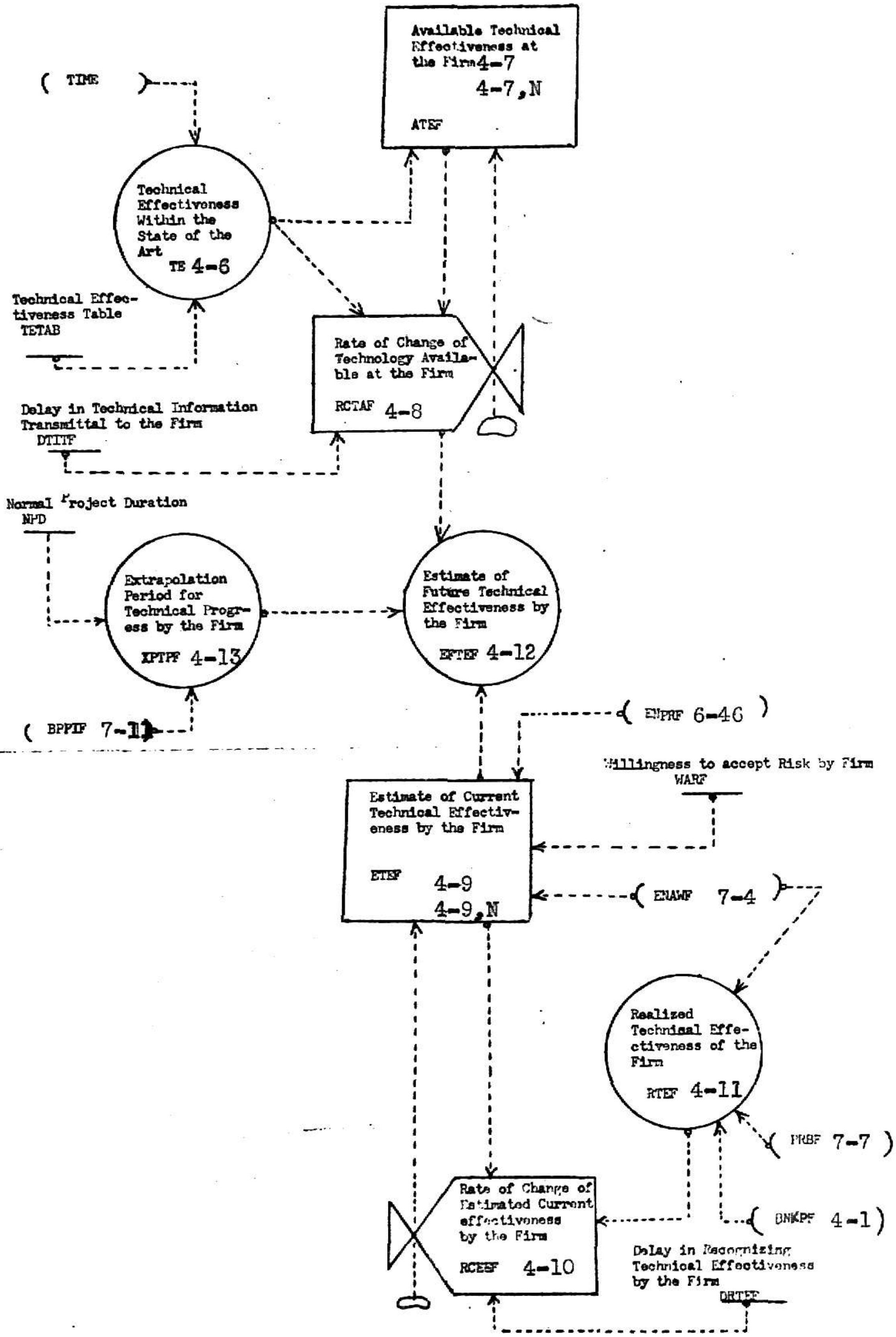


Figure 4.2 Firm's estimation of technical effectiveness

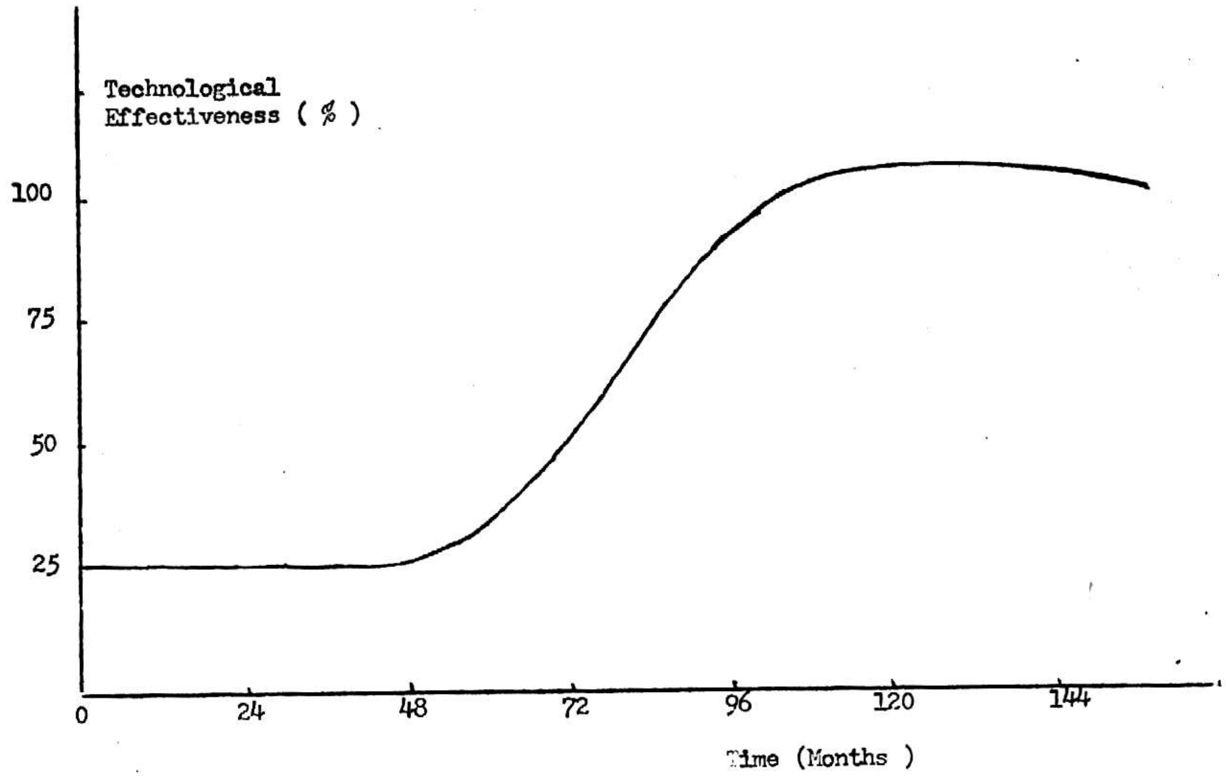


Figure 4.3 Technological state of art (3)

current technical effectiveness estimate. The realized technical effectiveness by the firm is a ratio of firm's progress rate to the engineers actually at work.

Based on the estimate of current technical effectiveness of engineers in the firm, the rate of change of technical effectiveness available to the firm and the extrapolated time over which the changes in technical effectiveness are expected to continue, the firm will estimate the future technical effectiveness of the firm's engineers.

EQUATIONS FOR FIRM'S TECHNICAL EFFECTIVENESS ESTIMATE

The changes in technical effectiveness (TE) within the state of art are given in equation 4-6, and it is the input to this estimation process

T.E.K = TABLE (TETAB, TIME.K, 0, 180, 6) (4-6,A)

TE - Technical Effectiveness with in the state of art (percentage effectiveness of engineers)

TETAB - Technical Effectiveness TABle, a table of stored numbers that will give the appropriate value for TE as a function of the project life cycle.

Available technical effectiveness to the firm (ATEF) is a summation of the changes in available technical effectiveness (RCTAF).

ATEF.K = ATEF.J + (DT)(RCTAF.JK) (4-7,L)

ATEF = TE (4-7,N)

ATEF - Available Technical effectiveness at the Firm (percentage effectiveness of engineers)

RCTAF - Rate of Change of Technology Available at the Firm (percentage effectiveness per month)

TE - Technical Effectiveness within the state of art (percentage effectiveness of engineers)

Initially, the available technology to the firm will be same as the technical effectiveness within the state of art and is given in equation (4-7,N). Over a period of time the firm acquires information relating to the exogenous state of art (TE) and estimates the rate of change (RCTAF) in available technical effectiveness (ATEF) to the firm.

$$RCTAF.KL = \frac{TE.K - ATEF.K}{DTITF} \qquad (4\text{-}8,R)$$

DTITF - 24 months

RCTAF - Rate of Change of Technology Available at the Firm (percentage effectiveness per month)

TE - Technical Effectiveness within the state of art (percentage effectiveness of engineers)

DTITF - Delay in Technical Information Transmittal to the Firm (months)

The estimate of the current technical effectiveness by the firm (ETEF) is a summation of all changes in the current technical effectiveness at the firm (RCEEF).

ETEF.K = ETEF.J + (DT)(RCEEF.JK) (4-9,L)

ETEF = (WARF)(ENPRF) / (ENAWF) (4-9,N)

ETEF - Estimate of current Technical Effectiveness by the Firm (percentage effectiveness of engineers).

RCEEF - Rate of Change of Estimated current Effectiveness by the firm (percentage effectiveness per month)

WARF - Willingness to Accept Risks by the Firm (percentage)

ENPRF - ENgineering PRoductivity rate at the Firm (effective man-months of effort per month)

ENAWF - ENgineers Actually at Work at the Firm (men)

The initial estimate of technical effectiveness by the firm represents a combination of the influences of the actual effectiveness of the firm's engineers and firm's relative optimism about its engineers. This initial estimate of current technical effectiveness by the firm is given in equation (4-9,N). The rate of change of estimated current effectiveness (RCEEF) is the difference between realized technical effectiveness (RTEF) and current technical effectiveness (ETEF) observed over a period, DRTEF, which is assumed to be 2 months.

$$\text{RCEEF.KL} = \frac{\text{RTEF.K} - \text{ETEF.K}}{\text{DRTEF}} \qquad \text{(4-10,R)}$$

RCEEF - Rate of Change of Estimated current Effectiveness by the Firm (percentage effectiveness per month)

RTEF - Realized Technical Effectiveness of the Firm (percentage effectiveness of engineers)

ETEF - Estimate of current Technical Effectiveness by the Firm (percentage effectiveness of engineers)

DRTEF - Delay in Recognizing Technical Effectiveness by the Firm (months)

The realized technical effectiveness by the firm (RTEF) is the firm's belief as to the current progress rate divided by the engineers actually at work (ENAWF). The current progress at the firm is a product of the believed progress rate (PRBF) and the believed job size (BNKPF)

$$RTEF.K = \frac{(PRBF.JK)(BNKPF.K)}{(ENAWF.K)} \qquad (4\text{-}11,A)$$

RTEF - Realized Technical Effectiveness of the Firm (percentage effectiveness of engineers)

BNKPF - Believed Needed Know-how for development of the Product by the Firm (effective man-months of effort)

ENAWF - ENgineers Actually at Work at the Firm (men)

PRBF - Progress Rate Believed by the Firm (percentage completion per month)

The firm's future technical effectiveness (EFTEF) is based on the current technical effectiveness (ETEF), the rate of change of available technical effectiveness (RCTAF) and the extrapolated time (XPTPF) over which the changes in technology are expected to continue.

$$EFTEF.K = ETEF.K + (XPTPF.K)(RCTAF.JK) \qquad (4\text{-}12,A)$$

EFTEF - Estimate of Future Technical Effectiveness by the Firm (percentage effectiveness of engineers)

ETEF - Estimate of current Technical Effectiveness by the Firm (percentage effectiveness of engineers)

XPTPF - extrapolation Period for Technical Progress by the Firm (months)

RCTAF - Rate of Change of Technology Available at the Firm (percentage effectiveness per month)

The extrapolation period recognizes the fact that if technology continues to grow at its current rate then, on the average, only half of the increase in technology from now until the end of the project will be available for utilization in the project work

$$XPTPF.K = (BPPIF.K)\left(\frac{NPD}{2}\right) \qquad (4\text{-}13,A)$$

$$NPD = 24$$

XPTPF - extrapolation Period for Technical Progress by the Firm (months)

BPPIF - Believed Percentage of Project Incomplete at the Firm (percentage)

NPD - Normal Project Duration (months)

FLOW DIAGRAM FOR FIRM'S ESTIMATION OF EFFORT AND COST

Figure 4.4 shows the flow diagram for estimation of effort and cost by both firm and customer. By adding the total amount of engineering effort to date (TEEF) to expected engineering effort needed in future, a complete estimate for effort (EERF) is obtained. Once this effort is determined, the estimate of total cost of the project (ETCPF) is obtained by multiplying EERF by the average monthly engineering cost and overhead rate (MESOH). Estimate of the cost to complete the project (ECCPF) is obtained by subtracting the cost to date (TECF) from total cost of the project (ETCPF)

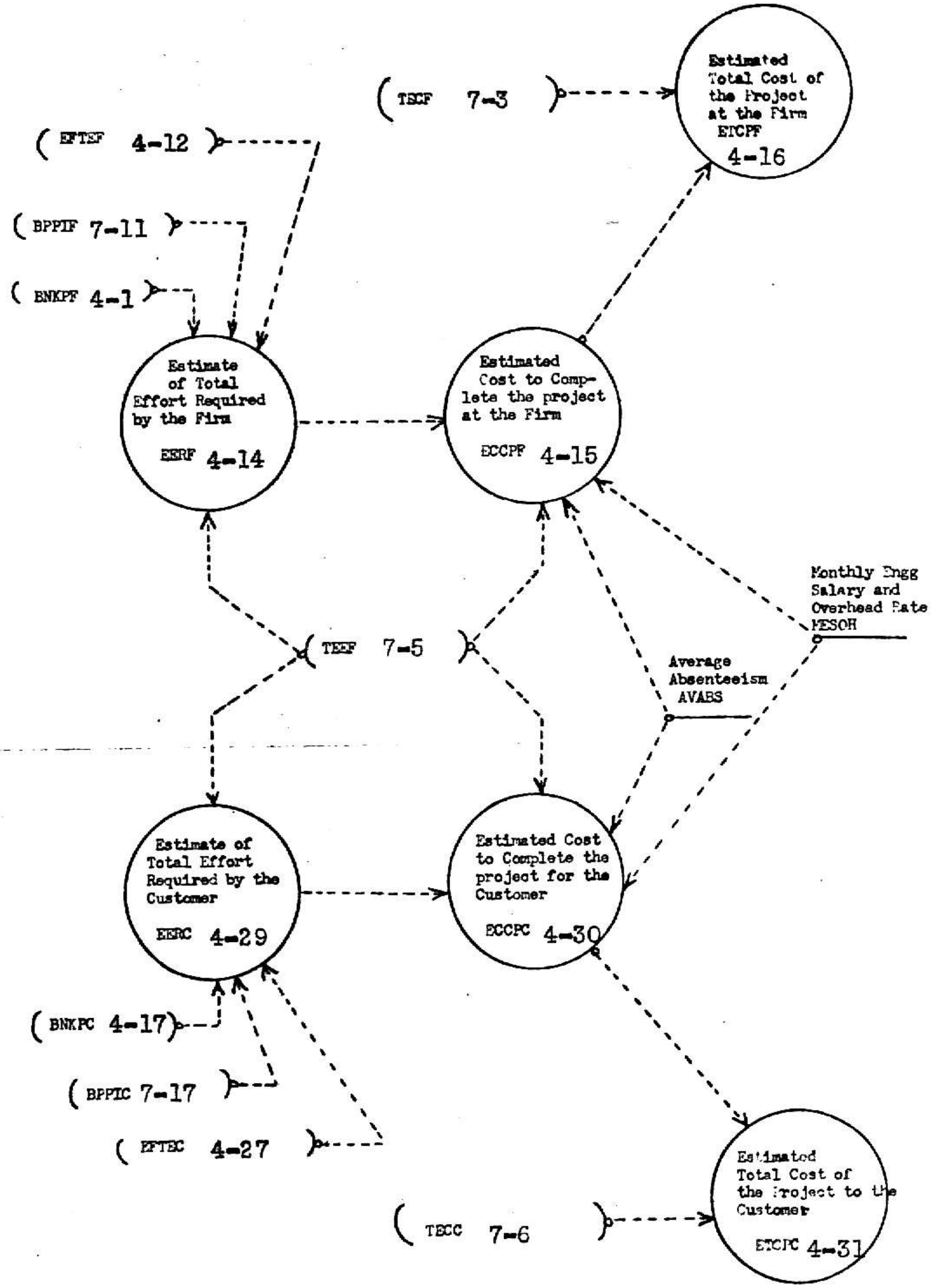


Figure 4.4 Estimation of effort and cost by both firm and customer(3)

EQUATIONS FOR FIRM'S ESTIMATION OF EFFORT AND COST

Estimation of total effort (EERF) is sum of effort expended to date (TEEF) and effort needed in future.

$$EERF.K = TEEF.K + \frac{(BPPIF.K)(BNKPF.K)}{(EFTEF.K)} \qquad (4\text{-}14,A)$$

EERF - Estimate of total Effort Required by the Firm (man-months of effort)

TEEF - Total Engineering Effort by the Firm (man-months of effort)

BPPIF - Believed Percentage of Project Incomplete at the Firm (percentage)

BNKPF - Believed Needed Know-how for development of the Product by the Firm (effective man-months of effort)

EFTEF - Estimate of Future Technical Effectiveness by the Firm (percentage effectiveness of the engineers)

The believed percent of project incomplete (BPPIF) multiplied by the believed job size (BNKPF) gives the believed amount of man-months of effort needed in future to complete the project. When this is divided by the estimated future technical effectiveness (EFTEF) we get the actual effort needed in future. The monthly engineering cost and over head rate (MESOH) comes to $2500 per month (3), and average absenteeism (AVABS) in the R and D firm comes to 11.5 percent (3).

MESOH = 2500

AVABS = 0.115

The expected cost to complete the porject (ECCPF) is given by equation (4-15).

$$ECCPF.K = \left(\frac{MESOH}{1-AVABS}\right)(EERF.K - TEEF.K) \qquad (4\text{-}15,A)$$

ECCPF - Estimated Cost to Complete the Project at the Firm (dollars)

EERF - Estimate of total Effort Required by the Firm (man-months)

TEEF - Total Engineering Effort at the Firm (man-months)

MESOH - Monthly Engineering Salary and Over Head rate (dollars per man month)

AVABS - AVerage ABSenteeism (percentage)

Total cost to complete the project (ETCPF) is sum of costs involved so far (TECF) and the expected cost to complete the project (ECCPF)

$$ETCPF.K = TECF.K + ECCPF.K \qquad (4\text{-}16,A)$$

ETCPF - Estimated Total Cost of the Project at the Firm (dollars)

TECF - Total Engineering Cost to the Firm (dollars)

ECCPF - Estimated Cost to Complete the Project at the Firm (dollars)

FLOW DIAGRAM AND EQUATIONS FOR CUSTOMER'S JOB SIZE ESTIMATION

Figure 4.5 shows the flow diagram for customers job size estimation. Based on the intrinsic size of the job (NLKP), his previous experience effect (PDPEC), and estimation ability (QC) the customer estimates the initial size of the job (BNKPC). Due to the gaps (GEAC) in estimated schedule (ESPCC) and believed percent of project completion (BPPCF) the customer revises his job size estimates. Fraction of customer's recognition of these gaps depends on the stage of project completion (PPC). The equations for this job size estimate can be written without

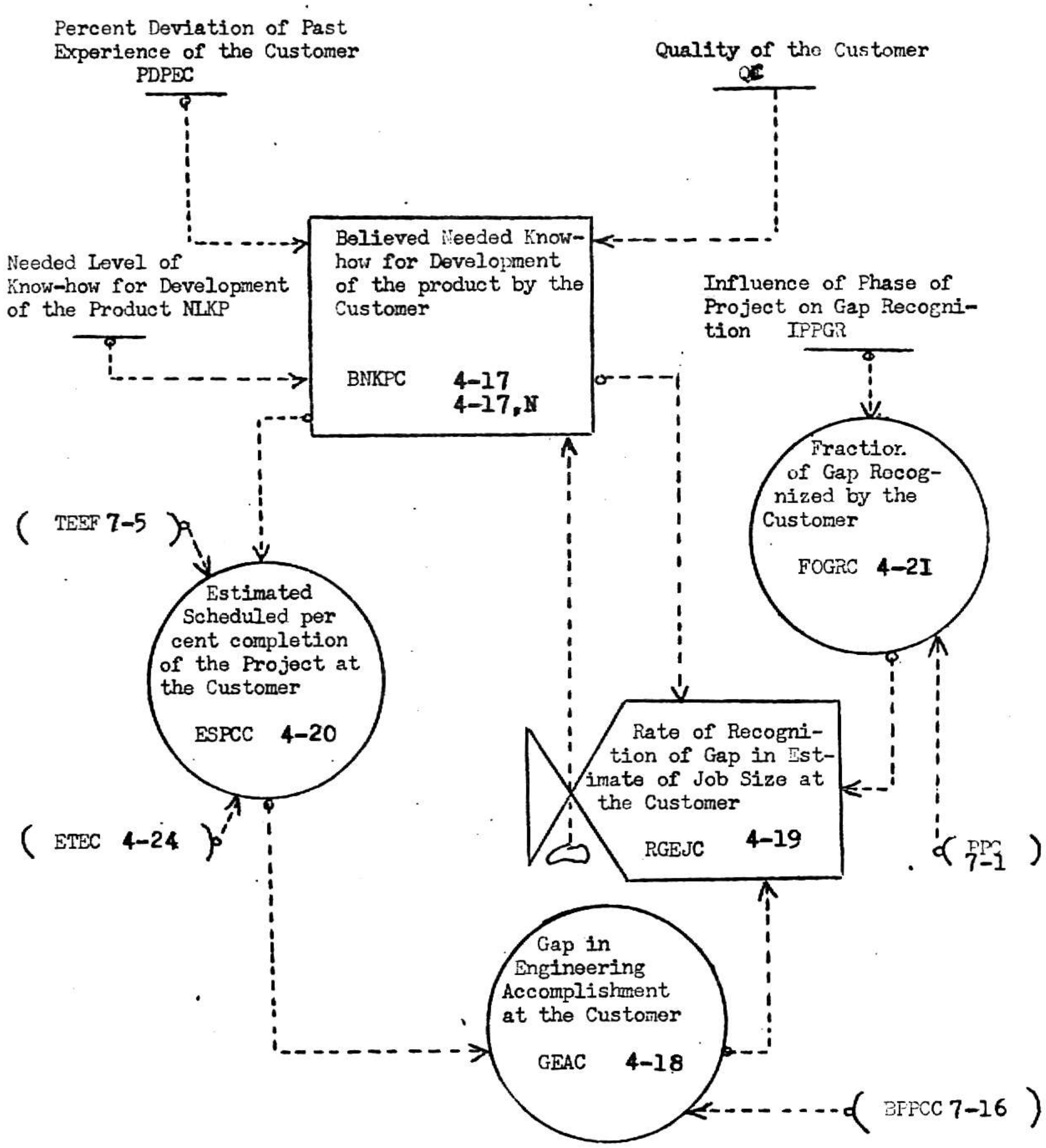


Figure 4.5 Customer's estimation of job size

much explanation as below.

BNKPC.K = BNKPC.J + (DT)(RGEJC.JK) (4-17,L)

BNKPC = (NLKP)(1 + PDPEC)/(QC) (4-17,N)

PDPEC = -0.175

QC = 0.6

$$GEAC.K = \frac{ESPCC.K - BPPCC.K}{BPPCC.K} \quad (4\text{-}18,A)$$

RGEJC.KL = (GEAC.K)(BNKPC.K)(FOGRC.K) (4-19,R)

$$ESPCC.K = \frac{(TEEF.K)(ETEC.K)}{(BNKPC.K)} \quad (4\text{-}20,A)$$

FOGRC.K = TABLE (IPPGR, PPC.K, 0, 1.0, 0.1) (4-21,A)

BNKPC - Believed Needed Know-how for development of the Product by the Customer (effective man-months of effort)

RGEJC - Rate of recognition of Gap in Estimate of Job size by the customer (effective man-months per month)

NLKP - Needed Level of Know-how for development of the Product (effective man-months of effort)

PDPEC - Percentage Deviation of Past Experience of the Customer (percentage)

QC - Quality of the customer (percentage)

GEAC - Gap in Engineering Accomplishment at the Customer (percentage error)

ESPCC - Estimated Scheduled Percentage Completion of the project at the Customer (percentage completion)

BPPCC - Believed Percentage of Project Completed by the Customer (percentage completion)

FOGRC - Fraction Of Gap Recognized by the Customer (percentage of gap recognized per month)

TEEF - Total Engineering Effort at the Firm (man-months of effort)

ETEC - Estimate of current Technical Effectiveness by the Customer (percentage effectiveness)

IPPGR - Influence of Phase of Project on Gap Recognition, table of stored numbers that gives the appropriate value for FOGRC for any given value of PPC

PPC - Percentage of Project Completion (percentage completion)

FLOW DIAGRAM AND EQUATIONS FOR CUSTOMER'S TECHNICAL EFFECTIVENESS

Figure 4.6 shows customer's estimation of technical effectiveness. The diagram is very much similar to that of the firm's flow diagram. Equations can be written without much explanation.

