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Abstract: This report deals with the dynamic behaviors of new product development (NPD) projects. It is a study of information - feedback characteristics of NPD project activities, to show how organizational structure, policies, decisions, actions and information processing interact to influence the NPD process. Basic functions of management included within the model are planning, staffing and controlling of NPD projects. Planning function addresses components of resource allocation, scheduling, projection and learning. Staffing function addresses recruiting, transferring and training. Controlling function deals with measurement, comparison, evaluation, replanning and implementation of corrective actions taken as a result of information feedback and learning.

We used DYNAMO language for the mathematical model. Model is simulated on PSU's IBM 4381 computer. It calculates NPD project-time states for the given input conditions. One major drawback of the model developed is that it is simulated on hypothetical data. Therefore it has been impossible to verify and validate the simulation results. Possible extensions and future research areas are identified.

SYSTEM DYNAMICS APPROACH FOR THE MANAGEMENT OF NEW PRODUCT DEVELOPMENT PROJECTS

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An effective way of studying a complex system, such as a NPD project, by use of system dynamics methodology seemed very effective for examining the underlying flows of activities that continuously interact to produce the complex behaviour.

A project life cycle may appear to start in an ordered time sequence, for example, the customer perceives the need for a product before it releases funds to the R&D and Marketing. But continuous changes over time of the underlying activities will establish the events within the life cycle. These actions continuously feed back upon the other decision areas of the project to induce further changes.

Continuous activity phases that constitute a NPD project can be described as below:

1.)World situation is continuously changing with regard to the need for new products and the technological capabilities for obtaining them. These changing factors can be taken as inputs.

2.)Potential customers of new products and Departments (R&D, Engineering, Marketing, etc) in the business of developing them, are continuously engaged in the activities aimed at perceiving the need for new products and potential market value of products.

Along with these value perception activities, Departments both consider the technological and market feasibility of the product development effort and estimate the resources needed. (Resources may be manpower, facilities and equipment)

Based on the above stated effort estimate, each of the above stated Departments attempt to judge the total resource requirements (so cost) of the project.

New evaluations are continuously being made by the individual Departments.

This continuing cycle of activities take place thru every NPD process, leading to the successful completion of the project or to the cancellation at some point prior to full completion. Increments of progress and change (real or observed) takes place continuously.

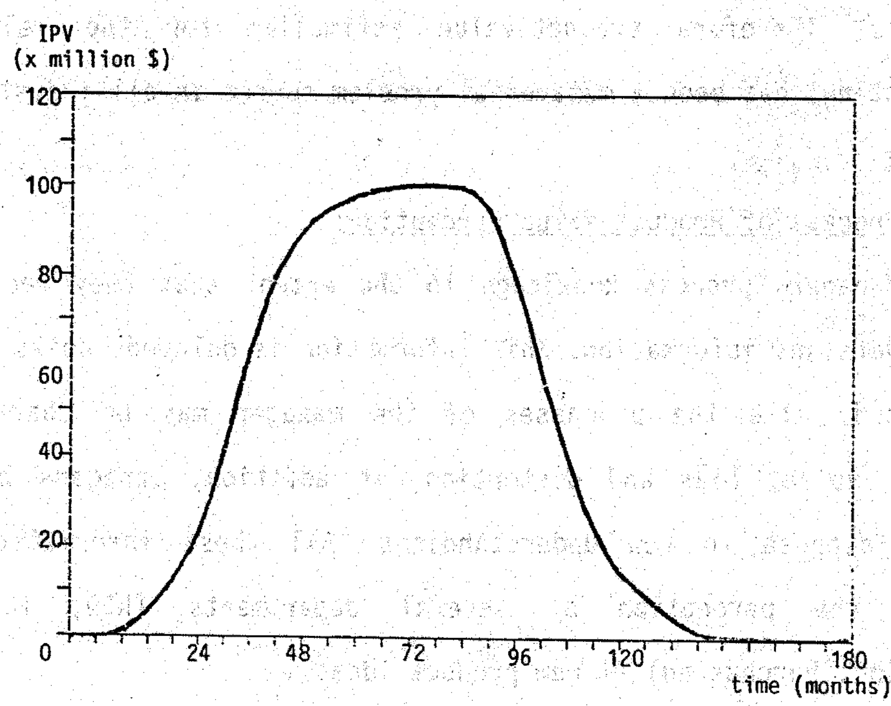
Succeding next five chapters are qualitative explanation of model corresponding to the preceding description of NPD project life cycle. Chapter.6 is an approach to come up with a quantitative continuous system simulation model for the process described above and explained qualitatively in the next five chapters. DYNAMO language is used for the mathematical model. Model is simulated on PSU's IBM 4381 computer. Complete program documentation and different outputs for different scenarios are included in the Appendixes. Model calculates NPD project time histories for the input conditions provided. One of the biggest problems has been to find actual data. Data which appear in the report is 100% hypothetical, therefore it has been impossible to verify and validate the simulation results, but though outputs seem reasonably meaningful for NPD project activities. Possible extensions and future research areas are tried to be identified and are included in Chapter.8 which mainly concern data and parameter supplement, and sensitivity analysis for the model. At the moment I would like to thank following persons for their help and support for this project.

