

A STUDY OF RESEARCH AND DEVELOPMENT MANAGEMENT SYSTEM

by

Y.V.P. NAGESWARARAO

B.E. (Mech), Andhra University, India, 1964

M. Tech (Foundry), I.I.T., Kharagpur, India, 1967

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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. Gerstenfeld (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 'Operations Research in Research and Development' 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.

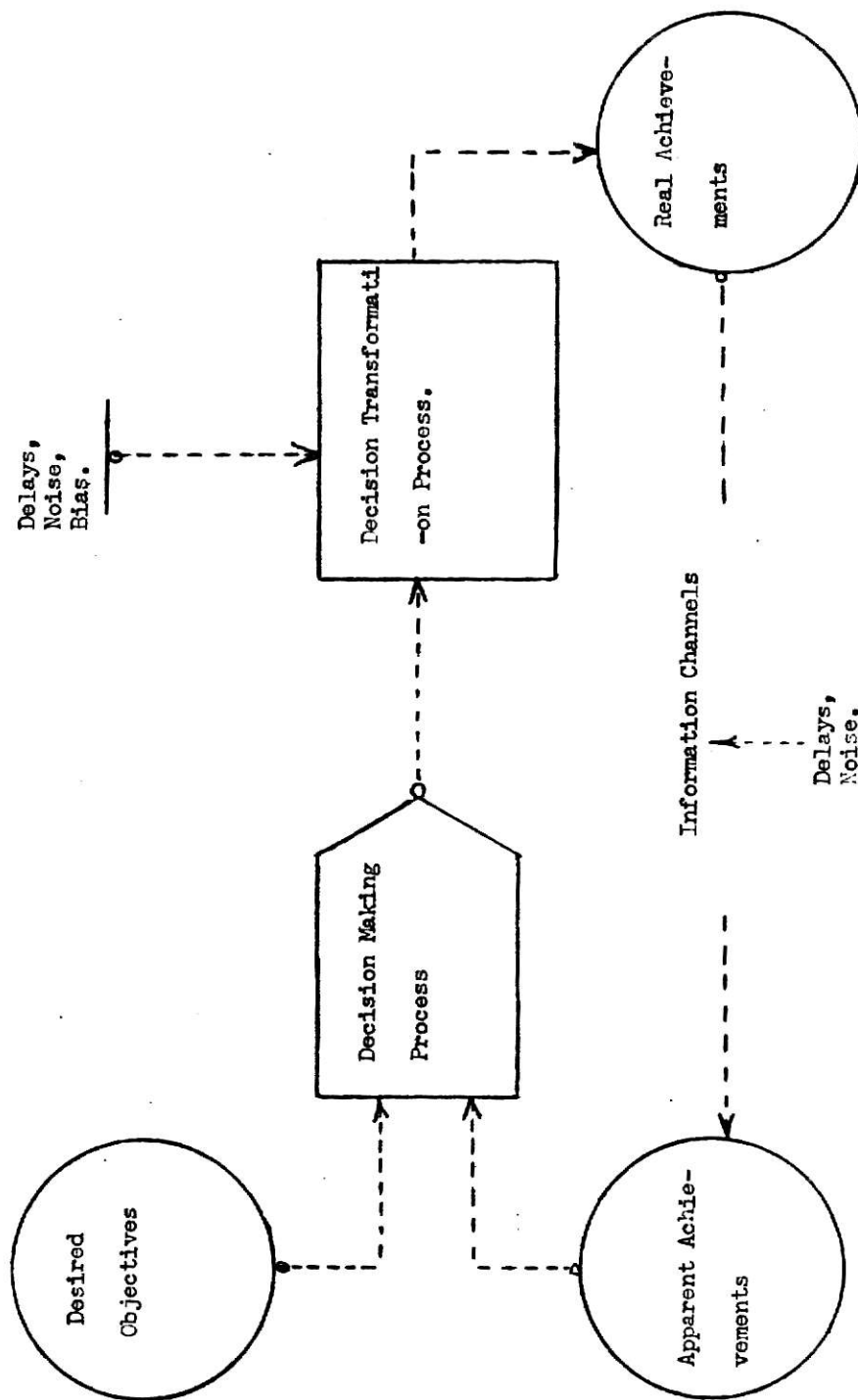


Figure 1.1 Control system structure of organisation (2)