$$ATEC.K = ATEC.J + (DT)(RCTAC.JK) \qquad (4\text{-}22,L)$$

$$ATEC = TE \qquad (4\text{-}22,N)$$

$$RCTAC.KL = \frac{(TE.K - ATEC.K)}{DTITC} \qquad (4\text{-}23,R)$$

$$DTITC = 12 \text{ months}$$

$$ETEC.K = ETEC.J + (DT)(RCEEC.JK) \qquad (4\text{-}24,L)$$

$$ETEC = (ATEC)(CNFC)(WARC) \qquad (4\text{-}24,N)$$

$$CNFC = 0.6$$

$$WARC = 0.6$$

$$RCEEC.KL = \frac{RTEC.K - ETEC.K}{DRTEC} \qquad (4\text{-}25,R)$$

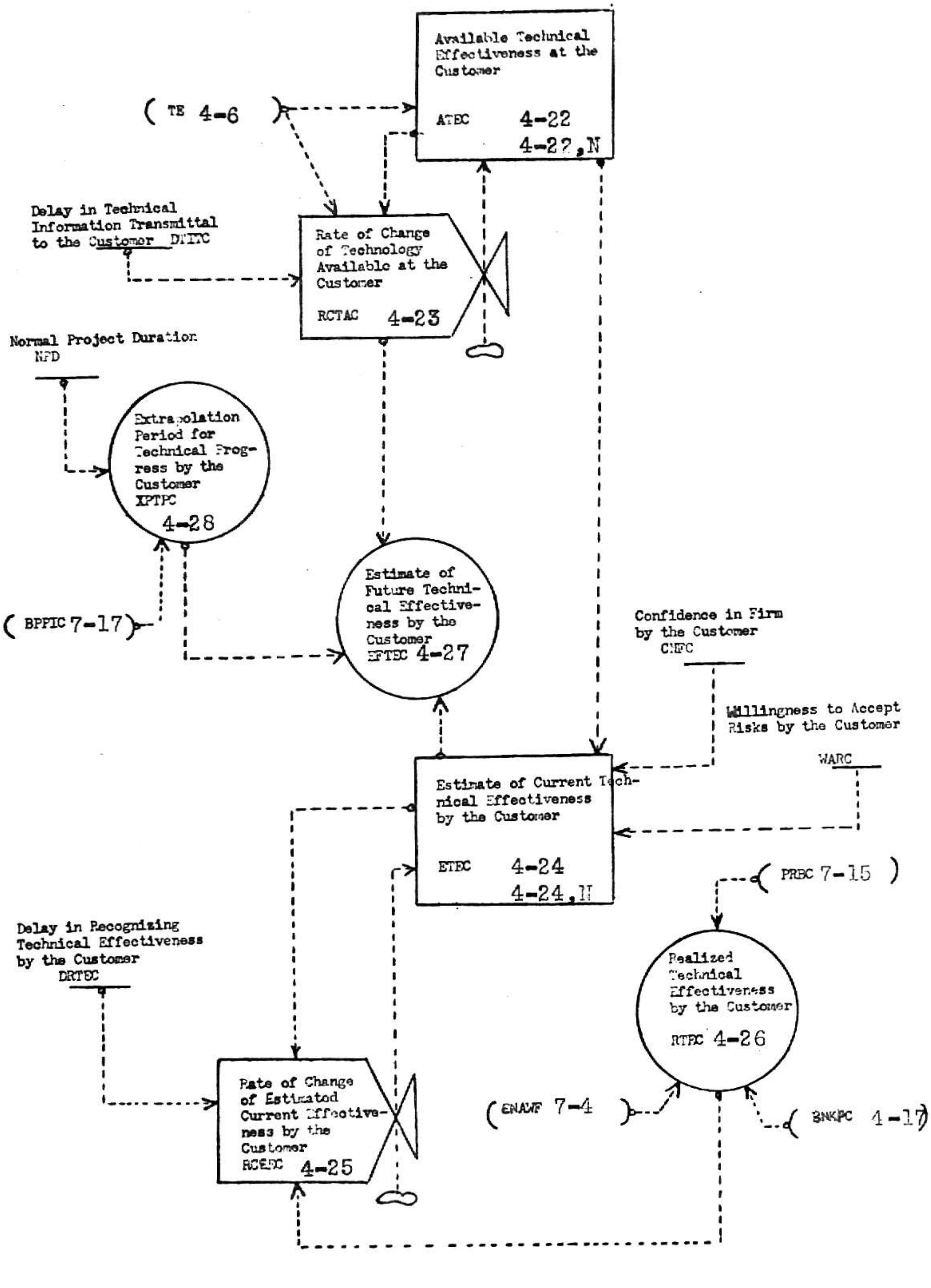


Figure 4.6 Customer's estimation of technical effectiveness

DRTEC = 8 montsh

$$RTEC.K = \frac{(PRBC.JK)(BNKPC.K)}{(ENAWF.K)} \quad (4.26,A)$$

$$EFTEC.K = ETEC.K + (XPTPC.K)(RCTAC.JK) \quad (4.27,A)$$

$$XPTPC.K = (BPPIC.K)(NPD/2) \quad (4.28,A)$$

ATEC - Available Technical Effectiveness at the Customer (percentage effectiveness of engineers)

RCTAC - Rate of Change of TEchnology Available at the Customer (percentage effectiveness per month)

TE - Technical Effectiveness within the state of art (percentage of engineers)

DTITC - Delay in Technical Information Transmittal to the Customer (months)

ETEC - Estimate of current Technical Effectiveness by the Customer (percentage effectiveness of engineers)

RCEEC - Rate of Change of Estimated current Effectiveness by the Customer (percentage effectiveness per month)

CNFC - Confidence iN Firm by the Customer (percentage)

WARC - Willingness to Accept Risks by the Customer (percentage)

RTEC - Realized Technical Effectiveness by the Customer (percentage effectiveness of engineers)

DRTEC - Delay in Recognizing Technical Effectiveness by the Customer (months)

PRBC - Progress Rate Believed by the Customer (percentage completion per month)

ENAWF - ENgineers Actually at Work at the Firm (men)

EFTEC - Estimate of Future Technical Effectiveness by the Customer (percentage effectiveness of engineers)

XPTPC - eXtrapolation Period for Technical Progress by the Customer (months)

BPPIC - Believed Percentage of Project Incomplete by the Customer (percentage)

NPD - Normal Project Duration (months)

FLOW DIAGRAM AND EQUATIONS FOR CUSTOMER'S EFFORT AND COST ESTIMATES

The flow diagram for this process is shown in Figure 4.4. The equations are given below.

$$EERC.K = TEEF.K + \frac{(BPPIC.K)(BNKPC.K)}{EFTEC.K} \quad (4.29,A)$$

$$ECCPC.K = \left(\frac{MESOH}{1-AVABS}\right)(EERC.K - TEEF.K) \quad (4.30,A)$$

$$ETCPC.K = TECC.K + ECCPC.K \quad (4-31,A)$$

EERC - Estimate of total Effort Required by the Customer (mass-months of effort)

TEEF - Total Engineering Effort by the Firm (man-months of effort)

BPPIC - Believed Percentage of Project Incomplete by the Customer (percentage)

BNKPC - Believed Needed Know-how for development of the Product by the Customer (effective man-months of effort)

EFTEC - Estimate of Future Technical Effectiveness by the Customer (percentage effectiveness of engineers)

ECCPC - Estimated Cost to Complete the Project for the Customer (dollars)

MESOH - monthly Engineering Salary and Over Head rate (dollars per man-month)

AVABS - AVerage ABSenteeism (percentage)

ETCPC - Estimated Total Cost of the Project to the Customer (dollars)

TECC - Total Engineering Cost to the Customer (dollars)

This completes the specification of equations for estimation of effort and cost by both firm and customer.

MODIFICATIONS IN THE FLOW DIAGRAMS

It is explained earlier in this chapter that the estimation of initial job size is influenced by 1) the intrinsic size of the job, 2) percent deviation of the past experience and 3) the quality of the firm (or the customer). The author has assumed that the initial estimation of the job size is directly influenced by the above three factors. These three factors are shown on the top of Figures 4.1 and 4.5. Roberts introduced a modifier, the value of which is assumed to depend on the percent deviation of past experience and quality of the firm (or the customer). He used this midifier and intrinsic size of the job to influence the initial estimation of the job size.

In figures 4.2 and 4.6 modifications were made in estimating the current technical effectiveness and future technical effectiveness. The author has assumed that the revision of current technical effectiveness is influenced by the rate of change of current technical effectiveness.

Roberts assumed that the revision in current technical effectiveness is influenced by the rate of change in current technical effectiveness and rate of correction of previous effectiveness. It is expalined earlier in this chapter that the estimation of future technical effectiveness of the engineers depend on current technical effectiveness, rate of change of technical effectiveness available to the firm (or customer) and the extrapolation period over which these changes are expected to continue. Roberts used an exponentially smoothed value for the rate of change of technical effectiveness. The author has used the actual rate of change of technical effectiveness between solution time intervals.

CHAPTER 5

FUNDING OF R AND D PROJECT

INTRODUCTION

The third major activity of R & D life cycle is funding of R and D project. This is divided into 3 phases.

1) Firm's request for financial support

2) Customer's evaluation and commitment of funds.

3) Firm's investment decision in the project.

Each phase is dealt in separately.

FLOW DIAGRAM FOR FIRM'S REQUEST FOR FINANCIAL SUPPORT

Figure 5.1 shows the flow diagram for firm's request for financial support. In this particular activity, the firm decides the rate of funds to be requested for the project from the customer.

In Chapter 2, it was mentioned that this sub activity is influenced by 1) the estimated future product value 2) the estimated total cost to complete the project and 3) the firm's integrity. These three factors are shown in the diagram at the bottom. The top half portion of the flow diagram shows the decision rule for requesting increases or decreases in project funds. The firm will change its level of project funding when it finds the expected under run in funds or biddable additional funds exceed a fixed percentage of current funding.

Depending on the integrity, the firm differs its cost estimates submitted to the customer from its original estimates. This estimate is denoted in the flow diagram as competitive estimate of completion costs

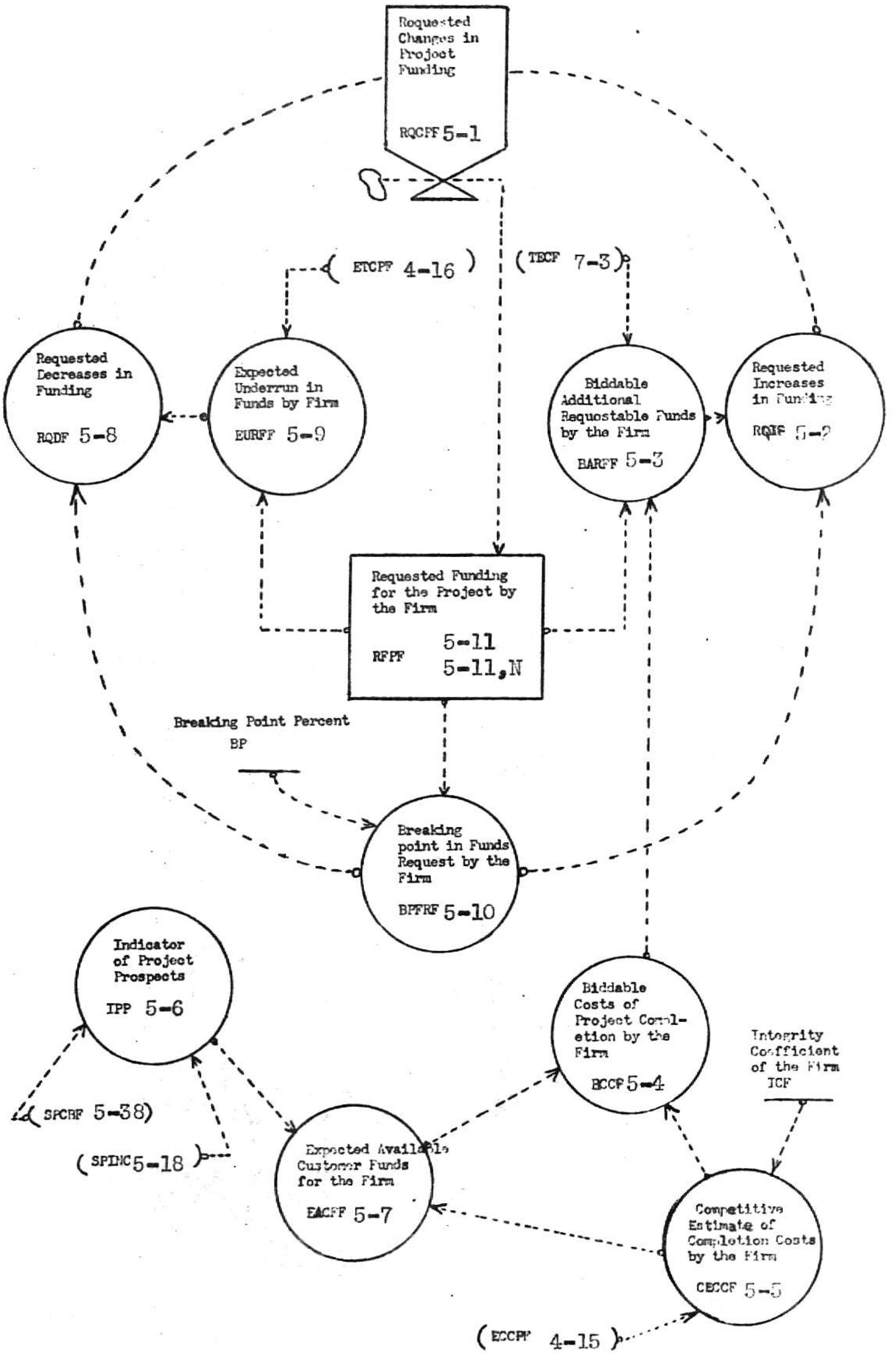


Figure 5.1 Firm's request for financial support

(CECCF). Based on these competitive costs and the suitability of the project (IPP), the firm estimates the funds available to the customer (EACFF). At any time, the firm will request the maximum of the competitive cost and the funds available to the customer.

EQUATIONS FOR FIRM'S REQUEST FOR FINANCIAL SUPPORT

Rate of change of project funding request (RQCPF) by the firm is a sum of requested increases (RQIF) and decreases (RQDF) in funds.

$$\text{RQCPF.KL} = \text{RQIF.K} + \text{RQDF.K} \tag{5-1,R}$$

RQCPF - ReQuested Changes in Project Funding (dollars per month)

RQIF - ReQuested Increases in Funding (dollars per month)

RQDF - ReQuested Decreases in Funding (dollars per month)

Whenever the biddable additional requestable funds (BARFF) exceeds a fixed percentage of funds requested previously, the firm requests for an increase (RQIF) in funds

$$\text{RQIF.K} = \begin{cases} \dfrac{\text{BARFF.K}}{\text{DT}} & \text{if BARFF} \geq \text{BPFRF} \\ 0 & \text{if BARFF} < \text{BPFRF} \end{cases} \tag{5-2,A}$$

RQIF - ReQuested Increases in Funding (dollars per month)

BARFF - Biddable Additional Requestable Funds by the Firm (dollars)

BPFRF - Breaking Point in Funds Request by the Firm (dollars)

The desired project funding is a summation of the level of the project costs (TECF) plus an additional amount which the firm believes it can request (BCCF). From this desired project funding the firm subtracts the funds previously requested (RFPF) to obtain the additional biddable costs (BARFF)

BARFF.K = TECF.K + BCCF.K - RFPF.K (5-3,A)

BARFF - Biddable Additional Requestable Funds by the Firm (dollars)

TECF - Total Engineering Cost to the Firm (dollars)

BCCF - Biddable Costs of project Completion by the Firm (dollars)

RFPF - Requested Funding for the Project by the Firm (dollars)

The amount that the firm believes it should request for further work on the project (BCCF) depends on 1) funds available to the customer (EACFF) and 2) the amount (CECFF) needed to complete the project which taking into account competitive conditions.

BCCF.K = MAX (EACFF.K, CECCF.K) (5-4,A)

BCCF - Biddable Costs of project Completion by the Firm (dollars)

EACFF - Expected Available Customer Funds for the Firm (dollars)

CECCF - Competitive Estimate of Completion Costs by the Firm (dollars)

The competitive estimate of completion costs by the firm (CECCF) is given by

CECCF.K = (ECCPF.K)(ICF) (5-5,A)

ICF = 0.9

CECCF - Competitive Estimate of Completion Costs by the Firm (dollars)

ECCPF - Estimated Cost to Complete the Project at the Firm (dollars)

ICF - Integrity Coefficient of the Firm (percentage)

IPP, indicator of project prospects is the maximum of firm's belief about suitability (SPCBF) and information obtained on customers belief about suitability (SPINC) of the project

IPP.K = MAX (SPCBF.K, SPINC.K) (5-6,A)

IPP - Indicator of Project Prospects (percentage)

SPCBF - Suitability of the Project to the Customer, Believed by the Firm (percentage)

SPINC - Suitability of the Project for INvestment by the Customer (percentage)

Firm's estimate of available funds to the customer (EACFF) depends on IPP and CECFF

$$EACFF.K = (IPP.K)(CECCF.K) \qquad (5\text{-}7,A)$$

EACFF - Expected Available Customer Funds for the Firm (dollars)

IPP - Indicator of Project Prospects (percentage)

CECCF - Competitive Estimate of Completion Costs by the Firm (dollars)

So far the equations represent the firm's request for additional funds. They describe the situation when the firm thinks it has requested less funds than it needs for R and D project and its actions. Now the following equations will represent the firm's request for decrease in funds. The firm requests a decrease (RQDF) in funds when the expected underrun (EURFF) in funds exceed a fixed percent of the requested funds (BPFRF)

$$RQDF.K = \begin{cases} \dfrac{EURFF.K}{DT} & \text{if } EURFF \geq BPFRF.K \\ 0 & \text{if } EURFF < BPFRF.K \end{cases} \qquad (5\text{-}8,A)$$

RQDF - ReQuested Decreases in Funding (dollars per month)

EURFF - Expected Under Run in Funds by the Firm (dollars)

BPFRF - Breaking Point in Funds Request by Firm (dollars)

When the requested funds (RFPF) exceed the estimated cost to complete the project (ETCPF) then there will be an underrun (EURFF) in the funds. Breaking point in funds request (BPFRF) is a fraction (BP) of the requested funds (RFPF)

EURFF.K = RFPF.K - ETCPF.K (5-9,A)

BPFRF.K = (BP)(RFPF.K) (5-10,A)

BP = 0.05

EURFF - Expected UnderRun in Funds by Firm (dollars)

RFPF - Requested Funding for the Project by the Firm (dollars)

ETCPF - Estimated Total Cost of the Project at the Firm (dollars)

BPFRF - Breaking Point in Funds Request by the Firm (dollars)

BP - Breaking Point percentage (percentage)

The level of requested funds (RFPF) is a summation of requested changes in funds (RQCPF)

RFPF.K = RFPF.J + (DT) (RQCPF.JK) (5-11,L)

RFPF = 0 (5-11,N)

RFPF - Requested Funding for the Project by the Firm (dollars)

RQCPF - ReQuested Changes in Project Funding (dollars per month)

FLOW DIAGRAM FOR CUSTOMER EVALUATION AND FUNDING OF THE PROJECT

The second sub-activity of funding of R and D project is represented in two Figures 5.2 and 5.3. Figure 5.2 shows the flow diagram for customer evalution and commitment of funds. Figure 5.3 shows the flow diagram for the customer's indirect project control activity. Each diagram is explained separately below.

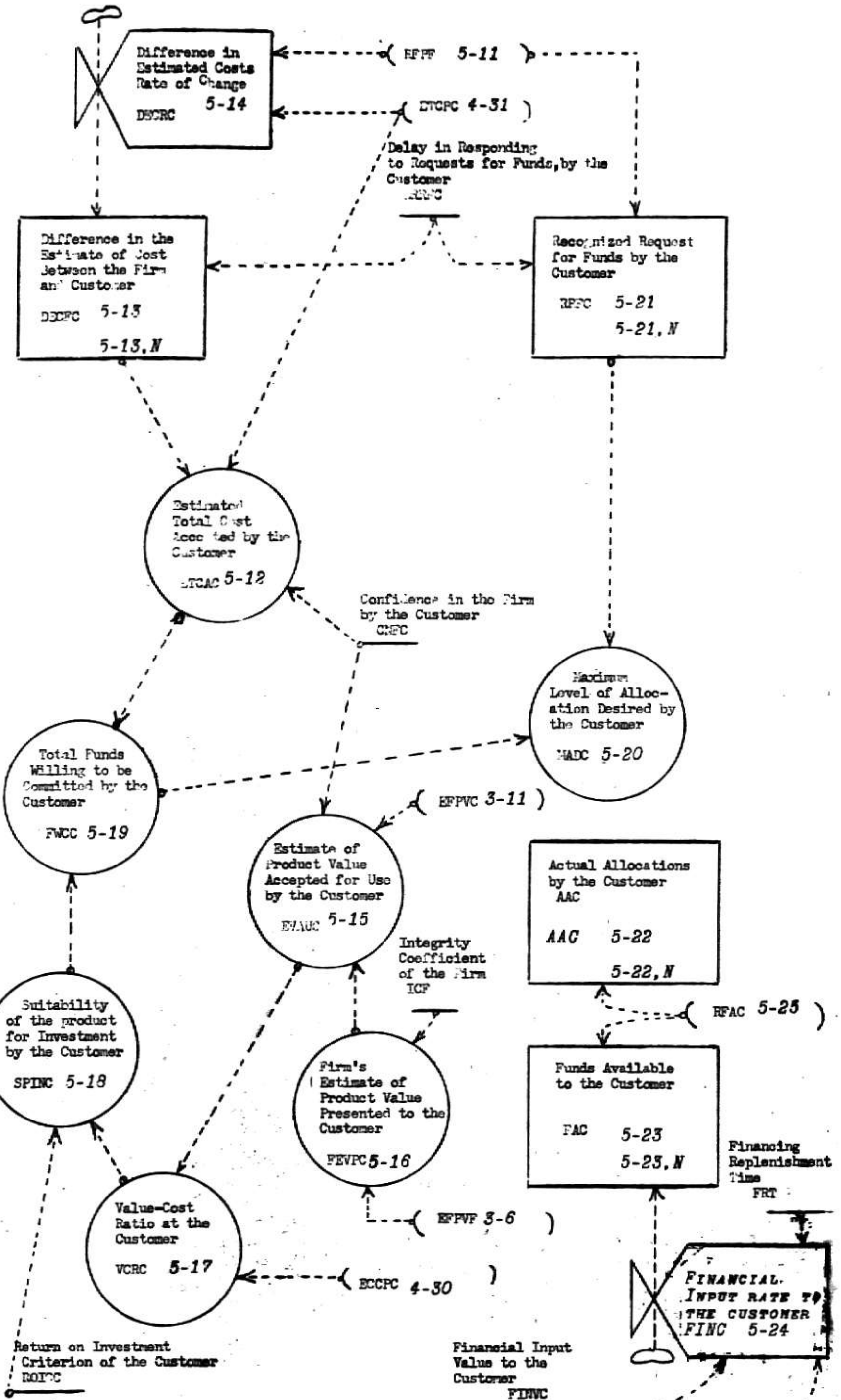


FIGURE 5.2 CUSTOMER EVALUATION AND FUNDING OF THE PROJECT

Figure 5.2 examines those aspects pertaining to the customer's evaluation and approach of the funds request and the actual allocation of funds. Based on the estimated future product value and estimated cost to complete the project and return on investment criterion, the customer decides the amount of funds he is willing to invest in the project. Depending on the confidence in the firm's estimates, the customer tries to adjust his internally held value, cost estimates with that of the firm. The maximum amount of funds allocation by the customer depends on funds request and funds which the customer is willing to invest in the project.

EQUATIONS FOR THE CUSTOMER'S PROJECT EVALUATION

From Figure 5.2, the estimated total cost acceptable by the customer (ETCAC) is given as the sum of the cost estimate by the customer (ETCPC) and fraction of the difference (DECFC) in estimates of the firm and customer. This fraction depends on customer confidence in the firm (CNFC).

$$ETCAC.K = ETCPC.K + (CNFC)(DECFC.K) \qquad (5\text{-}12,A)$$

$$DECFC.K = DECFC.J + \frac{(DT)}{(DRRFC)}(DECRC.JK - DECFC.J) \qquad (5\text{-}13,L)$$

$$DECFC = 0 \qquad (5\text{-}13,N)$$

ETCAC - Estimated Total Cost Accepted by the Customers (dollars)

ETCPC - Estimated Total Cost of the Project by the Customer (dollars)

CNFC - Confidence iN the Firm by the Customer (percentage)

DECFC - Difference in the Estimates of Cost between the Firm and the Customer (dollars)

DRRFC - Delay in Responding to Requests for Funds, by the Customer (months)

DECRC - Difference in Estimated Costs, Rate of Change (dollars)

DECFC is a smoothed average of the difference between the firm's request and the customer's internal estimate. This averaging in the difference is done over a period of DRRFC which is assumed to be 3 months. The rate of change of difference in estimated costs (DECRC) is equal to

$$DECRC.KL = RFPF.K - ETCPC.K \quad (5\text{-}14,R)$$

DECRC - Difference in Estimated Costs, Rate of Change (dollars)

RFPF - Requested Funding for the Project by the Firm (dollars)

ETCPC - Estimated Total Cost of the Project by the Customer (dollars)

The estimate of product value accepted for use by the customer (EVAUC) will be equal to the sum of the customer's estimate of product value (EFPVC) and a fraction of the difference between the estimates of firm and customer. This fraction again depends on customer's confidence in the firm (CNFC)

$$EVAUC.K = EFPVC.K + (CNFC)(FEVPC.K - EFPVC.K) \quad (5\text{-}15,A)$$

EVAUC - Estimate of product Value Accepted for Use by the Customer (dollars)

EFPVC - Estimate of Future Product Value by the Customer (dollars)

CNFC - Confidence iN the Firm by the Customer (percentage)

FEVPC - Firm's Estimate of product Value Presented to the Customer (dollars)

Firm's estimate of product value presented to the customer (FEVPC) differs from its original estimate (EFPVF) and it depends on firm's integrity.

$$FEVPC.K = EFPVF.K + (1-ICF)(EFPVF.K) \qquad (5\text{-}16,A)$$

FEVPC - Firm's Estimate of product Value Presented to the Customer (dollars)

EFPVF - Estimate of Future Product Value by the Firm (dollars)

ICF - Integrity Coefficient of the Firm (percentage)

Customer's value cost ratio (VCRC) is given by

$$VCRC.K = \frac{EVAUC.K}{ECCPC.K} \qquad (5\text{-}17,A)$$

EVAUC - Estimate of product Value Accepted for Use by the Customer (dollars)

ECCPC - Estimated Cost to Complete the Project by the Customer

Combined with return on investment criterion (ROICC) and value cost ratio (VCRC.K) the customer arrives at the suitability of the project for investment (SPINC)

$$SPINC.K = VCRC.K/ROICC \qquad (5\text{-}18,A)$$

SPINC - Suitability of the Project for INvestment by the Customer (percentage)

VCRC - Value - Cost Ratio at Customer (percentage)

ROICC - Return On Investment Criterion of the Customer

In the simulation model the value of "SPINC" is made between 0 and 1. There is no meaning to negative values of SPINC, and when SPINC is greater than 1, it is assumed that the customer will invest in the project.

This is done by replacing equation 5-18 by

$$TPINC.K = VCRC.K/ROICC \qquad (5\text{-}18a,A)$$

$$CONST6.K = \begin{cases} 0 & 0 \geq TPINC.K \\ TPINC.K & \text{if } 0 < TPINC.K \end{cases} \qquad (5\text{-}18b,A)$$

$$SPINC.K = \begin{cases} 1 & \text{if } TPINC.K \geq 1 \\ CONST6.K & \text{if } TPINC.K < 1 \end{cases} \qquad (5\text{-}18c,A)$$

ROICC is assumed to be 2. This means that customer will invest in the project only when the expected value is at least twice the expected cost of the project.

Total funds willing to be committed by the customer (TFWCC) depends on acceptable completion costs (ETCAC) to the customer and the suitability of the project (SPINC)

$$TFWCC.K = (ETCAC.K)(SPINC.K) \qquad (5\text{-}19,A)$$

TFWCC - Total Funds Willing to be Committed by the Customer (dollars)

ETCAC - Estimated Total Costs Accepted by the Customer (dollars)

SPINC - Suitability of the Project for INvestment by the Customer (percentage)

Maximum level of allocation of funds desired (MADC) by the customer will be equal to the minimum of the funds request by firm (RRFC) and customer's total funds willing to be committed (TFWCC)

$$MADC.K = MIN\ (TFWCC.K,\ RRFC.K) \qquad (5\text{-}20,A)$$

MADC - Maximum level of Allocation Desired by the Customer (dollars)

TFWCC - Total Funds Willing to be Committed by the Customer (dollars)

RRFC - Recognized Request for Funds by the Customer (dollars)

The level of recognized request for funds by the customer (RRFC) is a summation of the changes in requested funding

$$RRFC.K = RRFC.J + \left(\frac{DT}{DRRFC}\right)(RFPF.J - RRFC.J) \quad (5\text{-}21,L)$$

$$RRFC = 0 \quad (5\text{-}21,N)$$

$$DRRFC = 3$$

RRFC - Recognized Request for Funds by the Customer (dollars)

DRRFC - Delay in Responding to Requests for Funds by the Customer (months)

RFPF - Requested Funding for the Project by the firm (dollars)

Actual allocation of funds (AAC) by the customer is equal to previous allocations plus rate of funds allocation

$$AAC.K = AAC.J + (DT)(RFAC.JK) \quad (5\text{-}22,L)$$

$$AAC = 0 \quad (5\text{-}22,N)$$

AAC - Actual Allocations by the Customer (dollars)

RFAC - Rate of Funds Allocation by the Customer (dollars per month)

Funds available to the customer (FAC) is equal to his previously available funds plus rate of funds input to the customer (FINC) minus rate of funds allocation (RFAC) since previous funds.

$$FAC.K = FAC.J + (DT)(FINC.JK - RFAC.JK) \quad (5\text{-}23,L)$$

$$FAC = 0 \quad (5\text{-}23,N)$$

FAC - Funds Available to the Customer (dollars)

FINC - Financial INput rate to the Customer (dollars per month)

RFAC - Rate of Funds Allocation by the Customer (dollars per month)

An impulse type of financial input is assumed for the customer.