To Professor Dundar F. Kocaoglu, my deby of gratitude goes far beyond an appreciation for his support, constructive critical remarks and guidance on the underlying writing of this project. During two years

First phase of NPD process consists of the birth of the product idea, in other words; the recognition that a potential product can satisfy some underlying need of consumers.

Underlying Need of a Product:

Consumer need for a product relates first to the satisfaction of physical needs of individuals and to their psychological needs. The usefulness of any particular product raises over time. Prior to some point in time, there is little or no need for a product. Need for a product can be illustrated by a curve of type as shown below.



INTRINSIC PRODUCT VALUE

Any organization's perception of the need for a particular product depends upon (first) the intrinsic product value. However, the things that are occurring in environment are only potential inputs to the managers perception of the need for a new product. R&D or Marketing or both must first become aware of the occurrences. Therefore the delay in acquiring information is an important determinant of the timing of the perception of the need for a new product. However, just communication of the events doesn't lead to automatically the perception of the need for a new product. There is another delay entering into the perception process which is the time required to absorb the new information and recognize the value of the product. If we call this delay an absorption delay, it depends mainly upon the technical and managerial ability of the R&D or Marketing and reflects the familiarity of R&D or Marketing with the technical area, in which the events take place.

Above stated factors largely serve to determine the level of recognized current value of a new product. The decision to invest in a NPD program however is not based on an estimate of current worth of a new product. Rather it is based on an estimate of what the product will worth at some future when it is expected that the product can be made available. Estimate of current worth serves only as a foundation upon which Marketing and R&D Departments base their forecasts of the future state of affairs. And the future is often perceived by observing how rapidly the present situation is changing and then projecting for future the this rate of situation change. Therefore the rate of change of organization's (especially R&D's and Marketing's) current estimate of product worth can be a strong determinant of its estimate for future value of product.

R&D's Perception of Product Value:

Changing nature of world situation causes changes in intrinsic product value. Information as to the intrinsic product value is always in the process of being communicated. The gap between the existing accepted estimate of future product value and the current projected information can be a source of influence to revise for R&D, its original estimate of future product value. Therefore rate of recognition of product value is modeled dependent upon, both:

1.The actual information as to product value being communicated,

2.Delay in recognizing this information.

Delay may depend on generally the level of related know-how of the receiver of the information.

When new information is received, it builds up the level of product value which is currently recognized.

Also, R&D may become aware of an average rate of recognition of product value. Personnel in R&D Department may hold beliefs not only as to what the product currently worths but also how their estimates has changed in the past. And these may influence the projection of future product value.

As a result projected future product value may depend on two factors:

1.Average rate of recognition of product value,

2.How far the R&D is projecting (ie. projection horizon). This may mainly depend on the company's basic planning period for the establishment of budgets and the R&D's willingness to accept risk.

So, as the projected future product value changes, R&D will feel the pressure to change the original estimate of future product value.

At know-how level of zero, we can assume that the delay in assessing the information to the product value is very large. As the know-how increases, delay in receiving information decreases. With large amount of effective know-how, delay decreases to a minimum, (which is required for communication of product information).

Unrecognized product value information in R&D is determined over the period where delay in recognition of product value by R&D occurs. Rate of recognition of product value by R&D closes the gap between the level of recognized value and the actual input product value.