Transformation of decisions takes place through a complex process which includes the basic structure of organizational, human and market-relationships. 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,

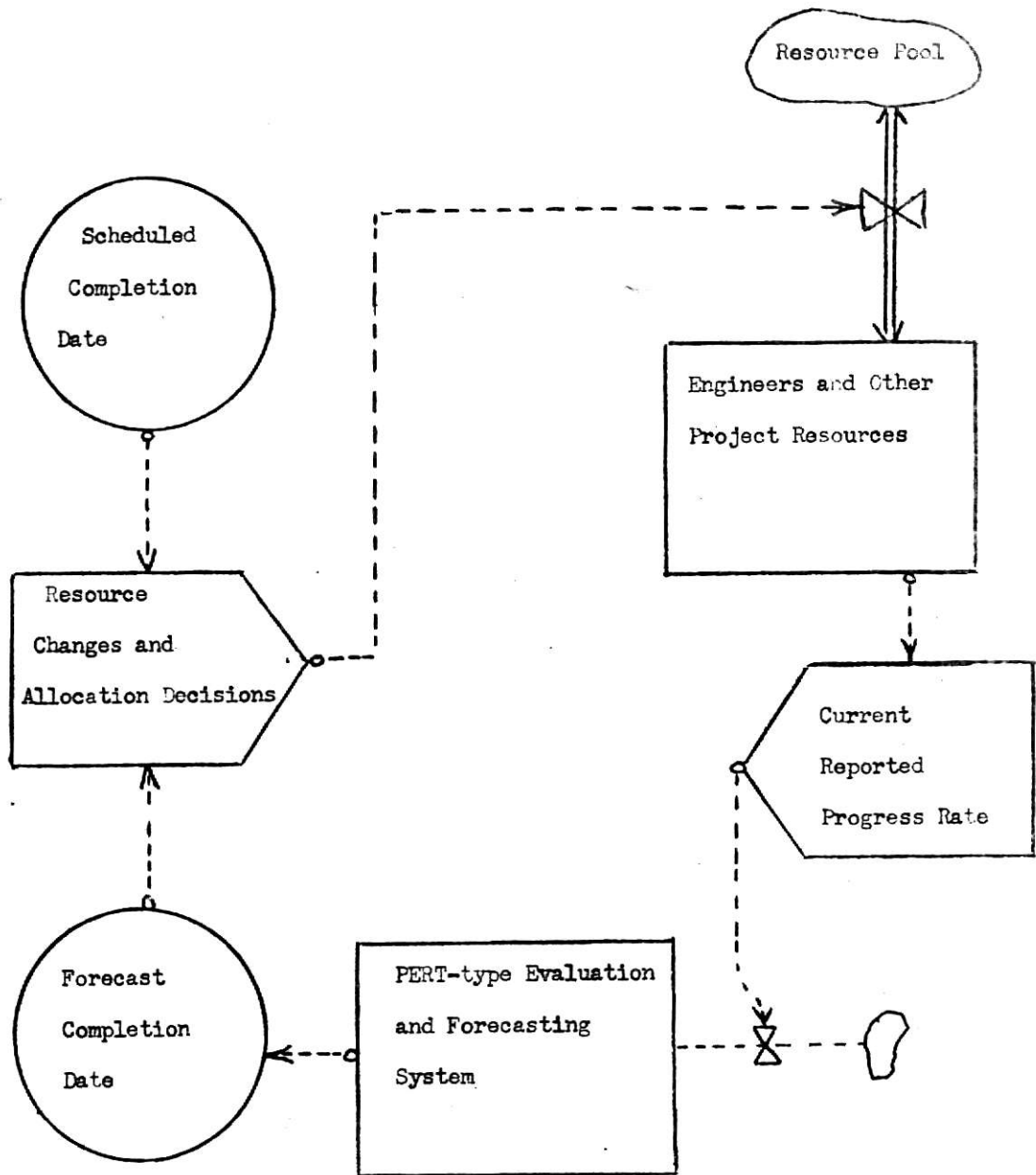


Figure 1.2 Assumed basis of current R and D project control (2)