FINC.KL = PULSE (FINVC, INTMC, FRT) (5-24,R)

FINC - Financial INput rate to the Customer (dollars per month)

FINVC - Financial INput Value to the Customer (dollars)

INTMC - INput TiMe of the Customer funds (months)

FRT - Financing Replinshment Time (months)

That is the customer is assumed to have FINVC dollars of input to his funds every FRT time period starting from time equal to INTMC. In the model these constants are assumed to be

FINVC = IEIO dollars

INTMC = 0

FRT = 500 months

Figure 5.3 represents the flow diagram for customer's project control activities. Customer will have an indirect control over the project activities by controlling the amount of funds allocation and scheduled project duration. Top portion of the flow diagram shows the factors affecting his scheduled project duration and bottom half of the flow diagram shows his control over allocation of funds.

Rate of funds allocation by the customer is limited by the funds available to the customer. Desired rate of funds allocation indicates the customer not to exceed his actual allocation rate by the desired

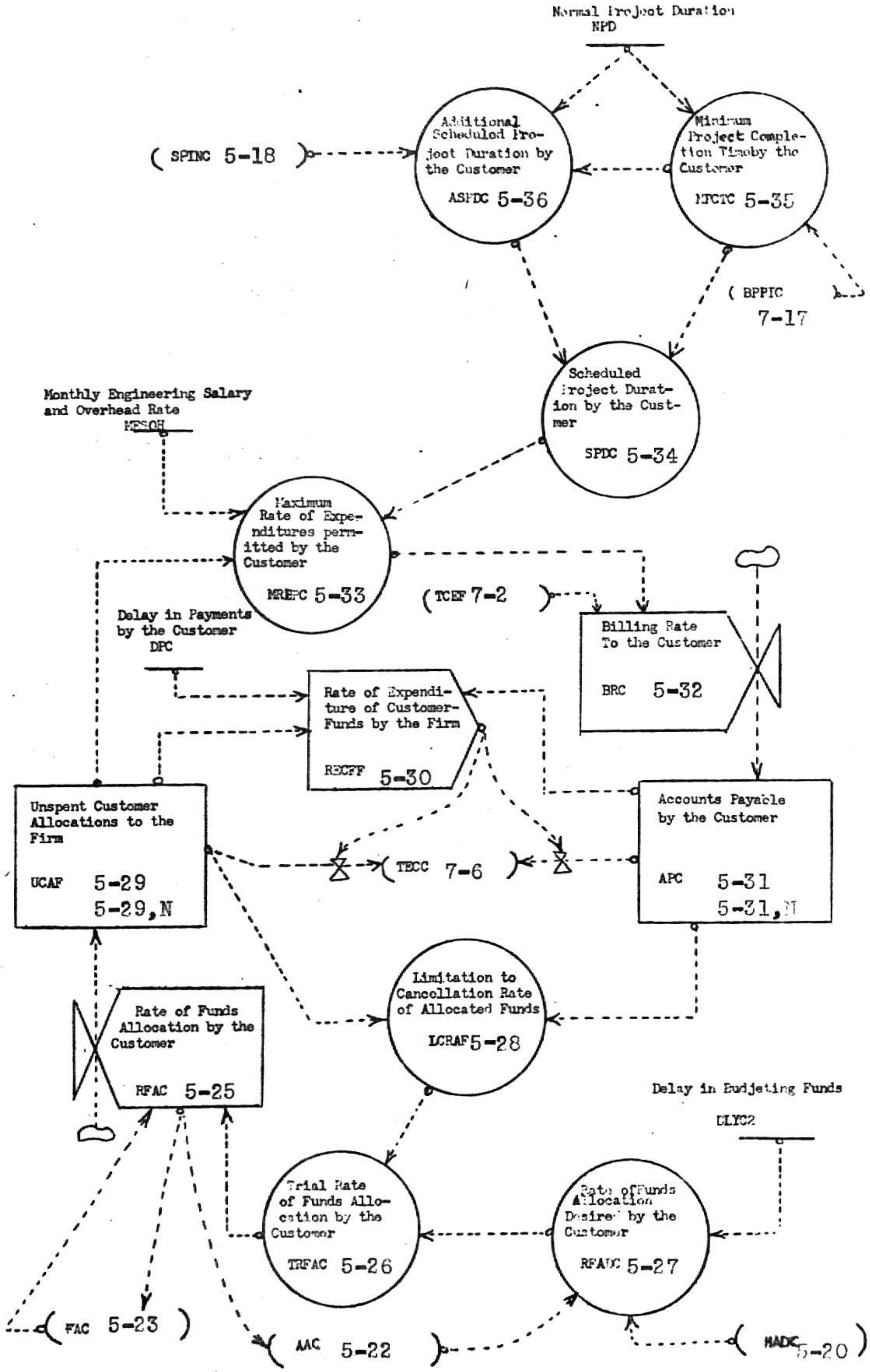


Figure 5.3 Customer project control activities

allocation rate. The customer can control the project activities by taking the suitable decision such as to release more funds or to cancel the previously allocated funds. From the flow diagram, it can be seen that the customer can not cancel more than the previously unspent allocations. Customer needs a certain amount of delay to take decisions about allocation of funds.

In arriving at the scheduled project duration, the customer tries to estimate expected scheduled time given the normal project duration and the percentage of work to be done. The customers strechout or speed up of the project schedule depends on the index of project suitability. If the project suitability is higher, the customer would like to speed up the project in order to obtain the project benefits earlier, and if the project suitability index is lower, then he would like to strechout the project duration by decreasing the funds allocation.

EQUATIONS FOR CUSTOMER PROJECT CONTROL ACTIVITIES

From the flow diagram in Figure 5.3, we can write the following equations. The rate of funds allocation (RFAC) would be equal to the amount of funds it can deplete in one solution time interval.

$$\text{RFAC.KL} = \begin{cases} \text{TRFAC.K} & \text{if TRFAC.K} \leq \dfrac{\text{FAC.K}}{\text{DT}} \\ \dfrac{\text{FAC.K}}{\text{DT}} & \text{if TRFAC.K} > \dfrac{\text{FAC.K}}{\text{DT}} \end{cases} \qquad \text{(5-25,R)}$$

RFAC - Rate of Funds Allocation by the Customer (dollars per month)

TRFAC - Trial Rate of Funds Allocation by the Customer (dollars per month)

FAC - Funds Available to the Customer (dollars)

The trial rate of funds allocation (TRAFC) will be the maximum of the desired rate of funds allocation (RFADC) and limitation to cancellation rate of allocated funds (LCRAF)

$$TRAFC.K = \begin{cases} RFADC.K & \text{if } RFADC.K \geq -LCRAF.K \\ -LCRAF.K & \text{if } RFADC.K < -LCRAF.K \end{cases} \qquad (5\text{-}26,A)$$

Desired rate of funds allocation (RFADC) will be the difference between the maximum allocation desired (MADC) and actual allocation by the customer (AAC) divided by the delay (DLYC2) period necessary for the customer to take action.

$$DLYC2 = 18$$

$$RFADC.K = \frac{MADC.K - AAC.K}{DLYC2} \qquad (5\text{-}27,A)$$

RFADC - Rate of Funds Allocation Desired by the Customer (dollars per month)

MADC - Maximum Allocation Desired by the Customer (dollars)

AAC - Actual Allocations by the Customer (dollars)

DLYC2 - Delay in budgeting funds by the customer (months)

Limitation to the rate of cancellation of funds (LCRAF) equals the difference between the unspent allocations (UCAF) and the accounts payable by the customer (APC) divided by the solution time interval.

$$LCRAF.K = \frac{UCAF.K - APC.K}{DT} \qquad (5\text{-}28,A)$$

LCRAF - Limitation to Cancellation Rate of Allocated Funds (dollars per month)

UCAF - Unspent Customer Allocations to the Firm (dollars)

APC - Accounts Payable by the Customer (dollars)

Customer's level of unspent allocations is a summation of the differences between rate of funds allocation (RFAC) and customers actual rate of expenditures (RECFF)

$$\text{UCAF.K} = \text{UCAF.J} + (\text{DT})(\text{RFAC.JK} - \text{RECFF.JK}) \qquad (5\text{-}29,\text{L})$$

$$\text{UCAF} = 0 \qquad (5\text{-}29,\text{N})$$

UCAF - Unspent Customer Allocations to the Firm (dollars)

RFAC - Rate of Funds Allocation by the Customer (dollars per month)

RECFF - Rate of Expenditure of Customer Funds by the Firm (dollars per month)

The customer's actual rate of expenditures (RECFF) is his normal payment of the approved billings by the firm (APC), up to the point at which he runs out of allocated funds

$$\text{RECFF.KL} = \begin{cases} \dfrac{\text{APC.K}}{\text{DPC}} & \text{if } \dfrac{\text{APC.K}}{\text{DPC}} \leq \dfrac{\text{UCAF.K}}{\text{DT}} \\ \dfrac{\text{UCAF.K}}{\text{DT}} & \text{if } \dfrac{\text{APC.K}}{\text{DPC}} > \dfrac{\text{UCAF.K}}{\text{DT}} \end{cases} \qquad (5\text{-}30,\text{R})$$

$$\text{DPC} = 2$$

RECFF - Rate of Expenditure of Customer Funds by the Firm (dollars per month)

APC - Accounts Payable by the Customer (dollars)

UCAF - Unspent Customer Allocations to the Firm (dollars)

DPC - Delay in Payments by the Customer (months)

The level of accounts payable by the customer (APC) is a summation of the difference between billing rate (BRC) and actual expenditure rate (RECFF) by the customer.

$$APC.K = APC.J + (DT)(BRC.JK - RECFF.JK) \qquad (5\text{-}31,L)$$

$$APC = 0 \qquad (5\text{-}31,N)$$

APC - Accounts Payable by the Customer (dollars)

BRC - Billing Rate to the Customer (dollars per month)

RECFF - Rate of Expenditure of Customer Funds by the Firm (dollars per month)

The firm's project billing rate (BRC) will be the minimum of firm's current expenditure rate (TCEF) and maximum expenditure rate allowed by the customer (MREPC)

$$BRC.KL = MIN\ (MREPC.K,\ TCEF.JK) \qquad (5\text{-}32,R)$$

and MREPC is given by

$$MREPC.K = \begin{cases} \dfrac{UCAF.K}{SPDC.K} & \text{if } \dfrac{UCAF.K}{SPDC.K} \geq MESOH \\ 0 & \text{if } \dfrac{UCAF.K}{SPDC.K} < MESOH \end{cases} \qquad (5\text{-}33,A)$$

MREPC - Maximum Rate of Expenditure Supported by the Customer (dollars per month)

TCEF - Total Current Expenditure rate by the Firm (dollars per month)

UCAF - Unspent Customer Allocations to the Firm (dollars)

SPDC - Scheduled Project Duration by the Customer (months)

MESOH - Monthly Engineering Salary and Over-Head rate (dollars per man month)

The scheduled project duration by the customer (SPDC) consists of two parts. The minimum project completion time (MPCTC) and additional project completion time (ASPDC). Minimum project completion time is half the normal time period that is needed to complete the project when the suitability index of the project is greater than or equal to one. Additional scheduled project duration is a strechout period in project schedule when the suitability index of the project (SPINC) is less than 1.

SPDC.K = ASPDC.K + MPCTC.K (5-34,A)

MPCTC.K = (BPPIC.K)(NPD)(0.5) (5-35,A)

ASPDC.K = (NPD - MPCTC.K)(1 - SPINC.K) (5-36,A)

SPDC - Scheduled Project Duration by the Customer (months)

ASPDC - Additional Scheduled Project Duration by the Customer (months)

MPCTC - Minimum Project Completion Time by the Customer (months)

BPPIC - Believed Percent of Project Incomplete by the Customer (percentage)

NPD - Normal Project Duration (months)

SPINC - Suitability of Project for INvestment by the Customer (percentage)

It is assumed that under any curcumstances the minimum time (MPCTC) needed to complete the project would be half the normal time needed to complete the project and it is given in equation 5-35. In simulation run, this minimum time is restricted to DT in order to avoid computational errors, and it is achieved by replacing the equation 5-35 by the following equations.

$$MPCTC.K = MAX\ (MPCT1.K,\ DT) \qquad (5\text{-}36a,A)$$

$$MPCTC1.K = (BPPIC.K)(NPD)(0.5) \qquad (5\text{-}36b,A)$$

FLOW DIAGRAM FOR FIRM'S INVESTMENT DECISION

Figure 5.4 shows the flow diagram for firm's investment decision. Based on the value cost ratio and the return on investment criterion by the customer, the firm arrives at the believed suitability of the project. Depending on the suitability of the project, estimated cost and expected profit rate, the firm estimates expected profit to the firm. Depending on firm's willingness, it will decide maximum desired investment from the expected profit. Limited by the funds available to the firm and maximum desired investment and its anticipated project duration, the firm decides the maximum desired rate of funds allocation. The firm has to allocate a basic rate of funds to support the engineers initially working in the project. The firm cancels the excess allocations from the unspent allocations once every budgeting period and it is shown on left hand top corner of the diagram.

EQUATIONS FOR FIRM'S INVESTMENT DECISION

Figure 5.4 shows the flow diagram for firm's investment decision. From the diagram the following equations can be written. The value cost ratio (VCRF) of the firm is a ratio of estimated future product value (EFPVF) and estimated total cost of the project (ETCPF). The value cost ratio when combined with investment criterion, the firm obtains its project suitability (SPCBF)

$$VCRF.K = \frac{EFPVF.K}{ETCPF.K} \qquad (5\text{-}37,A)$$

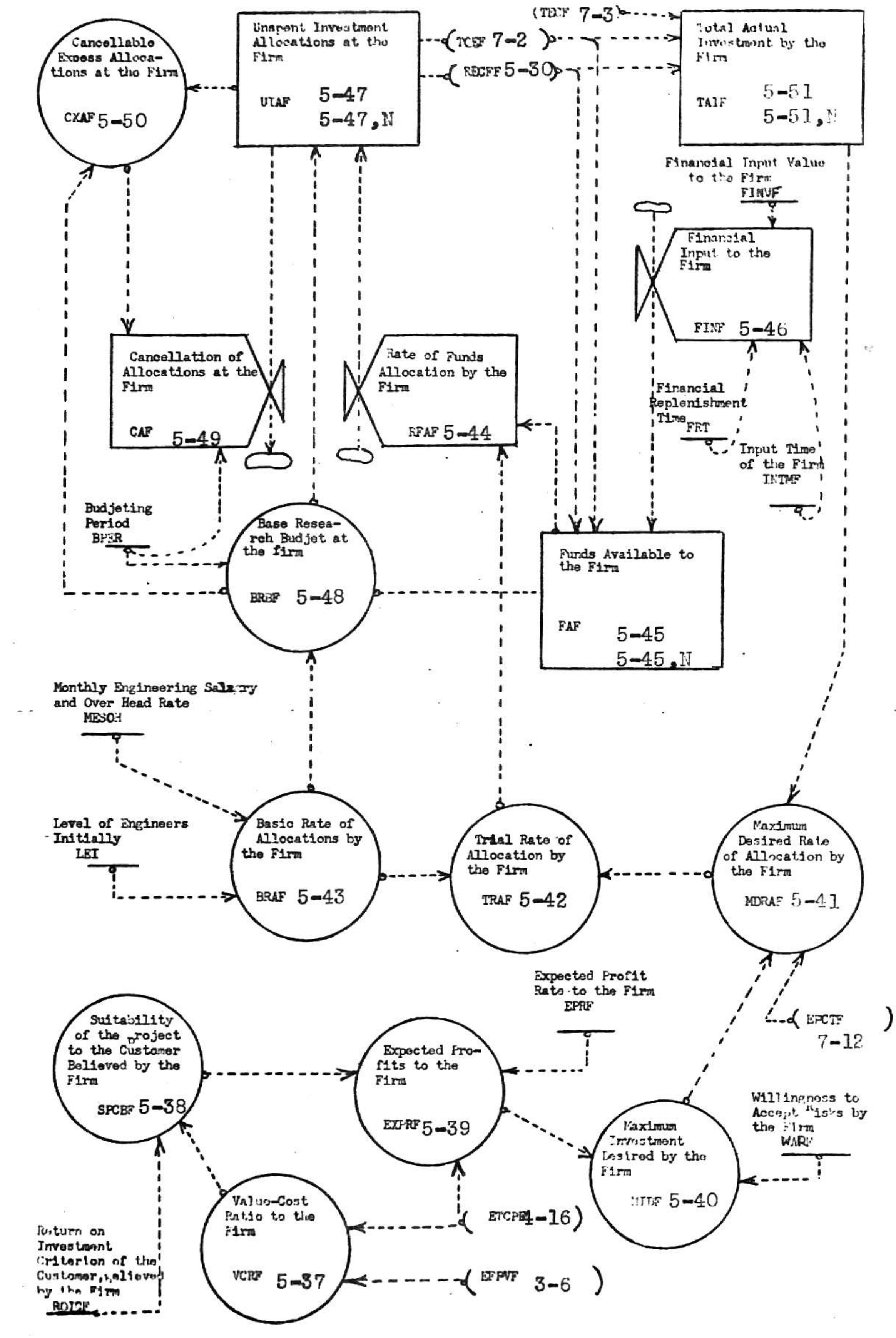


Figure 5.4 Firm's investment decision

$$SPCBF.K = \frac{VCRF.K}{ROICF} \qquad (5\text{-}38,A)$$

ROICF = 2.0

VCRF - Value - Cost Ratio of the Firm (percentage)

EFPVF - Estimated Future Product Value by the Firm (dollars)

ETCPF - Estimated Total Cost of the Project by the Firm (dollars)

SPCBF - Suitability of the Project to the Customer Believed by the Firm (percentage)

ROICF - Return on Investment criterion of the Customer, believed by the Firm (percentage)

Firms expected profit (EXPRF) can be determined by taking into account the total cost to complete the project (ETCPF), project suitability index (SPCBF) and expected profit rate (EPRF).

$$EXPRF.K = (EPRF)(SPCBF.K)(ETCPF.K) \qquad (5\text{-}39,A)$$

EPRF = 0.07

EXPRF - EXpected PRofits to the Firm (dollars)

EPRF - Expected Profit Rate to the Firm (percentage)

SPCBF - Suitability of the Project to the Customer, Believed by the Firm (percentage)

ETCPF - Estimated Total Cost of the Project by the Firm (dollars)

Depending on firms willingness to gamble (WARF) with the expected profit, the firm decides the maximum desired investment (MIDF) from the expected profit

$$MIDF.K = (WARF)(EXPRF.K) \qquad (5\text{-}40,A)$$

MIDF - Maximum Investment Desired by the Firm (dollars)

WARF - Willingness to Accept Risks by the Firm (percentage)

EXPRF - EXpected PRofits to the Firm (dollars)

Maximum desired rate of allocation by firm (MDRAF) will be the difference of amount between maximum desired investment (MIDF) and total actual investment (TAIF) divided by the expected completion time (EPCTC)

$$MDRAF.K = \frac{MIDF.K - TAIF.K}{EPCTC.K} \qquad (5\text{-}41,A)$$

MDRAF - Maximum Desired Rate of Allocation by the Firm (dollars per month)

MIDF - Maximum Investment Desired by the Firm (dollars)

TAIF - Total Actual Investment by the Firm (dollars)

EPCTF - Expected Project Completion Time by the Firm (months)

Trial rate of funds allocation by firm (TRAF) is assumed not to drop below the basic rate of allocation (BRAF) needed to support engineers initially. It is assumed that there is one engineer in the firm initially.

$$TRAF.K = \begin{cases} MDRAF.K & \text{if } MDRAF.K \geq BRAF \\ BRAF & \text{if } MDRAF.K < BRAF \end{cases} \qquad (5\text{-}42,A)$$

$$BRAF = (LEI)(MESOH) \qquad (5\text{-}43,A)$$

$$LEI = 1$$

TRAF - Trial Rate of Allocation by the Firm (dollars per month)

MDRAF - Maximum Desired Rate of Allocation by the Firm (dollars per month)

BRAF - Basic Rate of Allocation by the firm (dollars per month)

LEI - Level of Engineers Initially (men)

MESOH - Monthly Engineering Salary and Over Head rate (dollars per man-month)

The rate of fund allocation (RFAF) depends on trial rate of funds allocation (TRAF) and Funds available to the firm (FAF)

$$\text{RFAF.KL} = \begin{cases} \text{TRAF.K} & \text{if TRAF.K} \leq \frac{\text{FAF.K}}{\text{DT}} \\ \frac{\text{FAF.K}}{\text{DT}} & \text{if TRAF.K} > \frac{\text{FAF.K}}{\text{DT}} \end{cases} \qquad (5\text{-}44,\text{R})$$

RFAF - Rate of Fund Allocation by the Firm (dollars per month)

TRAF - Trial Rate of Allocation by the Firm (dollars per month)

FAF - Funds Available to the Firm (dollars)

The level of available funds (FAF) to the firm is a summation of financial input rate (FINC) by firm plus actual expenditure rate (RECFF) by customer minus total engineering expenditure rate (TCEF).

$$\text{FAF.K} = \text{FAF.J} + (\text{DT})(\text{FINF.K} + \text{RECFF.JK} - \text{TCEF.JK}) \qquad (5\text{-}45,\text{L})$$

$$\text{FAF} = 0 \qquad (5\text{-}45,\text{N})$$

FAF - Funds Available to the Firm (dollars)

FINF - Financial INput to the Firm (dollars per month)

RECFF - Rate of Expenditure of Customer Funds at the Firm (dollars per month)

TCEF - Total Current Expenditure rate by the Firm (dollars per month)

Firm is assumed to replenish the funds every financing replenishment time period with FINVF input, starting from time INTMF. Therefore the financial input rate FINF by the firm is given by

FINF.KL = PULSE (FINVF, INTMF, FRT) (5-46,R)

FINVF = 10E6

INTMF = 0

FRT = 500

FINF - Financial INput to the Firm (dollars per month)

FINVF - Financial INput Value to the Firm (dollars)

INTMF - INput TiMe of the Firm (months)

FRT - Financing Replenishment Time (months)

The level of unspent allocations at the firm (UIAF) is simply the accumulation of the new fund allocations (RFAF) plus cost reimbursements from the customer (RECFF) minus the amount of previous allocations cancelled by the firm (CAF). This level initially equals the base research budget (BRBF) which in turn provides the basic monthly rate of allocation for the length of the budgeting period (BPER).

UIAF.K = UIAF.J + (DT)(RFAF.JK + RECFF.JK - TCEF.JK - CAF.JK) (5-47,L)

UIAF = BRBF (5-47,N)

BRBF = (BPER)(BRAF) (5-48,N)

UIAF - Unspent Investment Allocations at the Firm (dollars)

RFAF - Rate of Funds Allocation by the Firm (dollars per month)

RECFF - Rate of Expenditure of Customer Funds at the Firm (dollars per month)

TCEF - Total Current Expenditure rate at the Firm (dollars per month)

CAF - Cancellation of Allocations at the Firm (dollars per month)

BRBF - Base Research Budget at the Firm (dollars)

BPER - Budgeting PERiod (month)

BRAF - Basic Rate of Allocation by the Firm (dollars per month)

Cancellation of funds (CAF) takes places at the end of every budget period (BPER) with an amount of CXAF

CAF.KL = PULSE (CXAF.K, BPER, BPER) (5-49,R)

BPER = 6 months

CAF - Cancellation of Allocations at the Firm (dollars per month)

CXAF - Cancellable eXcess Allocations at the Firm (dollars per month)

BPER - Budgeting PERiod (months)

CXAF is the cancellable excess allocations and is equal to the difference between the unspent investment allocation (UIAF) and the base research budget (BRBF)

$$CXAF.K = \frac{UIAF.K - BRBF}{DT} \qquad (5\text{-}50,A)$$

CXAF - Cancellable eXcess Allocations by the Firm (dollars per month)

UIAF - Unspent Investment Allocations by the Firm (dollars)

BRBF - Base Research Budget at the Firm (dollars)

The level of total actual investment by firm (TAIF) is a summation of the difference between the engineering costs by the firm (TCEF) and the customers actual expenditure Rate (RECCF)

$$TAIF.K = TAIF.J + (DT)(TCEF.JK - RECFF.JK) \qquad (5\text{-}51,L)$$

$$TAIF = 0 \qquad (5\text{-}51,N)$$

TAIF - Total Actual Investment by the Firm (dollars)

TCEF - Total Current Expenditure rate at the Firm (dollars per month)

RECFF - Rate of Expenditure of Customer Funds at the Firm (dollars per month)

The entire equations developed in this chapter complete the specification of model equations for funding of R and D project.

MODIFICATIONS IN THE FLOW DIAGRAMS

It is explained earlier in this chapter that the firm's fund request and customer's evaluation of fund request is influenced by the value cost relationship and return on investment criterion. Value cost relationship combined with return on investment criterion is denoted in the model as the suitability of the project for investment. The author has assumed that the suitability of the project to influence directly the firm's fund request and customer's evaluation of fund request. They are shown in Figures 5.1, and 5.2. Roberts assumed some kind of probability values which vary with the suitability of the project. He used these probability values in estimating the firm's fund request and customer's evaluation of fund request.

In figure 5.3 it is shown that the scheduled project duration consists of two parts. They are 1) minimum scheduled project duration and 2) additional scheduled project duration. The author has assumed that the additional scheduled project duration depends on the suitability of the project. Roberts assumed that the additional scheduled project duration depends on the expected percentage of over expenditure due to the increased suitability of the project.

In figure 5.4, the author has assumed that the firm's investment decision is influenced directly by the project suitability index, apart from other factors described earlier in this chapter. Roberts has assumed certain probability values which depend on the project suitability index. He used these probability values for determining the amount of funds to be invested by the firm.

CHAPTER 6

ACQUISITION AND UTILIZATION OF MANPOWER

INTRODUCTION

In this chapter DYNAMO equations and flow diagrams for acquisition and utilization of man power are presented. The various factors influencing this activity are enumerated in chapter 2. This activity is divided into two sub-activities, 1) acquisition of engineering manpower and 2) productivity of manpower. These two sub-activities are dealt with separately.

ACQUISITION OF MANPOWER

Figure 6.1 shows an over all flow diagram for the flow of manpower in the project. Figure 6.1 is further divided into Figures 6.2, 6.3, and 6.4. Figure 6.2 shows the factors affecting the desired number of engineers in the project. Figure 6.3 shows the firm's hiring and staff reassignment policy and Figure 6.4 shows the actual transfer rate of engineers in the firm. Each flow diagram is explained separately and DYNAMO equations are written as each flow diagram is explained.

Figure 6.1 shows the firm's flow of engineering manpower. Because of the firms engineering hiring activity, engineers join the firm. These engineers undergo a formal training in the firm. As they attain experience in the firm, some of them are reassigned to training and supervisory roles. Some of them are transferred to different projects or laid off depending on the need for engineers in the project. The transfer of engineers needs a short time delay for processing the paper work.