Over a period of time, R&D becomes aware of the average trend in its own recognition of product value. Personnel in R&D weigh more heavily the recent changes in their product value recognition and degree by degree forget about changes that have taken place farther back in the past. This can be defined to be the average rate of recognition of product value by R&D.

Generally, the departments within an organization are more near-sighted. Therefore, being near-sighted may lead R&D to respond rather quickly to changes that it has already recognized. Then we can assume that smoothed (or average) rate of recognition of product value is assumed to depend primarily on the occurrences in the last M time units. This can be denoted to be the delay in averaging recognized product value. Delay in averaging recognized product value does not mean that R&D recognizes changes in basic market value of the product in M time units. But it indicates that whatever R&D does recognize causes it to change its beliefs as to the future value expectations for the product area. To be effective in the process, R&D must try to forecast the future demands of the users.

own rate of change of this recognition. Extrapolation period or projection horizon is that fraction of Marketing's maximum planning period which its risk taking propensity influences it to utilize.

[References:9,11,14,19,20,23,25,26,29,35,40]

During the development of any new product there is a set of tasks for which magnitude is defined by the nature of the product. Many aspects of the product contribute to this job magnitude. These may include the complexity of the product, its physical size, environmental requirements, reliability expected from the product.

The amount of fully effective effort required to translate existing technical know-how into a complicated equipment design is defined as the 'intrinsic size of the job'. It is a characteristic of the job and represents the effort needed to design the end product, assuming that all the know-how to be used in the design is already exists.

But there is not only the translation of existing know-how into a product design, but also the development of know-how itself. Therefore state of the technological art can be the second product characteristics. This describes the potential technical effectiveness of the engineering effort. This concept indicates the effort R&D has to invest to accomplish the end result of a new product development process because the effort required depends on the extent to which R&D can use available technological know-how. On the other hand, the effort required from R&D depends on the extent to which it has to develop the technological know-how.

In all areas related to NPD management, state of the art is increasing (in planning, project management). Increasing state of the technical art increases the potential effectiveness of engineers and scientists.

stated above, there is the time required to absorb the know-how and to develop competence in the techniques.

Therefore there is a long time span from the initial development of a new technological idea to the application of that idea.

All these delays can be shortened when the new know-how comes from within the organization itself. 'Inside Developments' avoid the influence of NIH (Not Invented Here) factor which delays use of know-how obtained outside the department's own activities.

Delay in receiving information about changes in the state of the art is also dependent upon the allocation of effort for acquiring the new knowledge. Delay is also dependent upon the allocation of effort for acquiring the new knowledge. Company policy in this regard manifests itself in the managers' attitude toward encouraging workers to search the literature before undertaking development work in a new area.

It can show up in the manager's willingness to allow engineers to attend scientific conferences in their fields of activity, or take part in other professional engineering societies and activities. The need for engineer re-education has become especially serious since the rate of technological change in all fields has accelerated. Attitude of the manager for using outside consultants also reflects manager's policy for trying to acquire outside technological know-how for applying to the development of a new product. Also, engineer's own attitudes determine his willingness to take time to learn from the outside. This time allocation decision is influenced not only by rational considerations of the alternatives, but also by individual's personal educational objectives, desire for job than the organization that only guesses at the gross effort requirements.

R&D organizations attempting to estimate effort needed on a job take into account both the estimated scope of the proposed process tasks and the estimated effectiveness of the engineers who will be trying to accomplish those tasks.

In making their initial estimate of the size of a NPD project, R&D or Marketing or both are influenced by the relationship of their previous experience to the size of the one under consideration. Each job has an intrinsic underlying magnitude, whether or not initially recognized. The organization whose experience has included jobs of this magnitude is more capable of estimating correctly the scope of the anticipated project. Initial estimate of the R&D activities by either R&D or Marketing will be biased in part by the extent to which the department's experiences have been with larger or smaller jobs than the current one. Organizations that has handled larger jobs in the past tends to overestimate the size of the current one, and vice versa. Organizations that has handled large jobs has acquired experiences in which the degree of planning and organization for the conduct of activity tends to be large. Such a company tends to regard other jobs as being best managed by the same approach.

But there is also another tendency to underestimate all jobs. This is due to the motivations of the Marketing to see a job as being relatively inexpensive, and recognize it as being within the realm of economic feasibility.