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

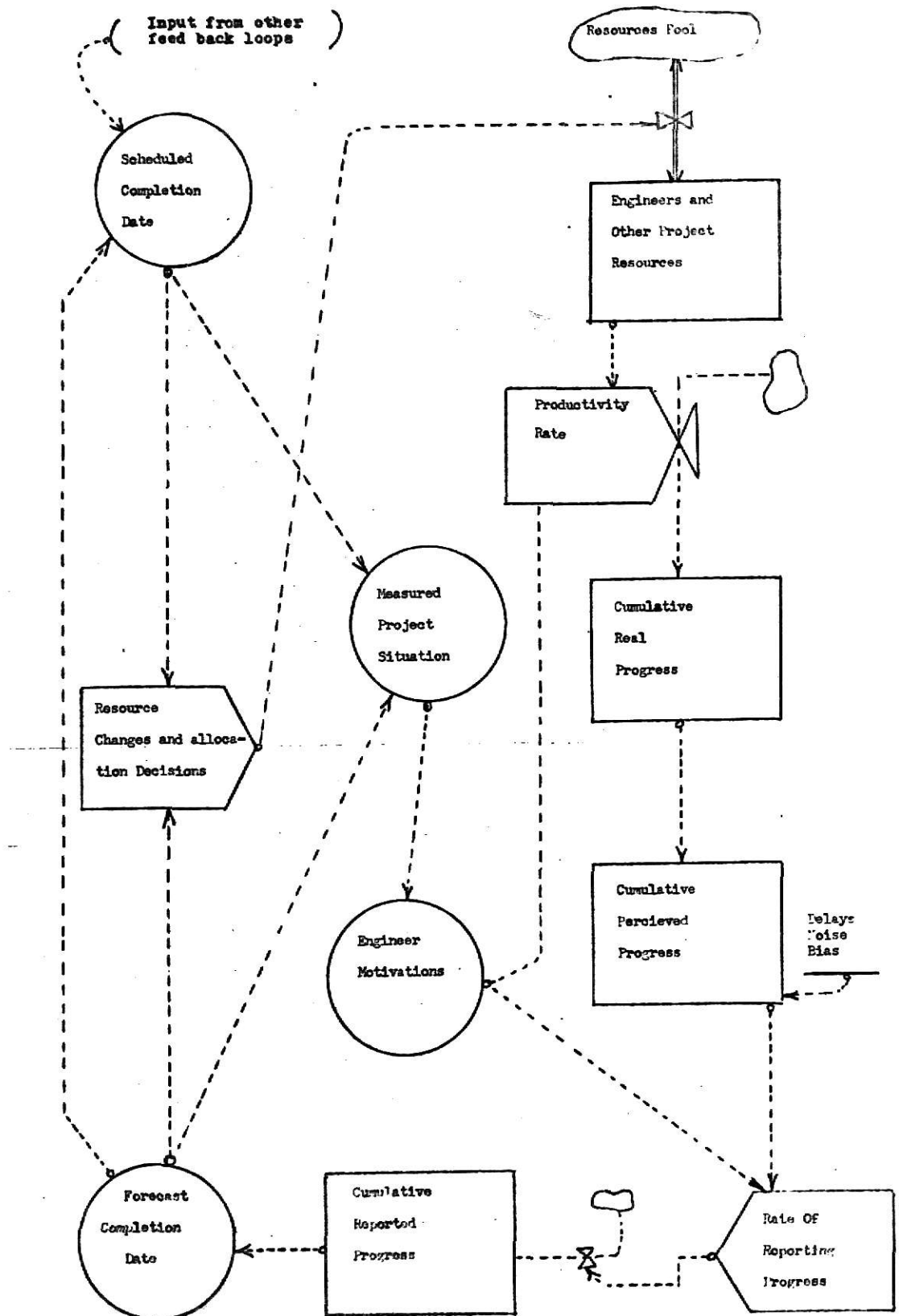


Figure 1.3 More complete representation of R and D system (2)