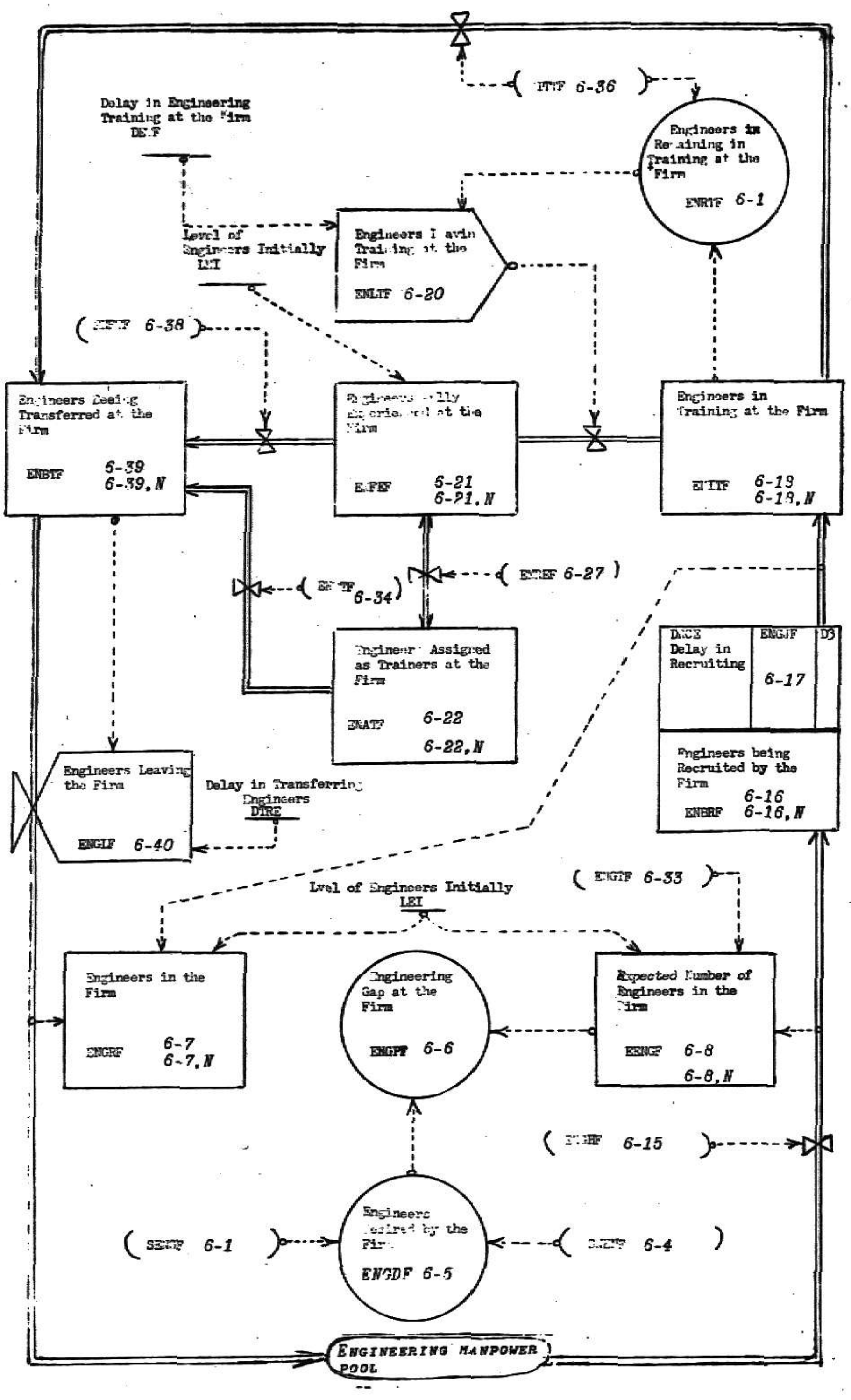


FIGURE 6.1 THE FLOW OF ENGINEERING MAN-POWER (3)

Some of the engineers who need training still remain in the training. This continuing flow of engineers into and out of the firm cumulatively produces two levels:

1) Engineers actually on the project and

2) Expected engineers on the project.

Firm will try to adjust the number of engineers in the project to desired level of engineers. The desired level of engineers is mainly based on the stable engineering workforce and supportable engineering force, which depend on the funds available to the firm.

Figure 6.2 shows the bottom portion of Figure 6.1, and shows the factors affecting the desired engineers in the firm. Supportable level of engineers by the firm depends on the expenditure rate available to the firm. Stable engineering work force level depends mainly on the estimated cost to complete the project, estimated time to complete the project and engineering costs and over head rate.

EQUATIONS FOR FACTORS AFFECTING NUMBER OF ENGINEERS DESIRED IN THE PROJECT

From Figure 6.2, the supportable engineers by the firm (SENGF) is equal to the expected expenditure rate (EERAF) divided by the monthly engineering and over head rate.

SENGF.K = EERAF.K / MESOH (6-1,A)

SENGF - Supportable number of ENGineers at the Firm (men)

EERAF - Expected Expenditure Rate Available to the Firm (dollars per month)

MESOH - Monthly Engineering Salary and Over Head rate (dollars per man-month)

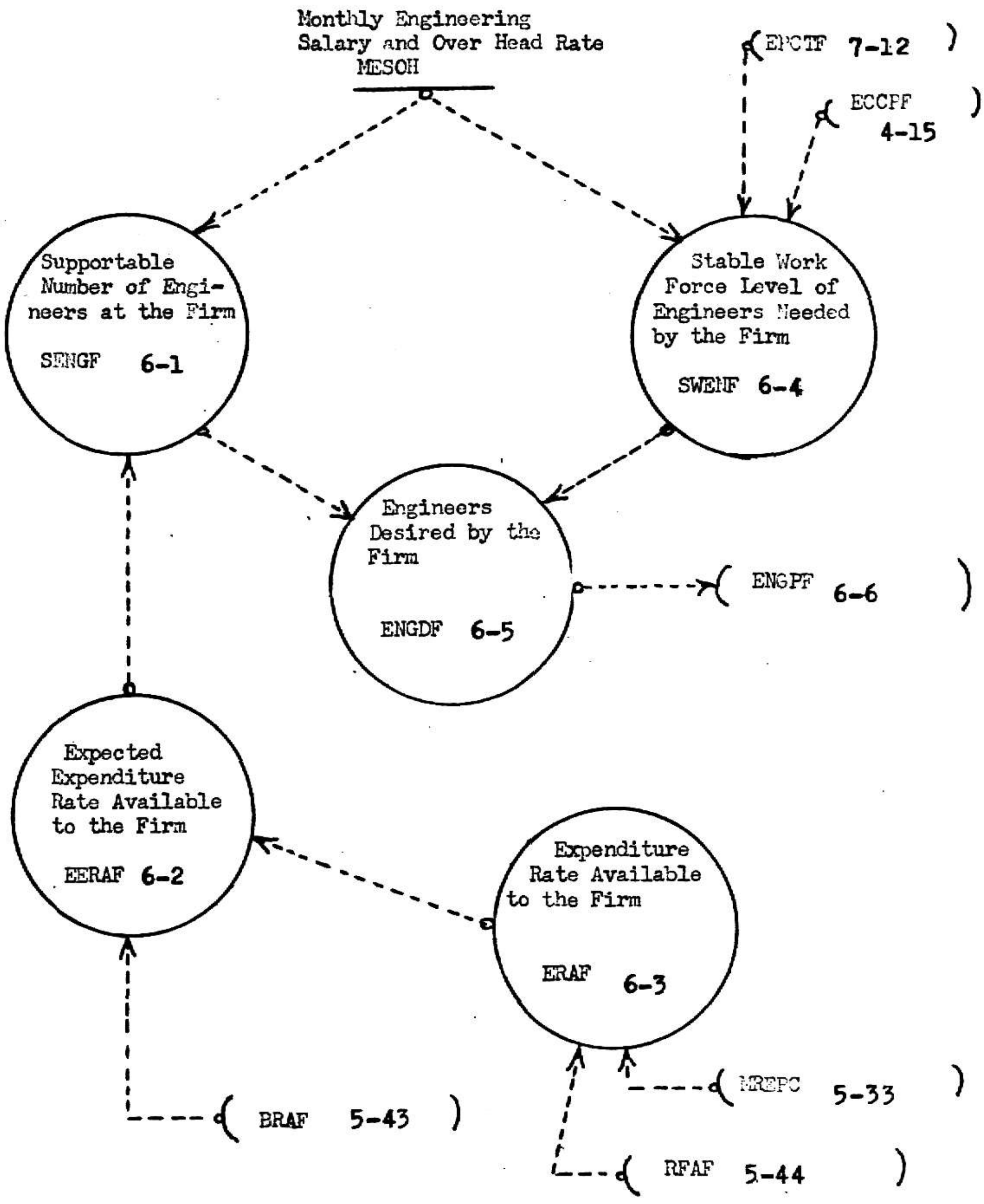


Figure 6.2 Factors affecting number of engineers desired in the project .

Expected expenditure rate (EERAF) will be the expenditure rate available to the firm (ERAF) unless it is restricted to the minimum basic rate of allocation (BRAF) needed to support initial engineers. Expenditure rate available to the firm (ERAF) will be the maximum of funds available to the firm (RFAF) and maximum expenditure rate permitted by the customer (MREPC)

$$\text{EERAF.K} = \text{MAX (BRAF, ERAF.K)} \tag{6-2,A}$$

$$\text{ERAF.K} = \text{MAX (RFAF.JK, MREPC.K)} \tag{6-3,A}$$

EERAF - Expected Expenditure Rate Available to the Firm (dollars per month)

ERAF - Expenditure Rate Available to the Firm (dollars per month)

BRAF - Basic Rate of Allocations by the Firm (dollars per month)

RFAF - Rate of Funds Allocation by the Firm (dollars per month)

MREPC - Maximum Rate of Expenditure Permitted by the Customer (dollars per month)

Stable work force level of engineers (SWENF) is equal to estimated cost to complete the project (ECCPF) divided by the cost of engineers till the time of completion

$$\text{SWENF.K} = \frac{\text{ECCPF.K}}{\text{(MESOH)(EPCTF)}} \tag{6-4,A}$$

SWENF - Stable Work force level of Engineers Needed by the Firm (men)

ECCPF - Expected Costs to Complete the Project by the Firm. (dollars)

MESOH - Monthly Engineering Salary and Over Head rate (dollars per man - month)

EPCTF - Expected Project Completion Time by the Firm (months)

Engineers desired in the project (ENGDF) is given in equation (6.5. Engineering gap at the firm (ENGPF) is simply the difference between the desired engineers (ENGDF) and expected engineers in the firm (EENGF)

ENGDF.K = MIN (SENGF.K, SWENF.K) (6-5,A)

ENGPF.K = ENGDF.K - EENGF.K (6-6,A)

ENGDF - ENGineers Desired by the Firm (men)

SENGF - Supportable number of ENGineers at the Firm (men)

SWENF - Stable Work force level of ENgineers Needed at the Firm (men)

ENGPF - ENgineering GaP at the Firm (men)

EENGF - Expected number of ENGineers at the Firm (men)

The number of engineers in the firm (ENGRF) is a summation of the difference between the rate of engineers joining (ENGJF) and rate of engineers leaving the firm (ENGLF)

ENGRF.K = ENGRF.J + (DT)(ENGJF.JK - ENGLF.JK) (6-7,L)

ENGRF = LEI (6-7,N)

ENGRF - ENGineeRs in the Firm (men)

ENGJF - ENGineers Joining in the Firm (men per month)

ENGLF - ENGineers Leaving the Firm (men per month)

LEI - Level of Engineers INitially (men)

LEI is the level of eingineers initially and it is assumed to be 1 in the model.

ENGINEERING HIRING AND REASSIGNMENT AT THE FIRM

Figure 6.3 shows the firm's engineering hiring and reassignment of staff. Hiring or transferring of engineers depends on the engineering gap (ENGPF). From bottom of the flow diagram, it can be seen that based on the engineering gap (ENGPF) and delay in changing the engineering level at the firm (DCEF) the firm arrives at the desired engineering hiring rate (DENHF). Depending on the number of experienced engineers (ENFEF) and engineer trainers (ENATF) and thier training capacity (TPSDF), the firm estimates the maximum number of engineers (MEITF) it can have in training. Based on the estimate of maximum number of engineers (MEITF) and the expected number of engineers in the training (EEITF), the firm further decides the maximum engineering hiring rate (MENHF). However, the firm's actual hiring rate (ENGHF) depends on the desired hiring rate (DENHF) and maximum hiring rate (MENHF). Based on the expected engineers in the training (EEITF), the firm estimates the desired trainers (ENDTF) in the project. Depending on the number of engineering trainers in the project (ENATF) and the desired trainers (ENDTF), the firm decides the extra engineers needed for reassignment as trainers (EDRTF).

EQUATIONS FOR FIRM'S HIRING AND REASSIGNMENT

From Figure 6.1, EENGF, expected engineers in the firm is a continuous summation of the difference between hiring rate (ENGHF) and transfer rate (ENGTF)

EENGF.K = EENGF.J + (DT)(ENGHF.JK - ENGTF.JK) (6-8,L)

EENGF = LEI (6-8,N)

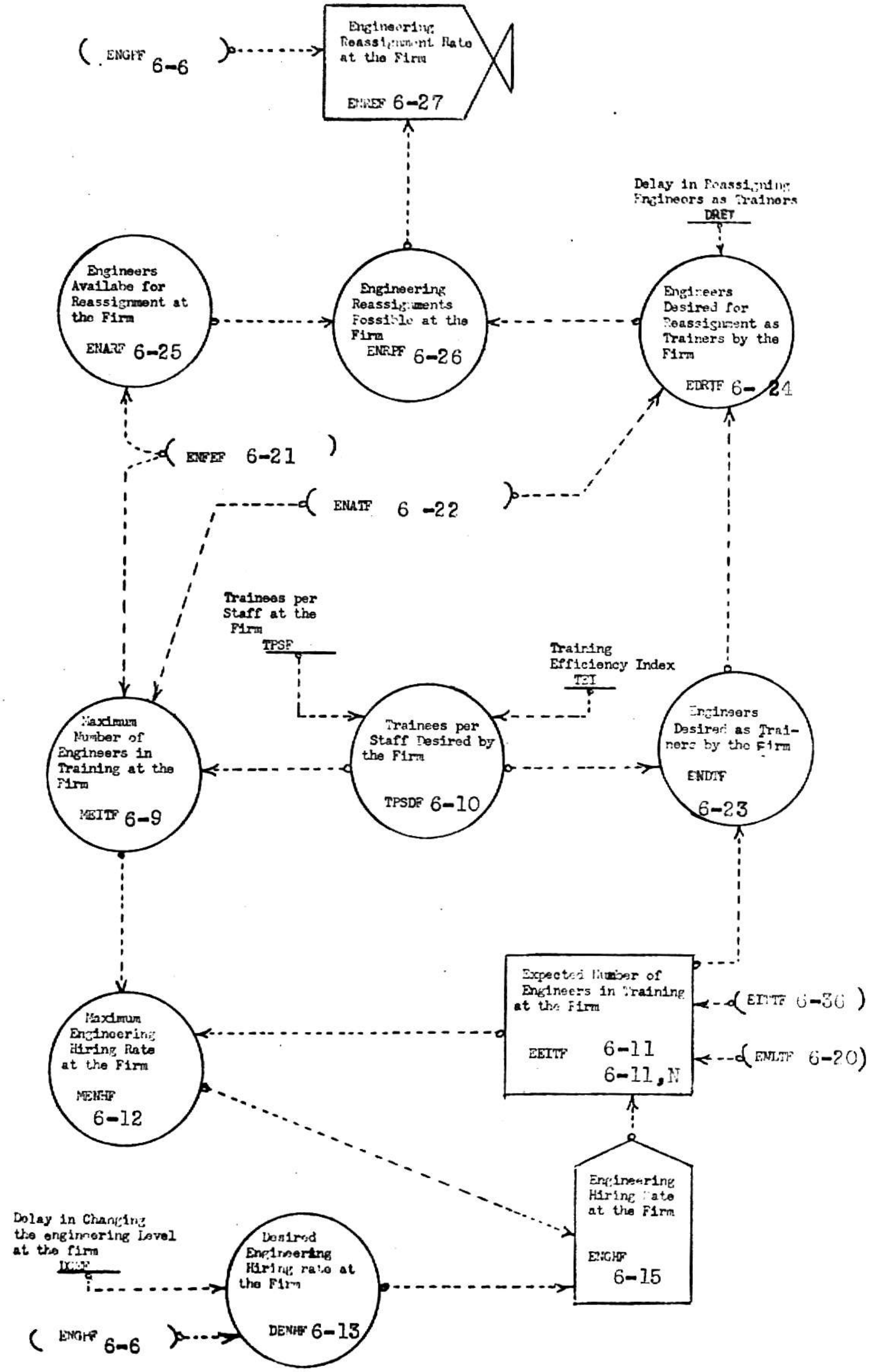


Figure 6.3 Engineering hiring and staff reassignment (3)

EENGF - Expected number of ENGineers in the Firm (men)

ENGHF - ENGineering Hiring rate at the Firm (men per month)

ENGTF - ENGineering Total transfer rate at the Firm (men per month)

LEI - Level of Engineers Initially (men)

From Figure 6.3, possible number of engineers in training (MEITF) is equal to experienced engineers (ENFEF) plus engineer trainers (ENATF) multiplied by their traning capacity (TPSDF) in terms of engineers they can train.

MEITF.K = (ENFEF.K + ENATF.K)(TPSDF) (6-9,A)

MEITF - Maximum number of Engineers In Training at the Firm (men)

ENFEF - ENgineers Fully Experienced at the Firm (men)

ENATF - ENgineers Assigned as Trainers at the Firm (men)

TPSDF - Trainees Per Staff Desired by the Firm (men per men)

The training capacity (TPSDF) of the engineers at the firm is equal to the trainees per staff (TPSF) multiplied by their training efficiency (TEI)

TEI = 1.0

TPSF = 2.5

TPSDF = (TPSF)(TEI) (6-10,N)

TPSDF - Trainees Per Staff Desired by the Firm (men per men)

TPSF - Trainees Per Staff at the Firm (men)

TEI - Training Efficiency Index (dimensionless)

The level of engineers expected in training (EEITF) is a continuous summation of firm's hiring rate (ENGHF) minus the rate of engineering trainers leaving (ENLTF) minus the firm's transfer rate of trainee engineers (EITTF).

$$EEITF.K = EEITF.J + (DT)(ENGHF.JK - ENLTF.JK - EITTF.J) \qquad (6\text{-}11,L)$$

$$EEITF = 0 \qquad (6\text{-}11,N)$$

EEITF - Expected number of Engineers Training at the Firm (men)

ENGHF - ENGineering Hiring rate at the Firm (men per month)

ENLTF - ENgineers Leaving Training at the Firm (men per month)

EITTF - Engineers In Training Transferred by the Firm (men per month)

The maximum engineering hiring rate (MENHF) will be the difference between the possible number of engineers in training (MEITF) minus expected engineers in training (EEITF).

$$MENHF.K = \frac{MEITF.K - EEITF.K}{DT} \qquad (6\text{-}12,A)$$

MENHF - Maximum ENgineering Hiring rate at the Firm (men per month)

MEITF - Maximum number of Engineers In Training at the Firm (men)

EEITF - Expected number of Engineers In Training at the Firm (men)

In the simulation model this MENHF is restricted to positive values by replacing equation (6-12) by the following equations

$$MENHF.K = MAX\ (MEHTF.K,\ 0) \qquad (6\text{-}12,a,A)$$

$$MEHTF.K = \frac{MEITF.K - EEITF.K}{DT} \qquad (6\text{-}12,b,A)$$

Hiring will take place when the desired change in the engineering force (ENGCF) is positive. ENGCF represents the engineer change desired by the firm. Desired engineering hiring (DENHF) by the firm is limited to positive values only and it is given in equation (6-13). Engineering hiring rate at the firm (ENGHF) will be the desired engineering hiring rate (DENHF) unless restricted by the maximum hiring rate (MENHF) and is given in equation (6-19).

$$\text{DENHF.K} = \text{MAX (ENGCF.K,0)} \qquad (6\text{-}13,\text{A})$$

$$\text{ENGCF.K} = \frac{\text{ENGPF.K}}{\text{DCEF}} \qquad (6\text{-}14,\text{A})$$

$$\text{ENGHF.KL} = \text{MIN (DENHF.K, MENHF.K)} \qquad (6\text{-}15,\text{R})$$

DCEF = 3 months

DENHF - Desired ENgineering Hiring rate at the Firm (men per month)

ENGCF - ENGingeer Change rate desired by the Firm (men per month)

ENGPF - ENgineering GaP at the Firm (men)

ENGHF - ENGineering Hiring rate at the Firm (men per month)

MENHF - Maximum ENgineering Hiring rate at the Firm (men per month)

DCEF - Delay in Changing the Engineering level at the Firm (months)

The level of engineers being recruited (ENBRF) is a summation of the difference between the hiring rate (ENGHF) and joining rate (ENGJF) of the engineers at the firm and is given in equation (6-16). Engineers joining rate (ENGJF) is assumed to be third order exponential delay of the hiring rate (ENGHF) and is given in equation (6-17).

The level of engineers in training (ENITF) is a continuous summation of engineering joining rate (ENGJF) minus rate of engineers leaving training (ENLTF) minus engineers transferred from training (EITTF) and is given in equation (6-18). Engineers remaining in the training (ENRTF) is equal to engineers in the training (ENITF) minus the engineers transferred from training (EITTF) and is given in equation (6-19). Engineers leaving the training (ENLTF) will be equal to engineers remaining in the training (ENRTF) divided by delay (DETF) in training these engineers and is given in equation (6-20). The level of fully experienced engineers at the firm (ENFEF) is a summation of rate of engineers leaving training (ENLTF) minus rate of fully experienced engineers transferred by the firm minus the rate of experienced engineers reassigned as trainers (ENREF) and is given in equation (6-21).

$$ENBRF.K = ENBRF.J + (DT)(ENGHF.JK - ENGJF.JK) \qquad (6\text{-}16,L)$$

$$ENBRF = 0 \qquad (6\text{-}16,N)$$

$$ENGJF.KL = DELAY3\ (ENGHF.JK,\ DRCE) \qquad (6\text{-}17,R)$$

$$DRCE = 6 \text{ months}$$

$$ENITF.K = ENITF.J + (DT)(ENGJF.JK - ENLTF.JK - EITTF.JK) \qquad (6\text{-}18,L)$$

$$EN1TF = 0 \qquad (6\text{-}18,N)$$

$$ENRTF.K = ENITF.K + (DT)(- EITTF.K) \qquad (6\text{-}19,A)$$

$$ENLTF.KL = \frac{ENRTF.K}{DETF} \qquad (6\text{-}20,R)$$

$$DETF = 18 \text{ months}$$

$$ENFEF.K = ENFEF.J + (DT)(ENLTF.JK - ENFTF.J - ENREF.JK) \qquad (6\text{-}21,L)$$

$$ENFEF = LEI \qquad (6\text{-}21,N)$$

ENBRF - ENgineers Being Recruited by the Firm (men)

ENGHF - ENGineering Hiring rate at the Firm (men per month)

ENGJF - ENGineers Joining the Firm (men per month)

DRCE - Delay in ReCruiting Engineers (months)

ENITF - ENgineers In Training at the Firm (men)

ENLTF - ENgineers Leaving Training at the Firm (men per month)

EITTF - Engineers In Training Transferred by the Firm (men per month)

ENRTF - ENgineers Remaining in Training at the Firm (men)

DETF - Delay in Engineering Training at the Firm (months)

ENFEF - ENgineers Fully Experienced at the Firm (men)

ENFTF - ENgineers Fully experienced Transferred by the Firm (men per month)

ENREF - ENgineering REassignment rate at the Firm (men per month)

LEI - Level of Engineers Initially (men)

The level of engineers assigned as trainers (ENATF) is a summation of the difference between engineering reassignment rate (ENREF) and engineering trainers transfer rate (ENTTF) at the firm and is given in equation (6-22). Engineers desired as trainers (ENDTF) is equal to the expected number of engineers in training (EEITF) divided by training capacity (TPSDF) of each trainer in the firm and is given in equation (6-23). The desired reassignment rate (EDRTF) is a fraction of gap between desired and actual no of trainers (ENDTF, ENATF) and is given in equation (6-24). ENARF, is the largest possible rate of reassignment of fully experienced engineers (ENFEF) and is given in equation (6-25). The engineering reassignment possible (ENRPF) is the minimum of ENARF and EDRTF and is given in equation (6-26). Depending on the engineering gap (ENGPF) positve or negative, the ENREF, the engineering reassignment rate will be equal to ENRPF, engineering reassignment possible or zero respectively and is given in equation (6-27).

$$ENATF.K = ENATF.J + (DT)(ENREF.JK - ENTTF.J) \qquad (6\text{-}22,L)$$

$$ENATF = 0 \qquad (6\text{-}22,N)$$

$$ENDTF.K = \frac{EEITF.K}{TPSDF} \qquad (6\text{-}23,A)$$

$$EDRTF.K = \frac{ENDTF.K - ENATF.K}{DRET} \qquad (6\text{-}24,A)$$

$$DRET = 1 \text{ month}$$

$$ENARF.K = \frac{ENFEF.K}{DT} \qquad (6\text{-}25,A)$$

$$ENRPF.K = MIN\ (ENARF.K,\ EDRTF.K) \qquad (6\text{-}26,A)$$

$$ENREF.KL = \begin{cases} 0 & \text{if } 0 \geq ENGPF \\ ENRPF.K & \text{if } 0 < ENGPF \end{cases} \qquad (6\text{-}27,R)$$

ENATF - ENgineers Assigned as Trainers at the Firm (men)

ENREF - ENgineering REassignment rate at the Firm (men per month)

ENTTF - ENgineering Trainers Transferred by the Firm (men per month)

ENDTF - ENgineers Desired as Trainers by the Firm (men)

TPSDF - Trainees Per Staff Desired at the Firm (men per men)

EDRTF - Engineers Desired for Reassignment as Trainers by the Firm (men per month)

EEITF - Expected Engineers In Training at the Firm (men)

DRET - Delay in Reassigning Engineers as Trainers (months)

ENARF - ENgineers Available for Reassignment at the Firm (men per month)

ENFEF - ENgineers Fully Experienced at the Firm (men)

ENRPF - ENgineering Reassignments Possible at the Firm (men per month)

ENGPF - ENgineering GaP at the Firm (men)

FLOW DIAGRAM FOR ENGINEERING TRANSFER RATE

Figure 6.4 shows the flow diagram for firm's engineering transfer rate. Whenever the firm finds excess of engineers, it will transfer some of them from project or from the firm. In this model it is assumed that the transfer of engineers will take place first from those employed as trainers. If further transfers are needed then the engineers in training will be transferred. If still further transfers are needed then the fully experienced engineers will be transferred last. This assumption is shown in Figure 6.4.