- 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

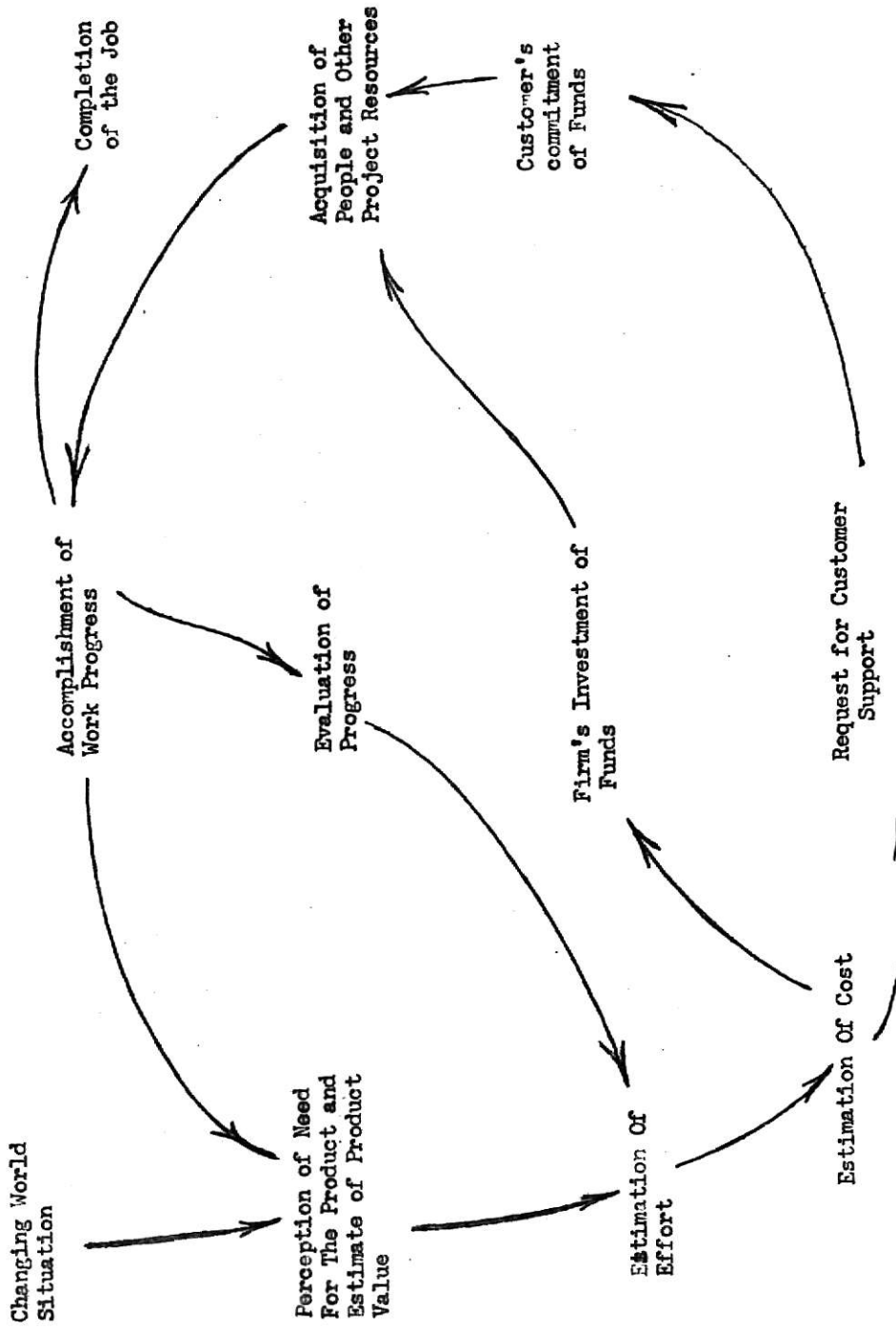


Figure 1.4 Dynamic system underlying project life cycle (3)

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 assess 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.

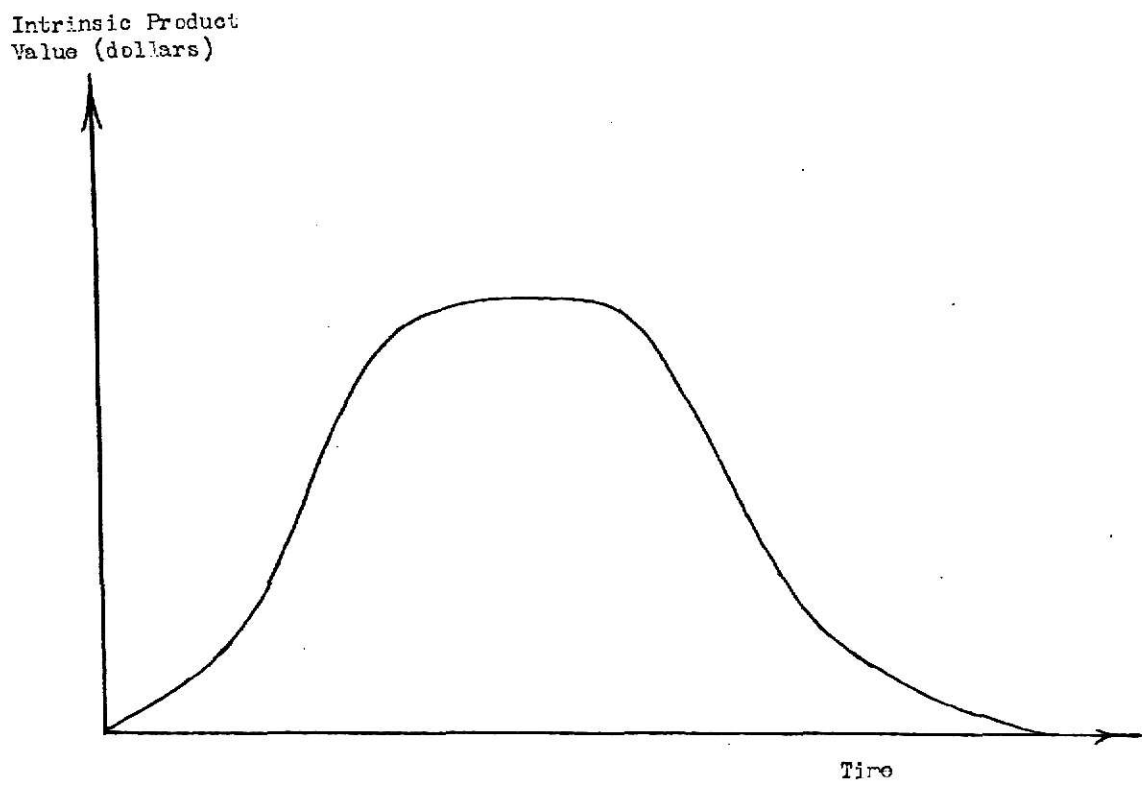


Figure 2.1 Time path of the underlying need for a product (3)

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) Categories 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 immorization 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 Vanguard 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 manpower. 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 activity 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 output 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