EQUATIONS FOR FIRM'S TRANSFER RATE

From Figure 6.4, the total engineers available for transfer (TEATF) is sum of engineers available for transfer from trainers (ETATF), from engineers in training (EITAF) and from fully experienced engineers (ENARF) and is given in equation (6-28). When the firm expects more engineers than it desires (that is engineering gap (ENGPF) is less than zero), then the firm transfers at the rate of ENGPF/DT unless sufficient engineers are not available for transfer. The engineering transfer rate desired (ENGTD) is given in equation (6-29). ENTDF, the

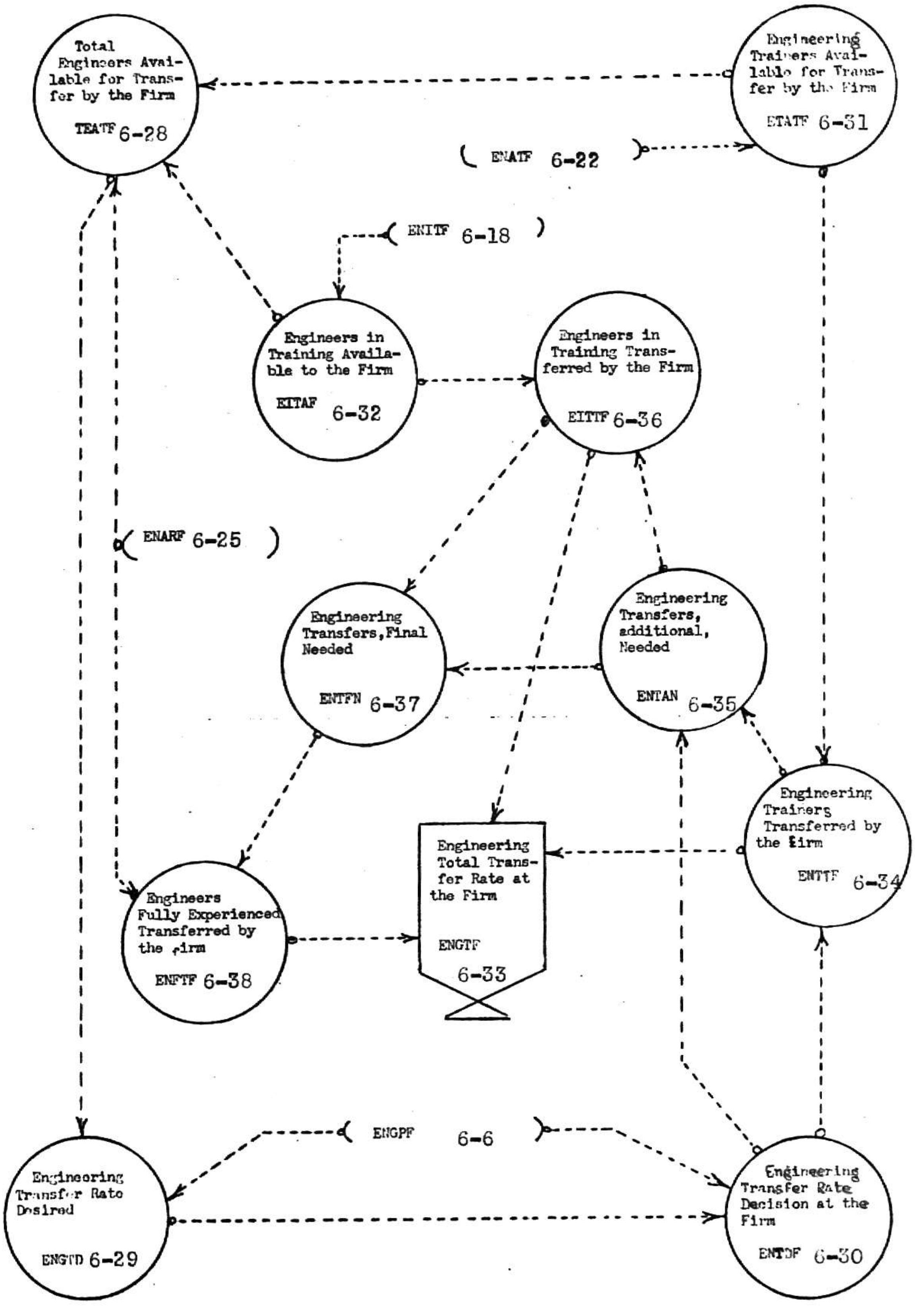


Figure 6.4 Engineering total transfer rate (3)

engineering transfer rate decision at firm, will be equal to ENGTD provided the engineering gap (ENGPF) is greater than zero and is given in equation (6-30). The maximum rate of transfer of engineers from trainers (ENATF) and from training (ENITF) would be that rate which can transfer all these engineers in one solution time interval, and they are given in equations (6-31), and (6-32). The actual transfer rate (ENGTF) is the sum of transfer rates from trainers (ENTTF), from engineers in training (EITTF) and from fully experienced engineers (ENFTF) and is given in equation (6-33).

$$TEATF.K = ETATF.K + EITAF.K + ENARF.K \qquad (6\text{-}28,A)$$

$$ENGTD.K = \begin{cases} -\dfrac{ENGPF.K}{DT} & \text{if } -\dfrac{ENGPF.K}{DT} \leq TEATF.K \\ TEATF.K & \text{if } -\dfrac{ENGPF.K}{DT} > TEATF.K \end{cases} \qquad (6\text{-}29,A)$$

$$ENTDF.K = \begin{cases} ENGTD.K & \text{if } 0 \geq ENGPF.K \\ 0 & \text{if } 0 < ENGPF.K \end{cases} \qquad (6\text{-}30,A)$$

$$ETATF.K = \frac{ENATF.K}{DT} \qquad (6\text{-}31,A)$$

$$EITAF.K = \frac{ENITF.K}{DT} \qquad (6\text{-}32,A)$$

$$ENGTF.KL = ENTTF.K + EITTF.K + ENFTF.K \qquad (6\text{-}33,R)$$

TEATF - Total Engineers Available for Transfer by the Firm (men per month)

ETATF - Engineering Trainers Available for Transfer by the Firm (men per month)

EITAF - Engineers In Training Available to the Firm (men per month)

ENARF - ENgineers Available for Reassignment by the Firm (men per month)

ENGTD - ENGineering Transfer rate Desired (men per month)

ENGPF - ENgineering GaP at the Firm (men)

ENTDF - ENgineering Transfer rate Decision at the Firm (men per month).

ENATF - ENgineers Assigned as Trainers at the Firm (men)

ENITF - ENgineers In Training at the Firm (men)

ENGTF - ENGineering Total transfer rate at the Firm (men per month)

ENTTF - ENgineering Trainers Transferred by the Firm (men per month)

EITTF - Engineers in Training Transferred by the Firm (men per month)

ENFTF - ENgineers Fully experienced, Transferred by the Firm (men per month)

Transfer of engineers takes place first from trainers, then from trainees and lastly from the fully experienced engineers. This is shown in equations (6-34) through (6-38).

ENTTF.K = MIN (ENTDF.K, ETATF.K) (6-34,A)

ENTAN.K = ENTDF.K - ENTTF.K (6-35,A)

EITTF.K = MIN (ENTAN.K, EITAF.K) (6-36,A)

ENTFN.K = ENTAN.K - EITTF.K (6-37,A)

ENFTF.K = MIN (ENARF.K, ENTFN.K) (6-38,A)

ENTTF - ENgineering Trainers Transferred by the Firm (men per month)

ENTDF - ENgineering Transfer rate Decision at the Firm (men per month)

ETATF - Engineering Trainers Available for Transfer by the Firm (men per month)

ENTAN - ENgineering Transfers, Additional, Needed (men per month)

EITTF - Engineers In Training Transferred by the Firm (men per month)

EITAF - Engineers In Training Available to the Firm (men per month)

ENTFN - ENgineering Transfers, Final, Needed (men per month)

ENFTF - ENgineers Fully experienced, Transferred, by Firm (men per month)

ENARF - ENgineers Available for Reassignment by the Firm (men per month)

The level of engineers being transferred (ENBTF) is a continuous summation of engineering transfer rates (ENGTF) minus rate of engineers leaving the firm (ENGLF). Rate of engineers leaving the firm (ENGLF) is given by equation (6-40).

$$ENBTF.K = ENBTF.J + (DT)(ENGTF.JK - ENGLF.JK) \qquad (6\text{-}39,L)$$

$$ENBTF = 0 \qquad (6\text{-}39,N)$$

$$ENGLF.KL = \frac{ENBTF.K}{DTRE} \qquad (6\text{-}40,R)$$

DTRE = 1 month

ENBTF - ENgineers Being Transferred by the Firm (men)

ENGTF - ENGineering Total transfer rate at the Firm (men per month)

ENGLF - ENGineers Leaving the Firm (men per month)

DTRE - Delay in Transferring Engineers (months)

FLOW DIAGRAM FOR ENGINEERING PRODUCTIVITY

Figure 6.5 shows the flow diagram for firm's engineering productivity. The firm's productivity depends on number of engineers and their productivity rates, the general level of potential technological utilization. The later is dependent on available technology to the firm, and firm's technical ability in using their available technology. Firms know-how level is a summation of effective man month of effort put by engineers actually at work. A fraction of firm's know-how level is transmitted to the customer to build the customer know-how level. Firm's know-how level has an effect on the engineers productivity rate. All these factors are shown in Figure 6-5.

EQUATIONS FOR PRODUCTIVITY OF FIRM'S ENGINEERS

From Figure 6.5, the utilized technological effectiveness (UTEF) is a product of firm's quality (QF) and available technology (ATEF) to the firm and is given in equation (6-41). The firm's know-how level (KLEVF) has a multiplicative effect on the productivity rate (ENPRF) of the engineers and in order to incorporate this factor, the relationship given in equation (6-42) is assumed between the know-how level (KLEVF) and the multiplier (MEPIK). The relative productivity (REPRF) of different catagories of engineers is given in equation (6-43).

UTEF.K = (QF)(ATEF.K) (6-41,A)

MEPIK.K = TABHL (TMEPK, KLEVF.K, 0,1, 0.1) (6-42,A)

REPRF.K = (PRIT)(ENITF.K) + (PRAT)(ENATF.K) + (PREBT)(ENBTF.K)
+ (1.0)(ENFEF.K) (6-43,A)

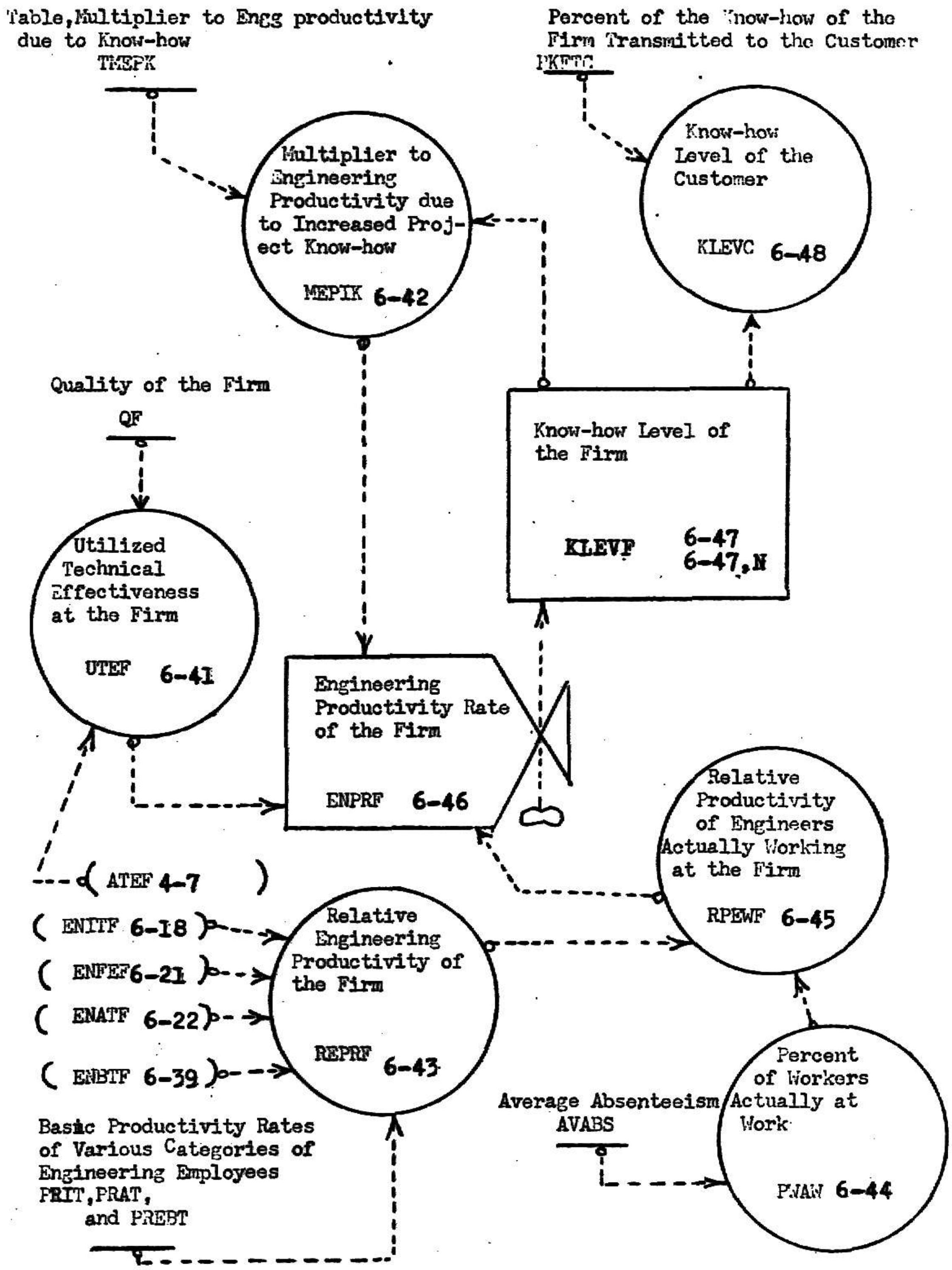


Figure 6.5 Engineering productivity.

PRIT = 0.4

PRAT = 0.7

PREBT = 0.2

UTEF - Utilized Technical Effectiveness at the Firm (percentage)

QF - Quality of the Firm (percentage)

ATEF - Available Technical Effectiveness at the Firm (percentage)

MEPIK - Multiplier to Engineering Productivity due to Increased project Know-how (percentage)

TMEPK - Table, Multiplier to Engineering Productivity due to Know-how

REPRF - Relative Engineering PRoductivity of the Firm (effective man-months of effort per month)

PRIT - PRoductivity of engineers In Training (months of effective effort per month of work)

ENITF - ENgineers In Training at the Firm (men)

PRAT - Productivity of engineers Assigned as Trainers (months of effective effort per month of work)

ENATF - ENgineers Assigned as Trainers at the Firm (men)

PREBT - PRoductivity of Engineers Being Transferred (months of effective effort per month of work)

ENBTF - ENgineers Being Transferred at the Firm (men)

ENFEF - ENgineers Fully Experienced at the Firm (men)

Percentage of workers actually at work (PWAW) is equal to 100 percent minus average percent of absenteeism (AVABS).

PWAW = 1 - AVABS (6-44,N)

PWAW - Percentage of Workers Actually at Work (percentage)

AVABS - AVerage ABSenteeism (percentage)

The relative productivity of engineers actually working (RPEWF) is given in equation (6-45).

RPEWF.K = (PWAW)(REPRF.K) (6-45,A)

RPEWF - Relative Productivity of Engineers actually Working at the Firm (effective man-months per month)

PWAW - Percentage of Workers Actually at Work (Percentage)

REPRF - Relative Engineering PRoductivity at the Firm (effective man-months of effort per month of work)

Engineering productivity rate (ENPRF) will be equal to the product of relative productivity of engineers actually at work (RPEWF), utilized technical effectiveness (UTEP) and multiplier to engineering productivity (MEPIK) due to know how level and is given in equation (6-46). Firm's know how level (KLEVF) is a summation of progress rate by the engineers and is given by equation (6-47). In order to avoid computational errors, initially the know-how-level is assumed to be 0.0001. Through its communications with the customer, the firm transmits a fraction of the acquired technological know how to the customer. The customer's know-how level (KLEVC) is given in equation (6-48).

ENPRF.K = (UTEF.K)(MEPIK.K)(RPEWF.K) (6-46,R)

KLEVF.K = KLEVF.J + (DT)(ENPRF.JK) (6-47,L)

KLEVF = 0.0001 (6-47,N)

KLEVC.K = (PKFTC)(KLEVF.K) (6-48,A)

PKFTC = 0.8

ENPRF - ENgineering PRoductivity rate of the Firm (effective man-months per month)

UTEF - Utilized Technical Effectiveness at the Firm (percentage)

MEPIK - Multiplier to Engineering Productivity due to Increased Know-how (percentage)

KLEVF - Know-how LEVel of the Firm (effective man-months of effort)

KLEVC - Know-how LEVel of the Customer (effective man-months of effort)

PKFTC - Percentage of Know-how of the Firm Transmitted to the Customer (percentage)

This completes specification of DYNAMO equations for acquisition and utilization of engineers in the firm.

Later in the model to introduce randomness in the absenteeism, equation (6-44) is replaced by the following equations.

PWAW.K = 1 - AVABS.K (6 - 44,A)

AVABS.K = NORMRN (MEAN,STDEV) (6-44 a,A)

MEAN = 0.115

STDEV = (0.25)(MEAN) (6-44 b,N)

PWAW - Percentage of Workers Actually at Work (percentage)

AVABS - AVerage ABSenteeism (percentage)

MEAN - MEAN value of the absenteeism (percentage)

STDEV - STandard DEViation (percentage)

NORMRN - A random number generator

MODIFICATIONS IN FLOW DIAGRAMS

In Figure 6.2, the author has assumed that the expected expenditure rate available to the firm depends on two factors. They are 1) expenditure rate available to the firm and 2) the basic rate of allocations at the firm. Roberts assumed that the expected expenditure rate depends on three factors. They are 1) the expenditure rate available to the firm, 2) the rate of change in expenditures available to the firm and 3) the extrapolation period over which these changes are expected to continue. Also in Figure 6.2, the author assumed that the desired number of engineers depends on two factors. They are 1) Supportable number of engineers and 2) Stable work force level of the engineers. Roberts assumed that the desired number of engineers depends on

1) Supportable number of engineers and

2) Weighted number of engineers which depends on supportable number of engineers and stable number of engineers.

CHAPTER 7

CONTROL OF R AND D PROGRESS

INTRODUCTION

In Chapter 2, the various factors influencing the control of R and D progress were enumerated. Control of R and D progress consists of four processes 1) Establishing a criteria, 2) Measuring the criteria, 3) Evaluating the criteria and 4) Taking necessary action. The various outcomes studied in this project simulation are

1) Estimated total cost of the project
2) Estimated future value of the product
3) Percentage of project completed
4) Number of engineers in the project
5) Total engineering costs at the firm

Percentage of project completed directly influences the estimated time to complete the project. The estimated time to complete the project and cumulative engineering costs will influence the estimated total cost to complete the project. Again the value cost relationships influence the funding of project by both firm and customer. The funding of R and D project which is controlled by value cost relationship directly controls the number of engineers in the project. The number of engineers in the project influence the progress rate in the project and know-how level of the firm. The firms know-how level influences the estimated future product value and percent of project completion. Again the percent of project completion influences the estimated time to complete the project and the cycle continues. This kind of control activities take place through out project life cycle and lead to completion or cancellation of the job.

FLOW DIAGRAM FOR FIRM'S CONTROL OF R AND D PROGRESS

Figure 7.1 shows the flow diagram for firm's control activity of R and D progress. As can be seen from top of the diagram the level of real job accomplishment (denoted as know how level of the firm, KLEVF in Chapter 6) and intrinsic size of the job produce a measure of actual percentage completion of the project. This combined with believed percent of project completion will produce a gap in percent completion of the project. The firm requires certain amount of time delay to reduce this gap. The gap and the delay directly influence firm's changing rate of progress.

From the bottom of the flow diagram, we can see that the total engineering costs are the accumulation of the current expenditure rate, which depend on the number of engineers in the project and their average monthly cost including the over head expenses. Total engineering effort is an accumulation of current rate of effort exerted by the engineers who are actually at work. The current effort rate of engineers and estimate of total effort needed for the job produces the firm's believed progress. The accumulation of current progress rate and change in believed progress rate gives the firm's believed percentage of project completion. Compliment of firm's believed percent of project completion gives the believed percent of project incompletion. From normal project duration and believed percent of project incompletion, firm estimates the time to complete the project.

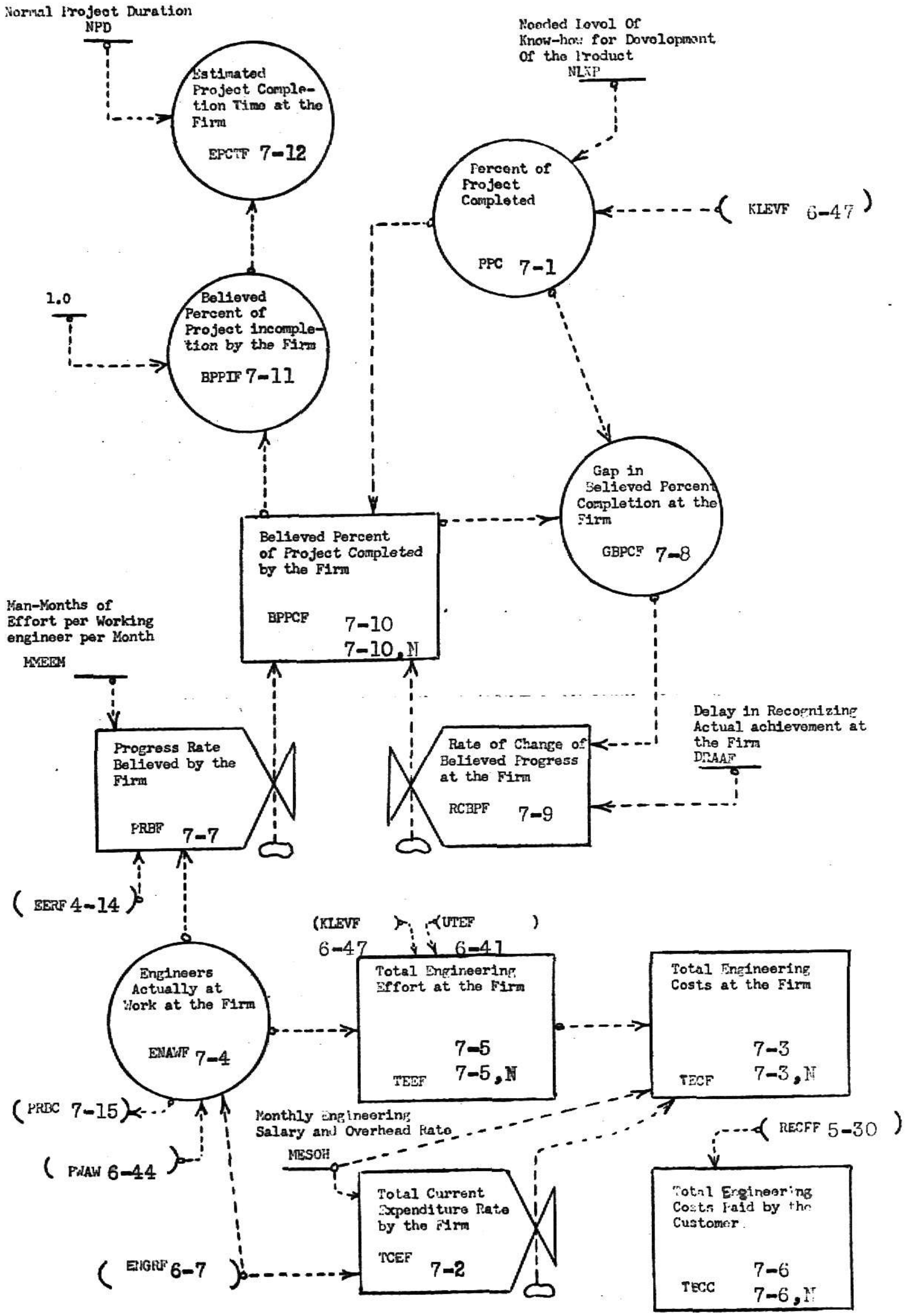


Figure 7.1 The control of R and D progress at the firm

EQUATIONS FOR FIRM'S CONTROL OF R AND D PROGRESS

From Figure 7.1, the actual percent of project completion (PPC) is a ratio of know-how level of the firm (KLEVF) and the intrinsic size of the job (NLKP)

$$PPC.K = \frac{KLEVF.K}{NLKP} \qquad (7.1,A)$$

PPC - Percentage of Project Completed (percentage)

KLEVF - Know-how LEVel of the Firm (effective man-months of effort)

NLKP - Needed Level of Know-how for development of the Product (effective man-months of effort.)

The current expenditure rate (TCEF) is dependent on number of engineers (ENGRF) and their monthly engineering salary and over head rate (MESOH) and is given in equation (7-2). The level of total engineering costs (TECF) is a continuous accumulation of current expenditure rate (TCEF) and is given in equation (7-3).

Fraction of engineers at work (PWAW) multiplied by the number of total engineers (ENGRF) in the firm gives the actual number of engineers at work and is given in equation (7-4). Total engineering effort (TEEF) is a continuous summation of effort expended to date by engineers actually at work (ENAWF) and is given in equation (7-5). Total engineering costs paid by the customer (TECC) is an accumulation of the rate of expenditure of customer funds by the firm (RECFF) and is given in equation (7-6). Progress rate believed by the firm (PRBF) is a ratio of current engineering effort and estimated effort to complete the project (EERF) and is given in equation (7-7). The current engineering effort is a product of engineers actually at work (ENAWF) and their individual effort rate (MMEEM).

$$TCEF.KL = (MESOH)(ENGRF.K) \qquad (7\text{-}2,R)$$

$$TECF.K = TECF.J + (DT)(TCEF.JK) \qquad (7\text{-}3,L)$$

$$TECF = (MESOH)(TEEF) \qquad (7\text{-}3,N)$$

$$ENAWF.K = (PWAW)(ENGRF.K) \qquad (7\text{-}4,A)$$

$$TEEF.K = TEEF.J + (DT)(ENAWF.J) \qquad (7\text{-}5,L)$$

$$TEEF = KLEVF/UTEF \qquad (7\text{-}5,N)$$

$$TECC.K = TECC.J + (DT)(RECFF.JK) \qquad (7\text{-}6,L)$$

$$TECC = 0 \qquad (7\text{-}6,N)$$

$$PRBF.KL = \frac{(MMEEM)(ENAWF.K)}{(EERF.K)} \qquad (7\text{-}7,R)$$

TCEF - Total Current Expenditure rate by the Firm (dollars per month)

MESOH - Monthly Engineering Salary and Over Head rate (dollars per man-month)

ENGRF - ENGineeRs at the Firm (men)

TECF - Total Engineering Costs at the Firm (dollars)

TEEF - Total Engineering Effort at the Firm (man-months)

ENAWF - ENgineers Actually at Work at the Firm (men)

PWAW - Percentage of Workers Actually at Work (percentage)

KLEVF - Know-how LEVel of the Firm (effective man-months of effort)

UTEF - Utilized Technical Effectiveness of the Firm (percentage effectiveness)

TECC - Total Engineering Costs paid by the Customer (dollars)

RECFF - Rate of Expenditure of Customer Funds by the Firm (dollars per month)

PRBF - Progress Rate Believed by the Firm (percentage of project per month)

MMEEM - Man-Months of Effort per working Engineer per Month (man-months per man-month)

EERF - Estimated Effort Required by the Firm (man-months)

GBPCF is a gap between actual percent of project completion (PPC) and believed percent of project completion (BPPCF) and is given in equation (7-8). Delay in recognizing actual accomplishment (DRAAF) and the gap (GBPCF) form the firm's rate of change of believed progress (RCBPF) and is given in (7.9). The believed per cent of project completion (BPPCF) is a summation of current progress rate believed by firm (PRBF) and rate of change of believed progress (RCBPF) and is given in equation (7-10). Believed percent of project in complete (BPPIF) is a compliment of believed percent of project complete (BPPCF) and is given in equation (7-11).

$$GBPCF.K = PPC.K - BPPCF.K \tag{7-8,A}$$

$$RCBPF.KL = \frac{GBPCF.K}{DRAAF} \tag{7-9,R}$$

$$DRAAF = 3 \text{ months}$$

$$BPPCF.L = BPPCF.J + (DT)(PRBF.JK + RCBPF.JK) \tag{7-10,L}$$

$$BPPCF = PPC \tag{7-10,N}$$

$$BPPIF.K = 1 - BPPCF.K \tag{7-11,A}$$

GBPCF - Gap in Believed Percentage Completion at the Firm (percentage)

PPC - Percentage of Project Completion at the Firm (percentage)

BPPCF - Believed Percentage of Project Completed by the Firm (percentage)

RCBPF - Rate of Change in Believed Progress at the Firm (percentage of project per month)

DRAAF - Delay in Recognizing Actual Achievement at the Firm (months)

PRBF - Progress Rate Believed by the Firm (percentage of project per month)

BPPIF - Believed Percentage of Project Incomplete at the Firm (percentage)

The value of BPPIF is limited to 100% to 0 % in the simulation run by replacing the equation (7-11) by the following equations.

TBPIF.K = 1 - BPPCF.K (7-11a,A)

BPPIF.K = MAX (TBPIF.K,0) (7-11b,A)

Under normal conditions, the estimate of project completion time (EPCTF) is a product of normal project duration (NPD) and Believed percent incomplete (BPPIF).

EPCTF.K = (NPD)(BPPIF.K) (7-12,A)

EPCTF - Estimated Project Completion Time at the Firm (months)

NPD - Normal Project Duration (months)

BPPIF - Believed Percent of Project Incomplete by the Firm (percentage)

In the simulation run the minimum value of EPCTF is limited to the solution time interval (DT) by incorporating the following equations instead of (7-12).

TPCTF.K = (BPPIF.K)(NPD) (7-12a,A)

EPCTF.K = MAX (TPCTF.K, DT) (7-12b,A)

FLOW DIAGRAM FOR CUSTOMER'S PROGRESS EVALUATION

Figure 7.2, shows the flow diagram for customer's progress evaluation. The diagram is very much similar to the top half of the firm's flow diagram for control of R and D progress. Hence without much explanation, the equations for customer's progress evaluation are written below.

EQUATIONS FOR CUSTOMER'S PROGRESS EVALUATION

From Figure 7.2, we have

GBPCC.K = PPC.K - BPPCC.K (7-13,A)

$$\text{RCBPC.KL} = \frac{\text{GBPCC.K}}{\text{DRAAC}} \qquad (7\text{-}14,\text{R})$$

DRAAC = 3 months

$$\text{PRBC.KL} = \frac{(\text{MMEEM})(\text{ENAWF.K})}{(\text{EERC.K})} \qquad (7\text{-}15,\text{R})$$

BPPCC.K = BPPCC.J + (DT)(RCBPC.JK + PRBC.JK) (7-16,L)

BPPCC = PPC (7-16,N)

BPPIC.K = 1 - BPPCC.K (7-17,A)

GBPCC - Gap in Believed Percentage Completion by the Customer (percentage)

PPC - Percentage of Project Completed (percentage)

BPPCC - Believed Percentage of Project Completed, at the Customer (percentage)

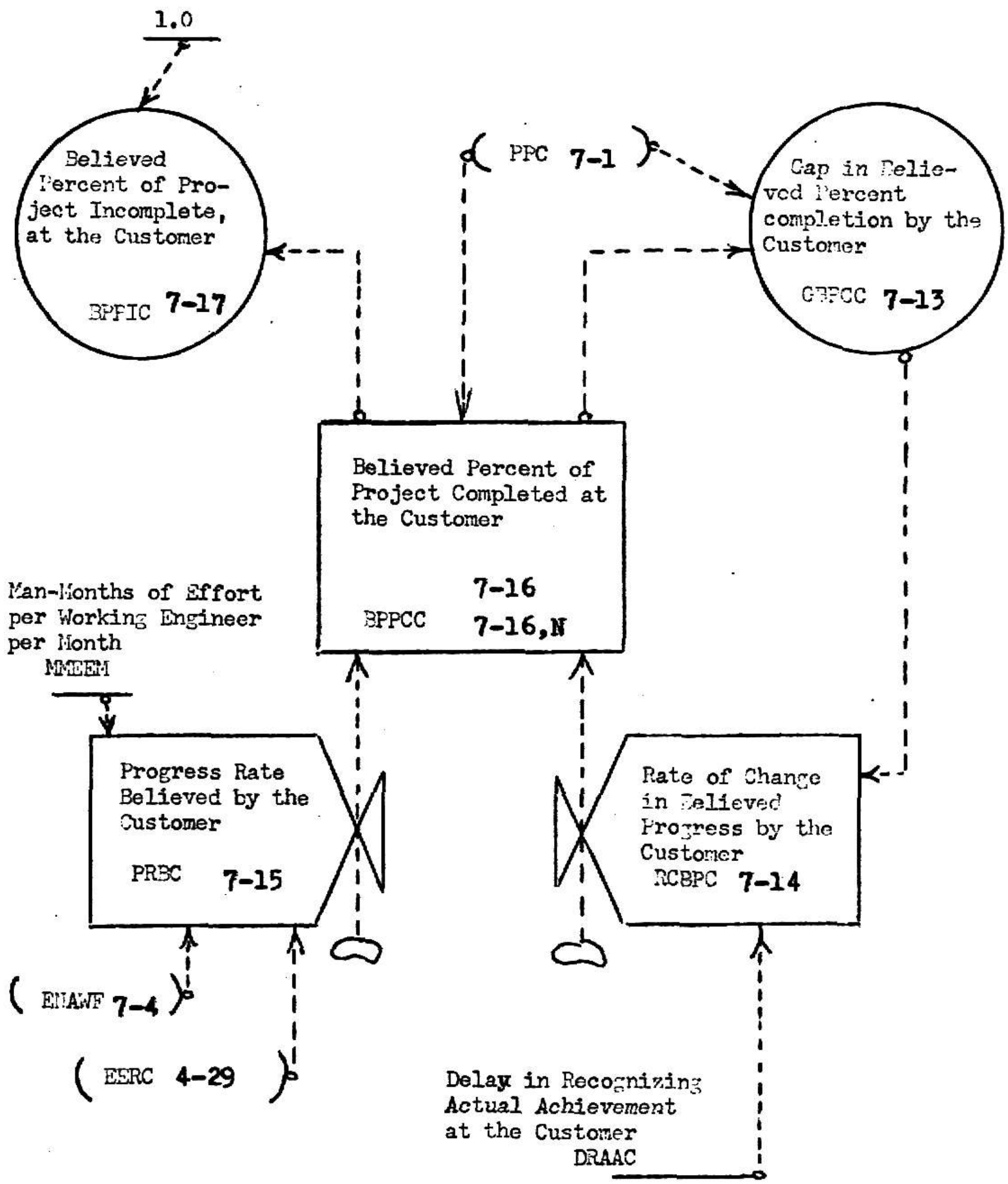


Figure 7.2 Believed progress at the customer.

DRAAC - Delay in Recognizing Actual Achievement at the Customer (months)

PRBC - Progress Rate Beleived by the Customer (percentage of project per month)

RCBPC - Rate of Change in Believed Progress by the Customer (percentage of project per month)

MMEEM - Man-months of Effort per working Engineer per Month (man-months per man-month)

ENAWF - ENgineers Actually at work at the Firm (men)

EERC - Estimated Effort Required by the Customer (man-months)

BPPIC - Believed Percent of Project Incomplete, at the Customer (percentage)

In the simulation run, the BPPIC is limited to 100% to 0 % by replacing equation (7-17) by the following equations.

TBPIC.K = 1 - BPPCC.K (7-17a,A)

BPPIC.K = MAX (TBPIC.K,0) (7-17b,A)

This completes the specification of equations for control of progress by the firm, and customer evaluation of R and D progress.

FLOW DIAGRAM FOR FIRM'S PROFITS

Figure 7.3 provides extra information on firm's profit rate which was not used in simulation computations. The profit rate (PRF) to the firm is the percentage of profit allowed on the project billings (PPP) times the rate of expenditure of customer funds (RECFF) and is given in equation (7-18). Gross profit to date (PROF) is a cumulative sum of profit rate (PRF) and is given in equation (7-19). Net profit before

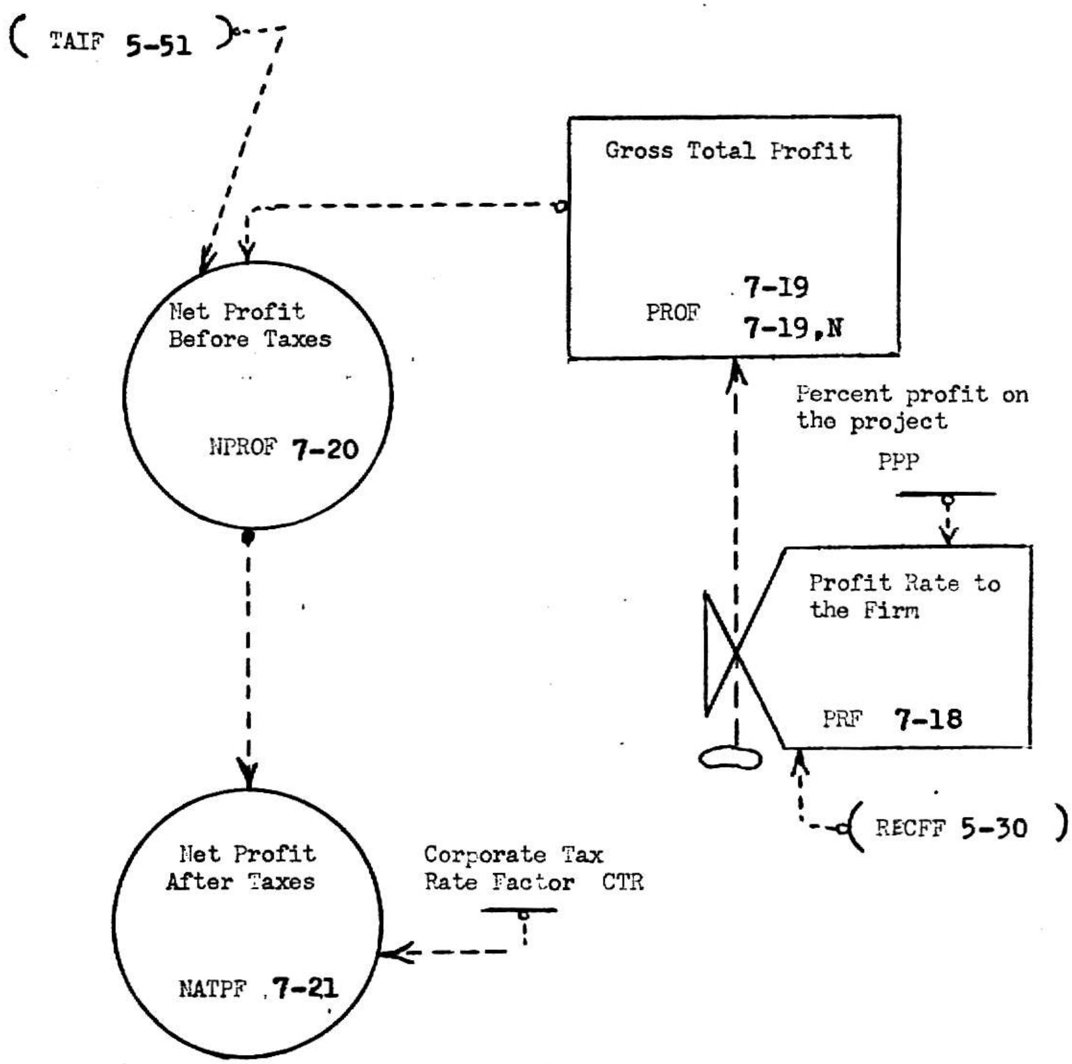


Figure 7.3 Supplementary information on profits (3) .

taxes (NPROF) will be the difference of gross profit (PROF) and total actual investments by the firm (TAIF) and is given in equation (7-20). Net profit after tax (NATPF) will be computed after taking the corporate tax factor (CTR) into consideration and it is given in equation (7-21).

PRF.KL = (PPP)(RECFF.JK) (7-18,R)

PROF.K = PROF.J + (DT)(PRF.JK) (7-19,L)

PROF = 0 (7-19,N)

NPROF.K = PROF.K - TAIF.K (7-20,A)

NATPF.K = (CTR)(NPROF.K) (7-21,A)

CTR = 0.5

PPP = 0.07

PRF - Profit Rate to the Firm (dollars per month)

PPP - Percentage of Profit on Project (percentage)

RECFF - Rate of Expenditure of Customer Funds by the Firm (dollars per month)

PROF - gross total PROFit (dollars)

NPROF - Net PROFit before taxes (dollars)

TAIF - Total Actual Investment by the Firm (dollars)

NATPF - Net After Tax ProFit (dollars)

CTR - Corporate Tax-Rate factor (percentage)

This completes the specification of equations for profit to the firm.

MODIFICATIONS IN THE FLOW DIAGRAMS

In Figures 7.1 and 7.2 the author assumed that the gap between actual percentage of project completion and believed percent of project completion influence the estimates of believed percent of project completion. It is shown on the right hand top corner of the diagrams.

Also a constant delay is assumed (for both customer and firm) to recognize this gap. Roberts assumed that the delay in recognizing the gap between the actual percent of project completion and believed percent of project completion depend on the significance of this gap. The significance of the gap depends on the fraction of the gap recognized and the gap itself.

CHAPTER 8

RESULTS - DISCUSSION

RESULTS

The results of the simulation model described in chapters 3 through 7 are shown in Table 8.1 and Figures 8.1 and 8.2. The model was simulated for a period of 150 months. Table 8.1 presents the simulated values of the various project outcomes for every 20 month intervals of the project life of the modified R and D model with uniform absenteeism. The variables tabulated in Table 8.1 from column 1 are

1) simulated time (months)
2) Estimated future value of the product by the firm (dollars)
3) Estimated total cost of the project by the firm (dollars)
4) Number of engineers in the project (men)
5) Number of engineers actually at work (men)
6) Percentage of project completed (percentage)
7) Suitability of the project to the customer believed by the firm (percentage)
8) Total engineering cots to the firm (dollars) and
9) Total engineering costs paid by the customer (dollars)

Figures 8.1 and 8.2 show the plotted values of the above variables (2 to 6 and 8) against the project life of the modified model with uniform and random absenteeism respectively. For a comparison of the results obtained in the present modified model, the results of Roberts (3) are shown in Table 8.2 and Figure 8.3. Curve 3 in these figures 8.1, 8.2, and 8.3 represent the intrinsic product value in dollars. Curve 3 is an input curve to the model.

Table 8.1 Simulated Values of the Various Project Outcomes of the Modified R and D Model with Uniform Absenteeism.

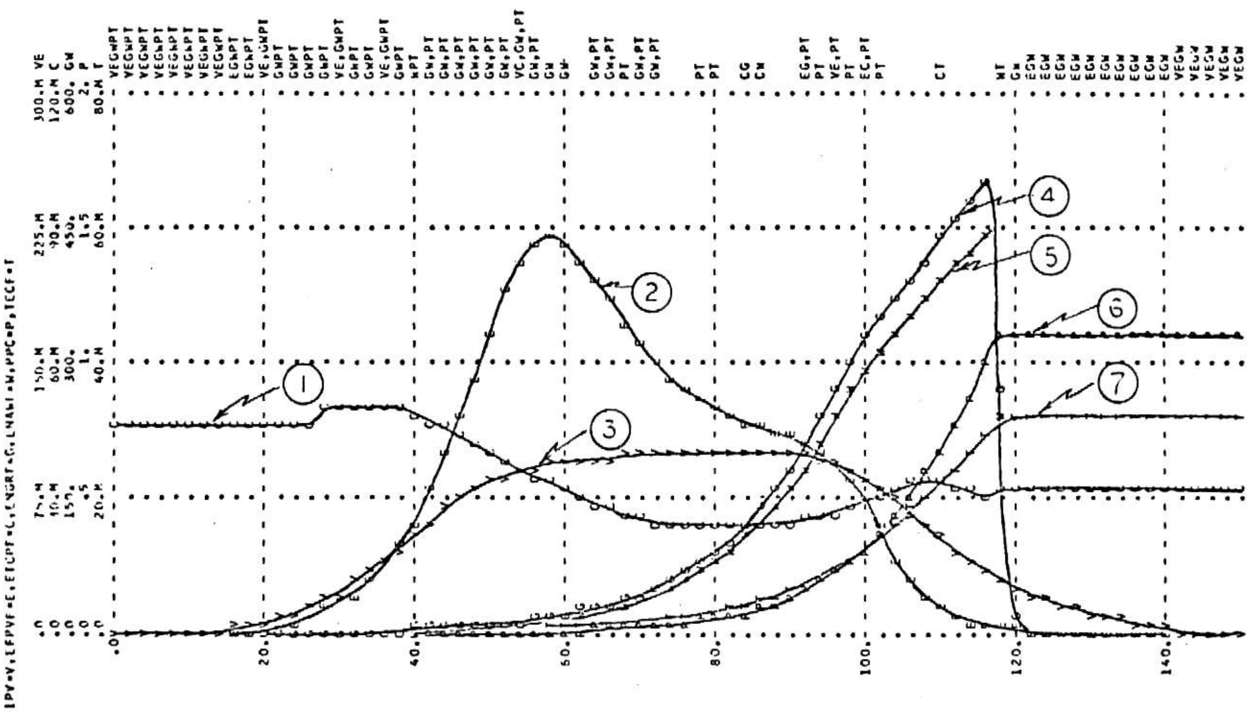
TIM (months)	EFPVF (X\$ 10^6)	ETCPF (X\$ 10^6)	EHGRF (man)	ENAWF (man)	PPC (%)	SPCBF (%)	TECF \$X 10^6	TECC \$X 10^6
0	0.0	46.6	1.0	0.89	0.0	0.0	0.0	0.0
20	3.12	46.3	1.0	0.89	0.0012	0.0337	0.050	0.0
40	61.55	47.93	5.57	4.93	0.0033	0.6420	0.185	0.108
60	215.82	31.69	22.39	19.81	0.0127	3.40	0.779	0.611
80	124.45	23.08	89.88	79.55	0.0592	2.7	3.165	2.63
100	73.47	29.59	329.07	291.2	0.3121	1.435	12.62	10.7
120	2.06	32.23	21.10	18.68	1.106	0.0403	32.23	30.69
140	0.08	32.31	0.0	0.0	1.108	0.0012	32.31	32.26

Table 8.2 Simulated Values of the Various Project Outcomes of Roberts' R and D Model with Uniform Absenteeism.

TIME (months)	EFPVF (X$ 10^6)	ETCPF (X$ 10^6)	ENGRF (man)	ENAWF (man)	PPC (%)	SPCBF (%)	TECF (X$ 10^6)	TECC (X$ 10^6)
0	0	62.14	1.0	0.89	0.0	0.0	0.00	0.0
20	1.72	62.01	1.0	0.89	0.0008	0.0138	0.05	0.0
40	36.28	51.22	1.05	0.93	0.0016	0.3592	0.100	0.0
60	134.53	48.41	7.77	6.88	0.0037	1.3895	0.300	0.149
80	182.80	35.37	31.20	27.62	0.0141	2.5835	1.128	0.850
100	93.31	29.06	125.29	110.88	0.0720	1.6052	4.454	3.664
120	3.97	39.914	502.99	445.14	0.4386	0.0538	17.807	14.963
140	0.12	36.38	5.56	4.92	1.1488	0.0017	36.387	36.171

Table 8.3 Deviation of Simulated Values of Modified Model from the Simulated Values of Roberts' Model (with uniform absenteeism)

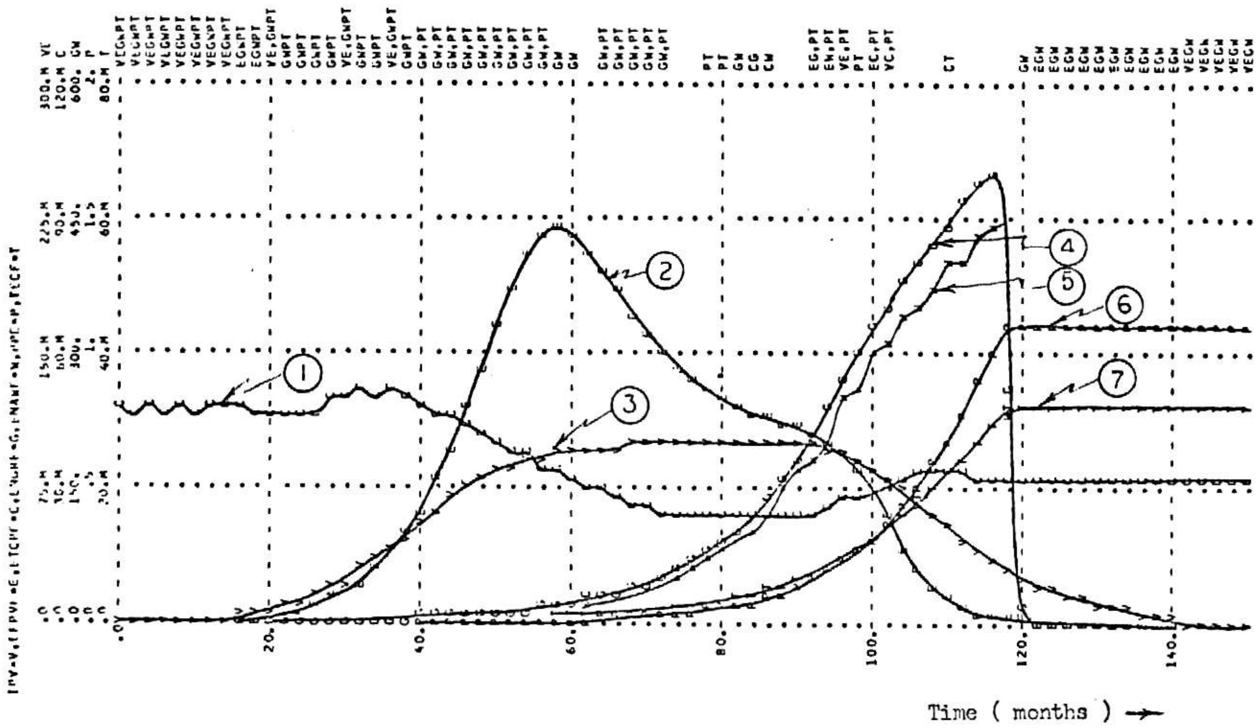
TIME (months)	EFPVF (%)	ETCPF (%)	ENGRF (%)	ENAWF (%)	PPC (%)	SPCBF (%)	TECF (%)	TECC (%)
0	0	+25	0.0	0.0	0.0	0.0	0.0	0.0
20	-81.4	+25.3	0.0	0.0	-50.0	-144	0.0	0.0
40	-69.7	+6.44	-430	-430	-106.	-78.8	-85.0	-
60	-60.4	+34.6	-190	-190	-243	-145	-159.5	-310
80	+31.9	+34.7	-188	-188	-309	-4.5	-168.0	-209
100	+21.2	-1.82	-162	-162	-334	+106	-179.0	-191.5
120	+48.1	+19.2	+95.8	+95.8	-152.5	+25.1	-79.5	-178.5
140	+33.4	+11.2	+100	+100	+35.6	+29.4	+11.5	12.1



Time(months) ⟶

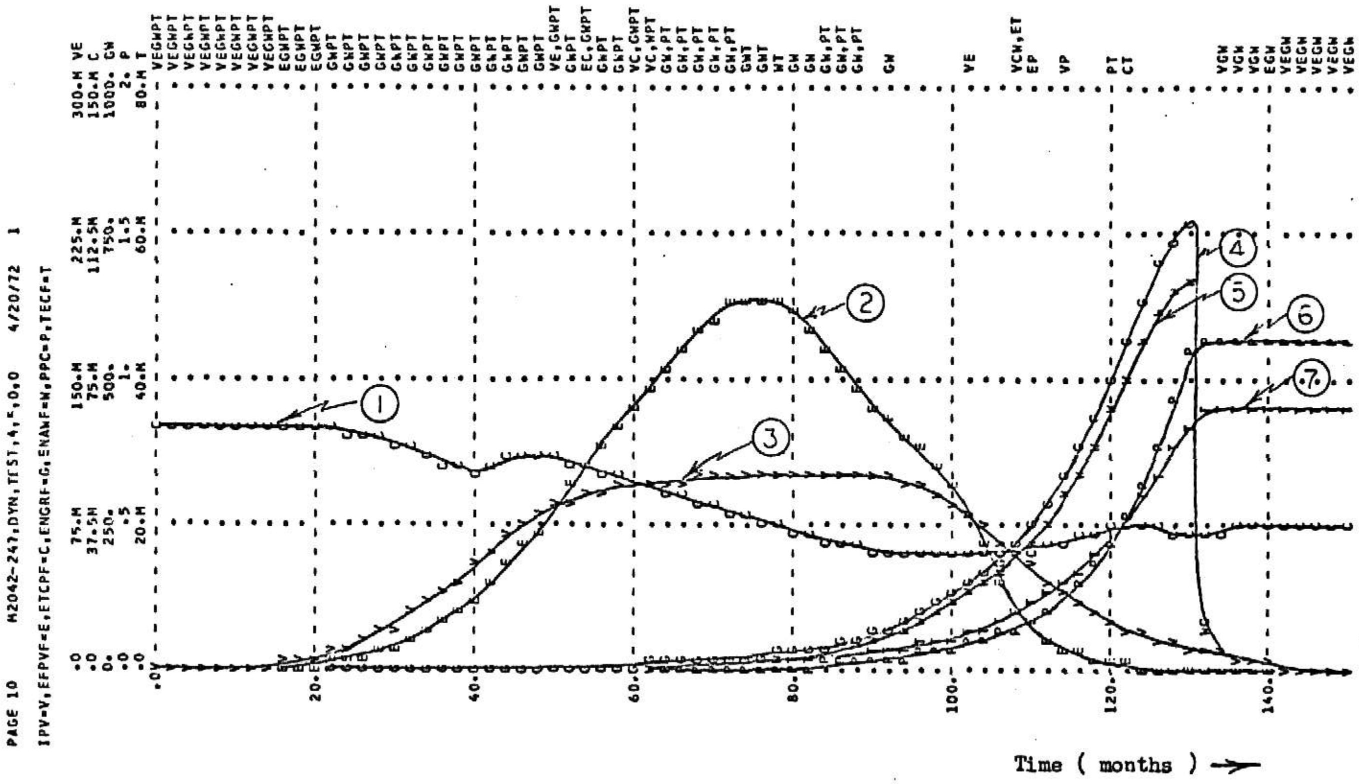
1) Estimated total cost (dollars X 10^6)
2) Estimated future product value(dollars X 10^6)
3) Intrinsic product value (dollars X 10^6)
4) Total number of engineers (men)
5) Number of engineers actually at work(men)
6) Percentage of project completion(percentage)
7) Cumulative engineering costs (dollars X 10^6)

Figure 8.1 Total R and D life cycle with uniform absenteeism



1) Estimated total cost of the project (dollars X 10^6)
2) Estimated future product value (dollars X 10)
3) Intrinsic product value (dollars X 10^6)
4) Total number of engineers (men)
5) Number of engineers actually at work (men)
6) percentage of project completion (percentage)
7) Cumulative engineering costs (dollars X 10^6)

Figure 8.2 Total R and D life cycle with random absenteeism



1) Estimated total cost of the project (dollars X 10^6)
2) Estimated future product value (dollars X 10^6)
3) Intrinsic product value (dollars X 10^6)
4) Total number of engineers (men)
5) Number of engineers actually at work (men)
6) percentage of project completed (percentage)
7) Cumulative engineering costs (dollars X10^6)

Figure 8.3 Total R and D project life cycle with uniform absenteeism (Roberts' Model)

Table 8.3 shows the percent deviation of the simulated values of the modified model from the results of Roberts. Negative values in the table indicate an increase while the positive values indicate a decrease in the estimated values of the modified model from the values of Roberts' results. The author could not reproduce the results of Roberts' model for a random absenteeism case. Hence a comparison of the results of modified model with that of the results of Roberts' model for a random absenteeism case was not done.

DISCUSSION

In Robert's model, the estimated future product value varied uniformly starting from zero value at the start of the project life and attained its peak value $192.16 millions at 75th month. This value started decreasing uniformly from 75th month and reached zero value at about 126th month. The values of the future product value at different project life time are shown in column 2 of Table 8.2 and curve 2 of Figure 8.3. In the present modified model the future product value has a zero at the start of the project life and increased uniformly and attained its maximum value of $219 millions at 58th month. From 58th month onwards this value decreased rapidly for a while and then decreased slowly and reached zero value at 121st month. The values of future product value at different project life time are shown in column 2 of Table 8.1., and curve 2 of Figure 8.1.

There is about - 81.4% to 33.4% variation in the values of the modified model from that of the Roberts' results. The variations in the future product value is due to the following reasons. It is explained in Chapter 3 that the estimated future product value depends on 1) current product value, 2) the rate of change in product value and 3) projection horizon of the firm (or customer). Roberts has used an exponentially smoothed value for the rate of change in product value. The author has used the rate of change in product value between solution time intervals.

In Roberts' model, the estimated total cost of the project has a value of 62.14 million dollars at the start of the project and remained constant till 24th month and then the value decreased slowly and reached $50.9 millions at 40th month which again increased and then decreased slowly and reached a minimum value of $29.06 millions at 100th month. From 100th month the value stared increasing and reached a value of $35.42 millions which practically remained constant till the end of the simulation time. In the present model the cost curve (1) followed the same trend. The value of the initial cost estimate is $46.6 millions which remained constant till 28th month and then with a small rise in cost which remained till 40th month. From 40th month the cost decreased slowly and uniformly and attained a minimum value of $23.00 millions at 82nd month. The cost value increased from 82nd month and reached a value of $33.57 millions at 109th month and then decreased to $32.29 millions at 119th month and remained practically constant till the end of the project life.

There is about - 1.82 % to 34.7 % variation in the cost estimates in the modified model from that of Roberts' results. The main reasons for the variations in cost estimates are 1) modifications made in job size estimation, and 2) modifications made in technical effectiveness. These modifications were explained at the end of Chapter 4. The cost curves are shown in Figures 8.1 and 8.3 by the curve 1.

Curve 4 represents the total number of engineers in the firm. Curve 4 in Figures 8.1 and 8.3 have similar trends. In both models (Roberts and modified) the number of engineers in the firm in the beginning is assumed to be one. In Roberts' model this curve (4) attained its maximum value of 759 men at 130th month and decreased sharply and reached a value of about 1 at 144th month. In the modified model curve 4 attained a maximum value of 501 men at 117th month and then decreased sharply and reached a value of one at 124th month. The number of engineers at any point is more (after 22nd month and till 117th month) in the modified model than in the Roberts' model, indicating an earlier hiring in the project. This is shown by the variations of - 430 % to 95 % (see column 3 of Table 8.3).

The reasons for these variations are due to the modifications made in Figure 6.2. The number of engineers desired in the firm is assumed to depend on two factors only. They are 1) supportable number of engineers, and 2) stable work force level of engineers. The supportable number of engineers depend on the expected available expenditure rate to the firm. The author assumed that the expected expenditure rate available to the firm depends on 1) expenditure rate available to the firm, and 2) basic rate of allocations (Fig. 6.2). Roberts assumed that the expected expenditure rate available to the firm depends on 1) expenditure rate available to the firm, 2) rate of change of expenditure rate available to the firm, and 3) the extrapolated period over which these changes are expected.

Curve 5 represents the number of engineers actually at work. Number of engineers actually at work is a fraction of the total number of engineers at the firm. So the curve follows the same trend as the curve for the total number of engineers, curve 4.

Curve 6 shows the actual percent of project completed. There is a variation of - 334 % to 35.6 % in the values of the modified model from that of Roberts' results. The reason for these variations are due to the modifications made in flow diagrams shown in Figures 6.2 and 6.5. These modifications were explained in Chapter 6. Modifications in Figure 6.2 are explained above. Modifications in engineering productivity (Figure 6.5) contributed to a great extent to the variations in the actual percent of project completion.

Curve 7 shows the firm's total engineering costs in dollars. This estimate directly depends on the total number of engineers in the firm. The estimated values varied from - 179 % to 11.5% (see column 8 of Table 8.3). These variations are due to the modifications made in 1) estimation of desired number of engineers in the firm (Chapter 6, Flow diagram 6.2).

The last column in Table 8.1 shows total engineering costs paid by the customer in the modified model. There is a variation of - 310 % to 12.1 % in these values from that of Roberts' values. This is due to the modification made in the activity, customer evaluation and commitment of funds (Chapter 5, Flow diagram 5.2). These modifications are explained at the end of the chapter 5.

Figure 8.2 shows the effect of random absenteeism on the project outcomes. The randomness is shown in the actual number of engineers at work in the project (curve 5) and also in the total cost curve, curve 1. The estimated total cost to complete the project is a sum of total engineering costs plus the estimate of cost to complete the project. The cost to complete the project is directly affected by the number of engineers actually at work and hence the later affects the total cost of the project. Therefore random behavior is observed in total cost curve. Remaining curves were not affected.

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APPENDIX I

COMPUTER PROGRAMS

MODIFIED R AND D MODEL   4/24/72

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*       MCDIFIED R AND D MODEL
NOTE
NOTE    ******************************************************************
NOTE    IN THIS MODEL IT IS ASSUMED THAT THERE IS AN UNIFORM ABSENTEEISM
NOTE    OF 11.5 PERCENT OF THE ENGINEERS
NOTE    ******************************************************************
NOTE
NOTE    PERCEPTION OF PRODUCT VALUE BY FIRM
NOTE
A       IPV.K=TABLE(PVTAB,TIME.K,0,180,6)    INTRISIC PRODUCT VALUE
C       PVTAB*=0/0/.5E6/5E6/12.5E6/22.5E6/40E6/62.5E6/80E6/90E6/95E6/97.5E
X1      6/99E6/100E6/100E6/100E6/95E6/80E6/60E6/40E6/25E6/15E6/10E6/5E6/1E
X2      6/.2E6/0/0/0/0/0
A       DRPVF.K=TABHL(TDVR,KLEVF.K,0,60,5)    DELAY IN RECOG PRODUCT VALUE
C       TDVR*=66/45.5/32/23.2/17.3/13.5/10.9/9.2/8.2/7.4/7.0/6.6/6.4
R       RPVF.KL=(1/DRPVF.K)(IPV.K-LRPVF.K)   RECOGNITION OF PRODUCT VALUE
L       LRPVF.K=LRPVF.J+(DT)(RPVF.JK+0.0)
N       LRPVF=0
A       TPFPVF.K=LRPVF.K+(PHF)(RPVF.JK)
C       PHF=48
A       PFPVF.K=MAX(TPFPVF.K,0)
C       WARF=1
L       EFPVF.K=EFPVF.J+(DT)(1/DAEVF)(PFPVF.J-EFPVF.J)
N       EFPVF=0
C       DAEVF=6   DELAY IN ADJUSTING ESTIMATE OF VALUE
NOTE
NOTE            CUSTOMER PERCEPTION OF PRODUCT NEED AND VALIE
NOTE
A       DRPVC.K=TABHL(TDVR,KLEVC.K,0,60,5)  DELAY IN RECOG PRODUCT VALUE
R       RPVC.KL=(1/DRPVC.K)(IPV.K-LRPVC.K)   RECOGNITION OF PRODUCT VALUE
L       LRPVC.K=LRPVC.J+(DT)(RPVC.JK+0)
N       LRPVC=0
A       TPFPVC.K=LRPVC.K+(PHC)(RPVC.JK)
C       PHC=36
A       PFPVC.K=MAX(TPFPVC.K,0)
L       EFPVC.K=EFPVC.J+(DT)(1/DAEVC)(PFPVC.J-EFPVC.J)  EST OF FUTURE PV
N       EFPVC=0
C       DAEVC=8   DELAY IN CUSTOMERS ADJUSTMENT OF VALUE ESTIMATE
NOTE
NOTE    FIRMS ESTIMATE OF JOB SIZE
NOTE
L       BNKPF.K=BNKPF.J+(DT)(RGEJF.JK)
N       BNKPF=(NLKP)(1+PDPEF)/QF
C       NLKP=5500
C       PDPEF=-0.25
C       QF=1.0
A       GEAF.K=(ESPCF.K-BPPCF.K)/BPPCF.K
R       RGEJF.KL=(BNKPF.K)(GEAF.K)(FCGRF.K)
A       ESPCF.K=(TEEF.K)(ETEF.K)/BNKPF.K
A       FCGRF.K=TABHL(IPPGR,PPC.K,0,1,.1)  TIME-SIGNIFICANCE OF GAP
C       IPPGR*=0/0/0/.05/.12/.20/.35/.60/.80/.99/1.0
NOTE
NOTE    FIRM'S ESTIMATE OF TECHNICAL EFFECTIVENESS
NOTE
A       TE.K=TABLE(TETAB,TIME.K,0,180,6)
C       TETAB*=.25/.25/.25/.25/.26/.27/.28/.30/.32/.35/.38/.42/.46/.51/.57
X1      /.63/.70/.77/.82/.86/.89/.91/.93/.94/.95/.96/.97/.98/.99/.995/1.0
L       ATEF.K=ATEF.J+(DT)(RCTAF.JK)
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MODIFIEC R AND D MODEL     4/24/72

N       ATEF=TE
R       RCTAF.KL=(TE.K-ATEF.K)/DTITF
L       ETEF.K=ETEF.J+(DT)(RCEEF.JK)
N       ETEF=(WARF)(ENPRF)/ENAWF
R       RCEEF.KL=(RTEF.K-ETEF.K)/DRTEF
A       RTEF.K=(PRBF.JK)(BNKPF.K)/ENAWF.K
A       EFTEF.K=ETEF.K+(XPTPF.K)(RCTAF.JK)
A       XPTPF.K=(BPPIF.K)(NPC/2)
C       DTITF=24
C       NPC=24
C       DRTEF=2
NOTE
NOTE    FIRMS ESTIMATE OF  EFFORT AND COST
NOTE
A       EERF.K=(1/EFTEF.K)((TEEF.K)(EFTEF.K)+(BNKPF.K)(BPPIF.K))
A       ECCPF.K=(SMEC)(EERF.K-TEEF.K)    EXPECTED ADDITIONAL COST
N       SMEC=MESOH/(1-AVABS)     SCALED MONTHLY ENG COSTS
C       MESCH=2500          MONTHLY ENGG SALARY
C       AVABS=0.115   AVERAGE ABSETEEISM
A       ETCPF.K=TECF.K+ECCPF.K   ESTIMATED TOTAL COST OF PROJECT
NOTE
NOTE    CUSTOMER'S EXTIMATE CF JOB SIZE
NOTE
L       BNKPC.K=BNKPC.J+(DT)(RGEJC.JK+0)   ESTIMATED JOB SIZE
N       BNKPC=(NLKP)(1+PDPEC)/QC
C       PDPEC=-0.175
C       QC=0.60
A       GEAC.K=(ESPCC.K-BPPCC.K)/BPPCC.K
R       RGEJC.KL=(BNKPC.K)(GEAC.K)(FOGRC.K)
A       ESPCC.K=(TEEF.K)(ETEC.K)/BNKPC.K
A       FOGRC.K=TABHL(IPPGR,PPC.K,0,1,.1)
NOTE
NOTE    CUSTOMER'S ESTIMATE OF TECHNOLOGICAL EFFECTIVENESS
NOTE
L       ATEC.K=ATEC.J+(DT)(RCTAC.JK+0)    AVAILABLE T.E.
N       ATEC=TE
R       RCTAC.KL=(1/DTITC)(TE.K-ATEC.K)
L       ETEC.K=ETEC.J+(DT)(RCEEC.JK)
N       ETEC=(WARC)(ATEC)(CNFC)
C       CNFC=0.6   CONFIDENCE IN FIRM BY CUSTOMER
C       WARC=0.6
R       RCEEC.KL=(1/DRTEC)(RTEC.K-ETEC.K)   RATE OF CHANGE OF EST EFFECT
A       RTEC.K=(PRBC.JK)(BNKPC.K)/ENAWF.K   REALIZED TE BY CUSTOMER
C       DTITC=12
C       DRTEC=8          DELAY IN RECOGNIZING T.E. AT FIRM
A       EFTEC.K=ETEC.K+(XPTPC.K)(RCTAC.JK)
A       XPTPC.K=(BPPIC.K)(NPD)/2   EXTRAPOLATION PERIOD FOR TECH PROGRESS
NOTE
NOTE    ESTIMATION OF EFFORT AND COST BY THE CUSTOMER
NOTE
A       EERC.K=(1/EFTEC.K)((TEEF.K)(EFTEC.K)+(BNKPC.K)(BPPIC.K))
A       ECCPC.K=(SMEC)(EERC.K-TEEF.K)    ESTIMATED COMPLETION COSTS
A       ETCPC.K=TECC.K+ECCPC.K      ESTIMATED TOTAL COST
NOTE
NOTE    FIRMS BID FOR SUPPORT
NOTE
R       RCCPF.KL=RQIF.K+RQDF.K
A       RQRIF.K=BARFF.K/DT
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A      RCIF.K=CLIP(RQRIF.K,C,BARFF.K,BPFRF.K)
A      BARFF.K=TECF.K+BCCF.K-RFPF.K
A      BCCF.K=MAX(CECCF.K,EACFF.K)
A      EACFF.K=(IPP.K)(CECCF.K)
A      CECCF.K=(ECCPF.K)(ICF)
A      IPP.K=MAX(SPINC.K,SPCBF.K)
A      RCRDF.K=EURFF.K/DT
A      RCCF.K=CLIP(RQRDF.K,C,EURFF.K,BPFRF.K)
A      BPFRF.K=(BP)(RFPF.K)
C      BP=0.05
A      EURFF.K=RFPF.K-ETCPF.K
L      RFPF.K=RFPF.J+(DT)(RQCPF.JK)
N      RFPF=0
C      ICF=0.9
NOTE
NOTE   CUSTOMER EVALUATION AND FUNDING OF THE PROJECT
NOTE
A      ETCAC.K=ETCPC.K+(CNFC)(DECFC.K)
L      DECFC.K=DECFC.J+(DT/DRRFC)(DECRC.JK-DECFC.J)
N      DECFC=0
C      DRRFC=3
R      DECRC.KL=RFPF.K-ETCPC.K
A      EVAUC.K=EFPVC.K+(CNFC)(FEVPC.K-EFPVC.K)
A      FEVPC.K=EFPVF.K+(1-ICF)(EFPVF.K)
A      VCRC.K=EVAUC.K/ECCPC.K
A      TPINC.K=VCRC.K/ROICC
C      ROICC=2.0
A      TFWCC.K=(ETCAC.K)(SPINC.K)
A      SPINC.K=CLIP(1,CONST6.K,TPINC.K,1)
A      CONST6.K=CLIP(0,TPINC.K,0,TPINC.K)
A      MADC.K=MIN(TFWCC.K,RRFC.K)
L      RRFC.K=RRFC.J+(DT/CRRFC)(RFPF.J-RRFC.J)
N      RRFC=0
L      AAC.K=AAC.J+(DT)(RFAC.JK)
N      AAC=0
L      FAC.K=FAC.J+(DT)(FINC.JK-RFAC.JK)
N      FAC=0
R      FINC.KL=PULSE(FINVC,INTMC,FRT)
C      FINVC=1E10
C      INTMC=0
C      FRT=500
NOTE
NOTE   ECUATIONS FOR CUSTOMER PROJECT CONTROL ACTIVITIES
NOTE
A      AFAC.K=FAC.K/DT
R      RFAC.KL=MIN(TRFAC.K,AFAC.K)
A      TRFAC.K=MAX(RFADC.K,-LCRAF.K)
A      RFADC.K=(MADC.K-AAC.K)/DLYC2
C      DLYC2=18
A      LCRAF.K=(UCAF.K-APC.K)/DT
L      UCAF.K=UCAF.K+(DT)(RFAC.JK-RECFF.JK)
N      UCAF=0
A      AAPC.K=APC.K/DPC
C      DPC=2
A      AUCAF.K=UCAF.K/DT
R      RECFF.KL=MIN(AAPC.K,AUCAF.K)
L      APC.K=APC.J+(DT)(BRC.JK-RECFF.JK)
N      APC=0
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R      BRC.KL=MIN(MREPC.K,TCEF.JK)
A      AUSP.K=UCAF.K/SPDC.K
A      MREPC.K=CLIP(AUSP.K,0,AUSP.K,MESOH)
A      SPDC.K=MPCTC.K+ASPDC.K
A      MPCTC.K=MAX(MPCT1.K,DT)      MIN. PROC COMPLETION TIME
A      MPCT1.K=(BPPIC.K)(.5)(NPD)
A      ASPDC.K=(NPD-MPCTC.K)(1-SPINC.K)
NOTE
NOTE   EQUATIONS FOR FIRM'S INVESTMENT DECISION
NOTE
A      VCRF.K=EFPVF.K/ETCPF.K
A      TPCBF.K=VCRF.K/ROICF
C      ROICF=2.0
A      SPCBF.K=CLIP(1,CONST3.K,TPCBF.K,1)
A      CONST3.K=CLIP(0,TPCBF.K,0,TPCBF.K)
C      EPRF=0.07
A      EXPRF.K=(EPRF)(SPCBF.K)(ETCPF.K)
A      MIDF.K=(WARF)(EXPRF.K)
A      MDRAF.K=(MIDF.K-TAIF.K)/(EPCTF.K)
A      TRAF.K=MAX(MDRAF.K,BRAF)
N      BRAF=(MESOH)(LEI)
C      LEI=1
A      TFAF.K=FAF.K/DT
R      RFAF.KL=MIN(TRAF.K,TFAF.K)
R      FINF.KL=PULSE(FINVF,INTMF,FRT)
C      FINVF=10E6
C      INTMF=0
L      FAF.K=FAF.J+(DT)(FINF.JK+RECFF.JK-TCEF.JK)
N      FAF=BRBF
L      UIAF.K=UIAF.J+(DT)(RFAF.JK+RECFF.JK-TCEF.JK-CAF.JK)
N      UIAF=BRBF
N      BRBF=(BPER)(MESOH)(LEI)
C      BPER=6
R      CAF.KL=PULSE(CXAF.K,BPER,BPER)
A      CXAF.K=MAX(XUAF.K,0)
A      XUAF.K=(UIAF.K-BRBF)/DT
L      TAIF.K=TAIF.J+(DT)(TCEF.JK-RECFF.JK)
N      TAIF=TECF
NOTE
NOTE   ACCUISITION OF ENGG MANPOWER
NOTE
L      ENGRF.K=ENGRF.J+(DT)(ENGJF.JK-ENGLF.JK)    ENGRS IN THE FIRM
N      ENGRF=LEI
A      ENGDF.K=MIN(SENGF.K,SWENF.K)          ENGINEERS DESIRED
A      SENGF.K=EERAF.K/MESOH
A      ERAF.K=MAX(MREPC.K,RFAF.JK)
A      EERAF.K=MAX(ERAF.K,BRAF)
A      SWENF.K=ECCPF.K/((MESOH)(EPCTF.K))    ENGRS NEEDED BY THE FIRM
L      EENGF.K=EENGF.J+(DT)(ENGHF.JK-ENGTF.JK)     ENGRS EXPECTED
N      EENGF=LEI
A      ENGPF.K=ENGDF.K-EENGF.K    ENGINEERING MANPOWER GAP
A      MEITF.K=(TPSDF)(ENFEF.K+ENATF.K)  MAXIMUM TRAINEES TO BE HANDLED
N      TPSDF=(TEI)(TPSF)  TPS DESIRED BY FIRM
C      TEI=1.0
C      TPSF=2.5   TRAINEES PER STAFF ENGINEER AT THE FIRM
L      EEITF.K=EEITF.J+(DT)(ENGHF.JK-ENLTF.JK-EITTF.J)
N      EEITF=0
NOTE
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NOTE   MAXIMUM HIRING RATE
NOTE
A      MENHF.K=MAX(MEHTF.K,0)   KEEP MAX HIRING +
A      MEHTF.K=(1/DT)(MEITF.K-EEITF.K)  MAX.HIRING TRIED
A      DENHF.K=MAX(ENGCF.K,0)    DESIRED ENGRG HIRING RATE
A      ENGCF.K=ENGPF.K/DCEF   TRIAL CHANGE,FOR HIRING RATE
C      DCEF=3.0     DELAY IN CHANGING ENGINEERS AT FIRM
R      ENGHF.KL=MIN(DENHF.K,MENHF.K)    ENGINEERING HIRING RATE
L      ENBRF.K=ENBRF.J+(DT)(ENGHF.JK-ENGJF.JK)    ENGRS BEING RECRUITED
N      ENBRF=0
R      ENGJF.KL=DELAY3(ENGHF.JK,DRCE)      ENGRS.JOINING
C      DRCE=6
L      ENITF.K=ENITF.J+(DT)(ENGJF.JK-ENLTF.JK-EITTF.J+0) ENGRS IN TRG
N      ENITF=0
A      ENRTF.K=ENITF.K+(DT)(-EITTF.K)  ENGRS REMAINING IN TRAINING
R      ENLTF.KL=ENRTF.K/DETF   LEAVING TRAINING AFTER COMPLETION
C      DETF=18       DELAY IN ENGINEERING TRAINING
L      ENFEF.K=ENFEF.J+(DT)(ENLTF.JK-ENFTF.J-ENREF.JK+0)  ENGRS FULLY EXP
N      ENFEF=LEI
L      ENATF.K=ENATF.J+(DT)(ENREF.JK-ENTTF.J)    TRAINEES
N      ENATF=0
A      ENDTF.K=EEITF.K/TPSDF    DESIRED NUMBER OF TRAINEES
A      EDRTF.K=(1/DRET)(ENDTF.K-ENATF.K)    DESIRED REASSIGNMENTS
C      DRET=1.0       DELAY IN REASSIGNING ENGRS TO-+-FROM
A      ENRPF.K=MIN(EDRTF.K,ENARF.K)  ENGRG REASSIGNMENTS POSSIBLE
A      ENARF.K=ENFEF.K/DT  AVAILABLE FOR REASSIGNMENT
R      ENREF.KL=CLIP(0,ENRPF.K,0,ENGPF.K)  REASSIGNMENT RATE FROM ENGRG
A      ENTDF.K=CLIP(ENGTD.K,0,0,ENGPF.K)     TRANSFERRING DECISION
A      ENGTD.K=MIN(-ENTRF.K,TEATF.K)      DESIRED TRANFERS
A      ENTRF.K=ENGPF.K/DT    ENGINEERING GAP TRANSFER RATE
A      TEATF.K=ENARF.K+ETATF.K+EITAF.K  TOTAL AVAILABLE TRANSFER RATE
A      ETATF.K=ENATF.K/DT    TRAINERS AVAILABLE FOR TRANSFER
A      EITAF.K=ENITF.K/DT   TRAINEES AVAILABE FOR TRANSFERS
R      ENGTF.KL=ENTTF.K+EITTF.K+ENFTF.K    TRANSFERING RATE
A      ENTTF.K=MIN(ENTDF.K,ETATF.K)    TRANSFERED AS TRAINERS
A      ENTAN.K=ENTDF.K-ENTTF.K      ADDITIONAL TRANSFERS NEEDED
A      EITTF.K=MIN(ENTAN.K,EITAF.K)   TRANSFERRED TRAINEES
A      ENTFN.K=ENTAN.K-EITTF.K
A      ENFTF.K=MIN(ENARF.K,ENTFN.K)
L      ENBTF.K=ENBTF.J+(DT)(ENGTF.JK-ENGLF.JK)   ENGRS BEING TRANSFERED
N      ENBTF=0
R      ENGLF.KL=ENBTF.K/DTRE
C      DTRE=1
NOTE
NOTE   ENGG PRODUCTIVITY
NOTE
A      UTEF.K=(QF)(ATEF.K)      UTILIZED EFFECTIVENESS
A      MEPIK.K=TABHL(TMEPK,KLEVF.K,0,1,.1)
C      TMEPK*=1/1.16/1.27/1.36/1.42/1.47/1.50/1.53/1.55/1.56/1.57
A      REPRF.K=(PRIT)(ENITF.K)+(PRAT)(ENATF.K)+(PREBT)(ENBTF.K)+(1.0)(ENF
X1     EF.K)
C      PRIT=0.4
C      PRAT=0.7
C      PREBT=0.2
N      PWAW=1-AVABS   PERCENT WORKERS ACTUALLY AT WORK
A      RPEWF.K=(PWAW)(REPRF.K)  RELATIVE PROD OF ENGRS AT WORK
R      ENPRF.KL=(UTEF.K)(MEPIK.K)(RPEWF.K)
L      KLEVF.K=KLEVF.J+(DT)(ENPRF.JK+0)  LEVEL OF KNOW-HOW OF THE FIRM
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MODIFIED R AND D MODEL    4/24/72

N      KLEVF=0.0001
A      KLEVC.K=(PKFTC)(KLEVF.K)   KNOWLEDGE LEVEL OF CUSTOMER
C      PKFTC=0.80   PERCENT OF KLEVF TRANSMITTED TO CUSTOMER
NOTE
NOTE   CONTROL OF R AND D PROGRESS
NOTE
A      PPC.K=KLEVF.K/NLKP   PERCENT OF PROJECT COMPLETED
R      TCEF.KL=(MESOH)(ENGRF.K)   TOTAL CURRENT EXPENDITURE RATE BY FIRM
L      TECF.K=TECF.J+(DT)(TCEF.JK+0)  TOTAL ENGRG COSTS AT FIRM
N      TECF=(TEEF)(MESOH)   ENGINEERS ACTUALLY AT WORK
A      ENAWF.K=(PWAW)(ENGRF.K)  ENGINEERS ACTUALLY AT WORK
L      TEEF.K=TEEF.J+(DT)(ENAWF.J+0)   TOTAL ENGINEERING EFFORT
N      TEEF=KLEVF/UTEF
L      TECC.K=TECC.J+(DT)(RECFF.JK+0.0)    TOTAL FINANCED BY CUST
N      TECC=0
L      BPPCF.K=BPPCF.J+(DT)(RCBPF.JK+PRBF.JK)
N      BPPCF=PPC
R      PRBF.KL=(ENAWF.K)(MMEEM)/EERF.K  PROGRESS RATE BELIEVED BY FIRM
C      MMEEM=1   MAN-MONTH OF EFFORT PER WORKING-ENGINEER PER MONTH
R      RCBPF.KL=GBPCF.K/DRAAF
C      DRAAF=3
A      GBPCF.K=PPC.K-BPPCF.K   GAP IN BELIEVED PERCENT COMPLETION
A      BPPIF.K=MAX(TBPIF.K,0)
A      TBPIF.K=1-BPPCF.K   TRAIL,BELIEVED PERCENT OF PROJ INCOMPLETE
A      EPCTF.K=MAX(TPCTF.K,DT)   EST PROJECT COMPLETION TIME
A      TPCTF.K=(BPPIF.K)(NPC)    TRIAL PCT
L      BPPCC.K=BPPCC.J+(DT)(RCBPC.JK+PRBC.JK)
N      BPPCC=PPC
R      PRBC.KL=(ENAWF.K)(MMEEM)/EERC.K  PROGRESS RATE BELIEVED BY CUST
R      RCBPC.KL=GBPCC.K/DRAAC
C      DRAAC=6
A      GBPCC.K=PPC.K-BPPCC.K   GAP IN BELIEVED PERCENT COMPLETION
A      BPPIC.K=MAX(TBPIC.K,0)
A      TBPIC.K=1-BPPCC.K   TRIAL,BELIEVED P.C.OF PROJ INCOMPLETE
NOTE
NOTE       SUPPLIMENTARY INFORMATION ON PROFITS TO THE FIRM
NOTE
R      PRF.KL=(PPP)(RECFF.JK)   PROFIT RATE TO THE FIRM
C      PPP=0.07     PERCENTAGE PROFIT ON THE PROJECT
L      PROF.K=PROF.J+(DT)(PRF.JK+0)   GROSS TOTAL PROFIT
N      PROF=0
A      NPROF.K=PROF.K-TAIF.K    NET PROFIT BEFORE TAXES
A      NATPF.K=(CTR)(NPROF.K)     NET PROFIT AFTER TAX
C      CTR=0.50      CORPORATE TAX RATE FACTOR
NOTE
NOTE   ****************************************************************
NOTE
PRINT 1)EPPVF(6.2)/2)EPPVC(6.2)/3)ETCPF(6.2)/4)ETCPC(6.2)/5)ENGRF(0.2)/6
X1     ENAWF(0.2)/7)PPC(0.4)/8)SPCBF(0.4)/9)TECF(6.3)/10)TECC(6.3)/11)NAT
X2     PF/12)ENBRF
PLOT   IPV=V,EPPVF=E(0,300E6)/ETCPF=C(0,120E6)/ENGRF=G,ENAWF=W(0,600)/PPC
X1     =P(0,2)/TECF=T(0,80E6)
PLOT  SPINC=C,SPCBF=F,IPP=I(0,1)/VCRC=V,VCRF=R
SPEC   DT=0.50/LENGTH=150/PLTPER=2/PRTPER=1
RUN    1
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MODIFIED R AND D MODEL 4/24/72

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*       MODIFIED R AND D MODEL
NOTE
NOTE    ****************************************************************
NOTE    IN THIS MODEL IT IS ASSUMED THAT THERE IS A RANDOMRM ABSENTEEISM
NOTE    ****************************************************************
NOTE
NOTE    PERCEPTION OF PRODUCT VALUE BY FIRM
NOTE
A       IPV.K=TABLE(PVTAB,TIME.K,0,180,6)   INTRISIC PRODUCT VALUE
C       PVTAB*=0/0/.5E6/5E6/12.5E6/22.5E6/40E6/62.5E6/80E6/90E6/95E6/97.5E
X1      6/99E6/100E6/100E6/100E6/95E6/80E6/60E6/40E6/25E6/15E6/10E6/5E6/1E
X2      6/.2E6/0/0/0/0/0
A       DRPVF.K=TABHL(TDVR,KLEVF.K,0,60,5)   DELAY IN RECCG PRODUCT VALUE
C       TDVR*=66/45.5/32/23.2/17.3/13.5/10.9/9.2/8.2/7.4/7.0/6.6/6.4
R       RPVF.KL=(1/DRPVF.K)(IPV.K-LRPVF.K)   RECOGNITION OF PRODUCT VALUE
L       LRPVF.K=LRPVF.J+(DT)(RPVF.JK+0.0)
N       LRPVF=0
A       TPFPVF.K=LRPVF.K+(PHF)(RPVF.JK)
C       PHF=48
A       PFPVF.K=MAX(TPFPVF.K,0)
C       WASF=1
L       EFPVF.K=EFPVF.J+(DT)(1/DAEVF)(PFPVF.J-EFPVF.J)
N       EFPVF=0
C       DAEVF=6   DELAY IN ADJUSTING ESTIMATE OF VALUE
NOTE
NOTE              CUSTOMER PERCEPTION OF PRODUCT NEED AND VALIE
NOTE
A       DRPVC.K=TABHL(TDVR,KLEVC.K,0,60,5)   DELAY IN RECCG PRODUCT VALUE
R       RPVC.KL=(1/DRPVC.K)(IPV.K-LRPVC.K)   RECOGNITION OF PRODUCT VALUE
L       LRPVC.K=LRPVC.J+(DT)(RPVC.JK+0)
N       LRPVC=0
A       TPFPVC.K=LRPVC.K+(PHC)(RPVC.JK)
C       PHC=36
A       PFPVC.K=MAX(TPFPVC.K,0)
L       EFPVC.K=EFPVC.J+(DT)(1/DAEVC)(PFPVC.J-EFPVC.J)   EST OF FUTURE PV
N       EFPVC=0
C       DAEVC=8   DELAY IN CUSTOMERS ADJUSTMENT OF VALUE ESTIMATE
NOTE
NOTE    FIRMS ESTIMATE OF JOB SIZE
NOTE
L       BNKPF.K=BNKPF.J+(DT)(RGEJF.JK)
N       BNKPF=(NLKP)(1+PDPEF)/OF
C       NLKP=5500
C       PDPEF=-0.25
C       OF=1.0
A       GEAF.K=(ESPCF.K-BPPCF.K)/BPPCF.K
R       RGEJF.KL=(BNKPF.K)(GEAF.K)(FCGRF.K)
A       ESPCF.K=(TEEF.K)(ETEF.K)/BNKPF.K
A       FCGRF.K=TABHL(IPPGR,PPC.K,0,1,.1)   TIME-SIGNIFICANCE OF GAP
C       IPPGR*=0/0/0/.05/.12/.20/.35/.60/.80/.99/1.0
NOTE
NOTE    FIRM'S ESTIMATE OF TECHNICAL EFFECTIVENESS
NOTE
A       TE.K=TABLE(TETAB,TIME.K,0,180,6)
C       TETAB*=.25/.25/.25/.25/.26/.27/.28/.30/.32/.35/.38/.42/.46/.51/.57
X1      /.63/.70/.77/.82/.86/.89/.91/.93/.94/.95/.96/.97/.98/.99/.995/1.0
L       ATEF.K=ATEF.J+(DT)(RCTAF.JK)
N       ATEF=TE
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MODIFIED R AND D MODEL    4/24/72
R      RCTAF.KL=(TE.K-ATEF.K)/DTITF
L      ETEF.K=ETEF.J+(DT)(RCEEF.JK)
N      ETEF=(WARF)(ENPFF)/ENAWF
R      RCEEF.KL=(RTEF.K-ETEF.K)/DRTEF
A      RTEF.K=(PRBF.JK)(BNKPF.K)/ENAWF.K
A      EFTEF.K=ETEF.K+(XPTPF.K)(RCTAF.JK)
A      XPTPF.K=(BPPIF.K)(NPD/2)
C      DTITF=24
C      NPD=24
C      DRTEF=2
NOTE
NOTE   FIRMS ESTIMATE OF  EFFORT AND COST
NOTE
A      EERF.K=(1/EFTEF.K)((TEEF.K)(EFTEF.K)+(BNKPF.K)(BPPIF.K))
A      ECCPF.K=(SMEC)(EERF.K-TEEF.K)   EXPECTED ADDITIONAL COST
N      SMEC=MESOH/(1-AVABS)     SCALED MONTHLY ENG COSTS
C      MESOH=2500              MONTHLY ENGG SALARY
A      ETCPF.K=TECF.K+ECCPF.K   ESTIMATED TOTAL COST OF PROJECT
NOTE
NOTE   CUSTOMER'S EXTIMATE OF JOB SIZE
NOTE
L      BNKPC.K=BNKPC.J+(DT)(RGEJC.JK+0)   ESTIMATED JOB SIZE
N      BNKPC=(NLKP)(1+PDPEC)/QC
C      PDPEC=-0.175
C      QC=0.60
A      GEAC.K=(ESPCC.K-BPPCC.K)/BPPCC.K
R      RGEJC.KL=(BNKPC.K)(GEAC.K)(FOGRC.K)
A      ESPCC.K=(TEEF.K)(ETEC.K)/BNKPC.K
A      FOGRC.K=TABHL(IPPGR,PPC.K,0,1,.1)
NOTE
NOTE   CUSTOMER'S ESTIMATE OF TECHNOLOGICAL EFFECTIVENESS
NOTE
L      ATEC.K=ATEC.J+(DT)(RCTAC.JK+0)     AVAILABLE T.E.
N      ATEC=TE
R      RCTAC.KL=(1/DTITC)(TE.K-ATEC.K)
L      ETEC.K=ETEC.J+(DT)(RCEEC.JK)
N      ETEC=(WARC)(ATEC)(CNFC)
C      CNFC=0.6   CONFIDENCE IN FIRM BY CUSTOMER
C      WARC=0.6
R      RCEEC.KL=(1/DRTEC)(RTEC.K-ETEC.K)   RATE OF CHANGE OF EST EFFECT
A      RTEC.K=(PRBC.JK)(BNKPC.K)/ENAWF.K   REALIZED TE BY CUSTOMER
C      DTITC=12
C      DRTEC=8         DELAY IN RECOGNIZING T.E. AT FIRM
A      EFTEC.K=ETEC.K+(XPTPC.K)(RCTAC.JK)
A      XPTPC.K=(BPPIC.K)(NPD)/2   EXTRAPOLATION PERIOD FOR TECH PROGRESS
NOTE
NOTE   ESTIMATION OF EFFORT AND COST BY THE CUSTOMER
NOTE
A      EERC.K=(1/EFTEC.K)((TEEF.K)(EFTEC.K)+(BNKPC.K)(BPPIC.K))
A      ECCPC.K=(SMEC)(EERC.K-TEEF.K)    ESTIMATED COMPLETION COSTS
A      ETCPC.K=TECC.K+ECCPC.K       ESTIMATED TOTAL COST
NOTE
NOTE   FIRMS BID FOR SUPPORT
NOTE
R      RCCPF.KL=RQIF.K+RQDF.K
A      RQRIF.K=BARFF.K/DT
A      RCIF.K=CLIP(RQRIF.K,0,BARFF.K,BPFRF.K)
A      BARFF.K=TECF.K+PCCF.K-RFPF.K
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MODIFIED R AND D MODEL     4/24/72
 A      BCCF.K=MAX(CECCF.K,EACFF.K)
 A      EACFF.K=(IPP.K)(CECCF.K)
 A      CECCF.K=(ECCPF.K)(ICF)
 A      IPP.K=MAX(SPINC.K,SPCBF.K)
 A      RCRDF.K=EURFF.K/DT
 A      RCDF.K=CLIP(RQRFF.K,0,ELRFF.K,BPFRF.K)
 A      BPFRF.K=(BP)(RFPF.K)
 C      BP=0.05
 A      ELRFF.K=RFPF.K-ETCPF.K
 L      RFPF.K=RFPF.J+(DT)(RQCPF.JK)
 N      RFPF=0
 C      ICF=0.9
NOTE
NOTE    CUSTOMER EVALUATION AND FUNDING OF THE PROJECT
NOTE
 A      ETCAC.K=ETCPC.K+(CNFC)(DECFC.K)
 L      DECFC.K=DECFC.J+(DT/DRRFC)(DECRC.JK-DECFC.J)
 N      DECFC=0
 C      DRRFC=3
 R      DECRC.KL=RFPF.K-ETCPC.K
 A      EVAUC.K=EFPVC.K+(CNFC)(FEVPC.K-EFPVC.K)
 A      FEVPC.K=EFPVF.K+(1-ICF)(EFPVF.K)
 A      VCRC.K=EVAUC.K/TCCPC.K
 A      TPINC.K=VCRC.K/RCICC
 C      RCICC=2.0
 A      TFWCC.K=(ETCAC.K)(SPINC.K)
 A      SPINC.K=CLIP(1,CONST6.K,TPINC.K,1)
 A      CONST6.K=CLIP(0,TPINC.K,0,TPINC.K)
 A      MADC.K=MIN(TFWCC.K,RRFC.K)
 L      RRFC.K=RRFC.J+(DT/DRRFC)(RFPF.J-RRFC.J)
 N      RRFC=0
 L      AAC.K=AAC.J+(DT)(RFAC.JK)
 N      AAC=0
 L      FAC.K=FAC.J+(DT)(FINC.JK-RFAC.JK)
 N      FAC=0
 R      FINC.KL=PULSE(FINVC,INTMC,FRT)
 C      FINVC=1E10
 C      INTMC=0
 C      FRT=500
NOTE
NOTE    EQUATIONS FOR CUSTOMER PROJECT CONTROL ACTIVITIES
NOTE
 A      AFAC.K=FAC.K/DT
 R      RFAC.KL=MIN(TRFAC.K,AFAC.K)
 A      TRFAC.K=MAX(RFADC.K,-LCRAF.K)
 A      RFADC.K=(MADC.K-AAC.K)/DLYC2
 C      DLYC2=18
 A      LCRAF.K=(UCAF.K-APC.K)/DT
 L      UCAF.K=UCAF.K+(DT)(RFAC.JK-RECFF.JK)
 N      UCAF=0
 A      AAPC.K=APC.K/DPC
 C      DPC=2
 A      AUCAF.K=UCAF.K/DT
 R      RECFF.KL=MIN(AAPC.K,AUCAF.K)
 L      APC.K=APC.J+(DT)(BRC.JK-RECFF.JK)
 N      APC=0
 R      BRC.KL=MIN(MREPC.K,TCEF.JK)
 A      ALSP.K=UCAF.K/SPDC.K
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MODIFIED R AND D MODEL     4/24/72

A      MREPC.K=CLIP(AUSP.K,0,AUSP.K,MESOH)
A      SPDC.K=MPCTC.K+ASPDC.K
A      MPCTC.K=MAX(MPCT1.K,DT)      MIN. PROD COMPLETION TIME
A      MPCT1.K=(BPPIC.K)(.5)(NPD)
A      ASPDC.K=(NPD-MPCTC.K)(1-SPINC.K)
NOTE
NOTE   EQUATIONS FOR FIRM'S INVESTMENT DECISION
NOTE
A      VCRF.K=EFPVF.K/ETCPF.K
A      TPCBF.K=VCRF.K/RCICF
C      RCICF=2.0
A      SPCBF.K=CLIP(1,CONST3.K,TPCBF.K,1)
A      CONST3.K=CLIP(0,TPCBF.K,0,TPCBF.K)
C      EPRF=0.07
A      EXPRF.K=(EPRF)(SPCBF.K)(ETCPF.K)
A      MIDF.K=(WARF)(EXPRF.K)
A      MDRAF.K=(MIDF.K-TAIF.K)/(EPCTF.K)
A      TRAF.K=MAX(MDRAF.K,BRAF)
N      BRAF=(MESOH)(LEI)
C      LEI=1
A      TFAF.K=FAF.K/DT
R      RFAF.KL=MIN(TRAF.K,TFAF.K)
R      FINF.KL=PULSE(FINVF,INTMF,FRT)
C      FINVF=10E6
C      INTMF=0
L      FAF.K=FAF.J+(DT)(FINF.JK+RECFF.JK-TCEF.JK)
N      FAF=BRBF
L      UIAF.K=UIAF.J+(DT)(RFAF.JK+RECFF.JK-TCEF.JK-CAF.JK)
N      UIAF=BRBF
N      BRBF=(BPER)(MESOH)(LEI)
C      BPER=6
R      CAF.KL=PULSE(CXAF.K,BPER,BPER)
A      CXAF.K=MAX(XUAF.K,0)
A      XUAF.K=(UIAF.K-BRBF)/DT
L      TAIF.K=TAIF.J+(DT)(TCEF.JK-RECFF.JK)
N      TAIF=TECF
NOTE
NOTE   ACQUISITION OF ENGG MANPOWER
NOTE
L      ENGRF.K=ENGRF.J+(DT)(ENGJF.JK-ENGLF.JK)    ENGRS IN THE FIRM
N      ENGRF=LEI
A      ENGDF.K=MIN(SENGF.K,SWENF.K)          ENGINEERS DESIRED
A      SENGF.K=EERAF.K/MESOH
A      ERAF.K=MAX(MREPC.K,RFAF.JK)
A      EERAF.K=MAX(ERAF.K,BRAF)
A      SWENF.K=ECCPF.K/((MESOH)(EPCTF.K))    ENGRS NEEDED BY THE FIRM
L      EENGF.K=EENGF.J+(DT)(ENGHF.JK-ENGTF.JK)     ENGRS EXPECTED
N      EENGF=LEI
A      ENGPF.K=ENGDF.K-EENGF.K    ENGINEERING MANPOWER GAP
A      MEITF.K=(TPSDF)(ENFEF.K+ENATF.K)  MAXIMUM TRAINEES TO BE HANDLED
N      TPSDF=(TEI)(TPSF)   TPS DESIRED BY FIRM
C      TEI=1.0
C      TPSF=2.5   TRAINEES PER STAFF ENGINEER AT THE FIRM
L      EEITF.K=EEITF.J+(DT)(ENGHF.JK-ENLTF.JK-EITTF.J)
N      EEITF=0
NOTE
NOTE   MAXIMUM HIRING RATE
NOTE
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MODIFIED R AND D MODEL   4/24/72

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A     MENHF.K=MAX(MEHTF.K,0)    KEEP MAX HIRING +
A     MEHTF.K=(1/DT)(MEITF.K-EEITF.K)  MAX.HIRING TRIED
A     DENHF.K=MAX(ENGCF.K,0)    DESIRED ENGRG HIRING RATE
A     ENGCF.K=ENGPF.K/DCEF   TRIAL CHANGE,FOR HIRING RATE
C     DCEF=3.0    DELAY IN CHANGING ENGINEERS AT FIRM
R     ENGHF.KL=MIN(DENHF.K,MENHF.K)   ENGINEERING HIRING RATE
L     ENBRF.K=ENBRF.J+(DT)(ENGHF.JK-ENGJF.JK)   ENGRS BEING RECRUITED
N     ENBRF=0
R     ENGJF.KL=DELAY3(ENGHF.JK,DRCE)      ENGRS.JOINING
C     DRCE=6
L     ENITF.K=ENITF.J+(DT)(ENGJF.JK-ENLTF.JK-EITTF.J+0) ENGRS IN TRG
N     ENITF=0
A     ENRTF.K=ENITF.K+(DT)(-EITTF.K)  ENGRS REMAINING IN TRAINING
R     ENLTF.KL=ENRTF.K/DETF   LEAVING TRAINING AFTER COMPLETION
C     DETF=18        DELAY IN ENGINEERING TRAINING
L     ENFEF.K=ENFEF.J+(DT)(ENLTF.JK-ENFTF.J-ENREF.JK+0)  ENGRS FULLY EXP
N     ENFEF=LEI
L     ENATF.K=ENATF.J+(DT)(ENREF.JK-ENTTF.J)   TRAINEES
N     ENATF=0
A     ENDTF.K=EEITF.K/TPSDF    DESIRED NUMBER OF TRAINEES
A     EDRTF.K=(1/DRET)(ENDTF.K-ENATF.K)   DESIRED REASSIGNMENTS
C     DRET=1.0       DELAY IN REASSIGNING ENGRS TO-+-FROM
A     ENRPF.K=MIN(EDRTF.K,ENARF.K)  ENGRG REASSIGNMENTS POSSIBLE
A     ENARF.K=ENFEF.K/DT  AVAILABLE FOR REASSIGNMENT
R     ENREF.KL=CLIP(0,ENRPF.K,0,ENGPF.K)  REASSIGNMENT RATE FROM ENGRG
A     ENTDF.K=CLIP(ENGTD.K,0,0,ENGPF.K)     TRANSFERRING DECISION
A     ENGTD.K=MIN(-ENTRF.K,TEATF.K)      DESIRED TRANFERS
A     ENTRF.K=ENGPF.K/DT     ENGINEERING GAP TRANSFER RATE
A     TEATF.K=ENARF.K+ETATF.K+EITAF.K  TOTAL AVAILABLE TRANSFER RATE
A     ETATF.K=ENATF.K/DT     TRAINERS AVAILABLE FOR TRANSFER
A     EITAF.K=ENITF.K/DT   TRAINEES AVAILABE FOR TRANSFERS
R     ENCTF.KL=ENTTF.K+EITTF.K+ENFTF.K    TRANSFERING RATE
A     ENTTF.K=MIN(ENTDF.K,ETATF.K)     TRANSFERED AS TRAINERS
A     ENTAN.K=ENTDF.K-ENTTF.K       ADDITIONAL TRANSFERS NEEDED
A     EITTF.K=MIN(ENTAN.K,EITAF.K)   TRANSFERRED TRAINEES
A     ENTFN.K=ENTAN.K-EITTF.K
A     ENFTF.K=MIN(ENAFF.K,ENTFN.K)
L     ENBTF.K=ENBTF.J+(DT)(ENGTF.JK-ENGLF.JK)   ENGRS BEING TRANSFERED
N     ENBTF=0
R     ENGLF.KL=ENBTF.K/DTRE
C     DTRE=1
NOTE
NOTE  ENGG PRODUCTIVITY
NOTE
A     UTEF.K=(QF)(ATEF.K)      UTILIZED EFFECTIVENESS
A     MEPIK.K=TABHL(TMEPK,KLEVF.K,0,1,.1)
C     TMEPK*=1/1.16/1.27/1.36/1.42/1.47/1.50/1.53/1.55/1.56/1.57
A     REPRF.K=(PRIT)(ENITF.K)+(PRAT)(ENATF.K)+(PREBT)(ENBTF.K)+(1.0)(ENF
X1    EF.K)
C     PRIT=0.4
C     PRAT=0.7
C     PREBT=0.2
A     PWAW.K=1-AVABS.K
A     AVABS.K=NORMRN(MEAN,STDEV)
N     MEAN=.115
N     STDEV=(0.25)(MEAN)
A     RPEWF.K=(PWAW.K)(REPRF.K)
R     ENPRF.KL=(UTEF.K)(MEPIK.K)(RPEWF.K)
```

MODIFIED R AND D MODEL 4/24/72

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L      KLEVF.K=KLEVF.J+(DT)(ENRRF.JK+0)  LEVEL CF KNCW-HCW CF THE FIRM
N      KLEVF=0.0001
A      KLEVC.K=(PKFTC)(KLEVF.K)   KNOWLEDGE LEVEL OF CUSTOMER
C      PKFTC=0.80   PERCENT CF KLEVF TRANSMITTEC TO CUSTOMER
NOTE
NOTE   CCNTROL OF R AND D PROGRESS
NOTE
A      PPC.K=KLEVF.K/NLKP   PERCENT CF PRCJECT COMPLETED
R      TCEF.KL=(MESOH)(ENGRF.K)   TOTAL CURRENT EXPENDITURE RATE BY FIRM
L      TECF.K=TECF.J+(DT)(TCEF.JK+0)   TOTAL ENGRG COSTS AT FIRM
N      TECF=(TEEF)(MESPH)   ENGINEERS ACTUALLY AT WCRK
A      ENAWF.K=(PWAW.K)(ENGRF.K)
L      TEEF.K=TEEF.J+(DT)(ENAWF.J+0)   TOTAL ENGINEERING EFFORT
N      TEEF=KLEVF/UTEF
L      TECC.K=TECC.J+(DT)(RECFF.JK+0.0)    TCTAL FINANCED BY CUST
N      TECC=0
L      BPPCF.K=BPPCF.J+(DT)(RCBPF.JK+PRBF.JK)
N      BPPCF=PPC
R      PRBF.KL=(ENAWF.K)(MMEEM)/EERF.K  PROGRESS RATE BELIEVED BY FIRM
C      MMEEM=1   MAN-MONTH OF EFFORT PER WORKING-ENGINEER PER MONTH
R      RCBPF.KL=GBPCF.K/DRAAF
C      DRAAF=3
A      GBPCF.K=PPC.K-BPPCF.K   GAP IN BELIEVED PERCENT COMPLETION
A      BPPIF.K=MAX(TBPIF.K,0)
A      TBPIF.K=1-BPPCF.K   TRAIL,BELIEVED PERCENT CF PROJ INCOMPLETE
A      EPCTF.K=MAX(TPCTF.K,DT)   EST PROJECT CCMPLETION TIME
A      TPCTF.K=(BPPIF.K)(NPD)   TRIAL PCT
L      BPPCC.K=BPPCC.J+(DT)(RCBPC.JK+PRBC.JK)
N      BPPCC=PPC
R      PRBC.KL=(ENAWF.K)(MMEEM)/EERC.K  PROGRESS RATE BELIEVED BY CUST
R      RCBPC.KL=GBPCC.K/DRAAC
C      DRAAC=6
A      GBPCC.K=PPC.K-BPPCC.K   GAP IN BELIEVED PERCENT COMPLETION
A      BPPIC.K=MAX(TBPIC.K,0)
A      TBPIC.K=1-BPPCC.K   TRIAL,BELIEVED P.C.CF PRCJ INCOMPLETE
NOTE
NOTE      SUPPLIMENTARY INFORMATION ON PROFITS TO THE FIRM
NOTE
R      PRF.KL=(PPP)(RECFF.JK)   PROFIT RATE TO THE FIRM
C      PPP=0.07    PERCENTAGE PROFIT ON THE PROJECT
L      PRCF.K=PROF.J+(DT)(PRF.JK+0)   CROSS TCTAL PROFIT
N      PRCF=0
A      NPROF.K=PROF.K-TAIF.K   NET PRCFIT BEFCRE TAXES
A      NATPF.K=(CTR)(NPROF.K)    NET PROFIT AFTER TAX
C      CTR=0.50     CORPORATE TAX RATE FACTOR
NOTE
NOTE   ********************************************************************
NOTE
PRINT  1)EFPVF(6.2)/2)EFPVC(6.2)/3)ETCPF(6.2)/4)ETCPC(6.2)/5)ENGRF(0.2)/6
X1     ENAWF(0.2)/7)PPC(0.4)/8)SPCBF(0.4)/9)TECF(6.3)/10)TECC(6.3)/11)NAT
X2     PF/12)ENBRF
PLOT   IPV=V,EFPVF=E(C,300E6)/ETCPF=C(C,120E6)/ENGRF=G,ENAWF=W(0,600)/PPC
X1     =P(0,2)/TECF=T(C,80E6)
SPEC   DT=0.50/LENGTH=*50/PLTPER=2/PRTPER=1
RUN    1
```

A STUDY OF RESEARCH AND DEVELOPMENT MANAGEMENT SYSTEM

by

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AN ABSTRACT OF A MASTER'S REPORT

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MASTER OF SCIENCE

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ABSTRACT

The purpose of this study is to understand the research and development management system and its dynamic behavior. The report is mainly based on Roberts' The Dynamics of Research and Development.

The structures used by PERT and PERT/COST approaches are explained and the reasons for failures of R and D organizations based on such structures are pointed out. Then the Industrial Dynamics approach used by Roberts to study R and D project life cycle is explained and the various activities that take place in the project life are summarized.

In order to understand the mathematical model developed by Roberts, his simulation results are reproduced. A few modifications are made in the structure of the R and D system to simulate reasons for failures of R and D management. A comparison of the results of the modified model with those of Roberts' model is made.