Then we can characterize the initial job size estimate by three factors:

Revisions in the Effort Estimates:

Initial estimate describes the process of effort estimation prior to the R&D's initiation of engineering work on the NPD project. But the passage of time and the new work experiences provide information to both departments upon which they base revisions of their effort requirement estimates. Initially they establish an estimated schedule of completion of tasks, problems, milestones, program elements. Therefore the total engineering effort applied up to any point in time corresponds to an expected (and scheduled) level of completion. In addition to referring to this previous schedule, both departments continually attempt to assess the progress actually made to date. A department can modify its earlier estimate of job size as long as it has the ability to recognize its anticipated schedule as deviating from its current believed progress.

An important question at the moment is whether or not the department responds quickly to this gap between a scheduled and apparent achievement. Degree of responsiveness can be a function of how far along in the project the department is or believes it is in. In the early phases of the process, it is difficult to determine the existence of gaps between the scheduled and the actual progress. Later, gaps in progress become too obvious to ignore. Estimation errors become too obvious to ignore. And these estimation errors become more significant and their recognition results in changed size of job estimates. Other factors that cause revisions in the estimates are the observed changes in technology and in the expectations of continuation of such advances.

Delays in making revisions are also dependent on the departments' characteristics and on how far along the project has gone. During the early influenced by other factors other than the real job size. These factors may be the estimation bias due to their past experiences, the general tendency to underestimate the complexity of a job, and the technical and managerial ability of the organization, all of which effect the initial estimate of the job-size. This initial estimate provides a starting point for the organization's continuous redetermination of job-size thru out the life cycle of the product. During the process (project life) changes are made in this initial job-size estimate in response to gaps that the organization detects in the scheduled engineering accomplishment. These gaps may exist between the scheduled percentage completion of the job and organization's estimate of the percentage completion of the project to date. The fraction of this gap, which can be taken into account in changing the existing estimate of job size, depends upon the stage of the project. As stated in preceding pages, during the early phases of the process, it is very difficult to recognize any errors in schedule. And this may get easier as the process advances toward completion.

[References:1,2,4,5,7,8,13,14,16,17,18,20,23,34,40]

In previous pages, I have explained the ways in which both R&D and Marketing determine their estimates of the worth and the cost of the project. These elements are essential to the activities required for providing funds for the project. The activities include three possible phases :

1.The R&D's requests for support of engineering effort,

2.Marketing's evaluation of the requests for funds and its response in the granting of such funds,

3.The R&D's decisions to invest its own money in the project.

1.R&D's Bids for Support:

R&D Departments employ, as a matter of necessity, at least a small number of people who are constantly looking into new product possibilities. Large investments in equipment, factories and personnel force these units to be aggressive in seeking business opportunities. They can't afford to sit idly by, waiting for the customers to decide that a certain piece of equipment is needed. They must go ahead on their own, anticipating needs, and carrying out the preliminary planning at their own cost and at their own risk. As R&D engages in such activities, it develops insights into the need for and value of new products. Similarly, R&D begins to estimate the amount of effort and cost required to complete such projects. Over a long period of time, R&D's assesment of the value of the product versus its cost may lead to an opinion that Marketing will not yet deem the project economically feasible.

However, as R&D begins to feel that the resulting project idea might be valuable enough for both it and Marketing to consider further, it usually attempts to get Marketing to support some of the initial study costs. R&D must compare the estimates of cost and value that it believes Marketing and the potential customers hold.

As time evolves, as the study activities continue, and as the estimates of project value and cost change, R&D's assesment of the project desirability also changes. R&D may be willing to participate in the project and may also begin to feel that Marketing deems the project worthwhile. R&D may apply many different criteria in determining its own willingness to participate in NPD project. Forexample, R&D may not be interested in taking part in any NPD project of size or expected profitability smaller than some minimal amount. R&D may be concerned with long-run effects on the Department's technological capabilities. It may consider the concentration within some technical area to which the NPD project would lead. Follow-on production work or potential derivative commercial products may also be considered by some R&Ds. Thus several prerequisites may be necessary before R&D is willing even to try to obtain a larger scale NPD project. However the possibility of obtaining short term profits is usually sufficient for most R&Ds.

Once R&D is willing to go ahead, it must consider whether it is reasonable to expect that Marketing will support such a project. R&D's feeling that a full-scale development proposal is now timely may result from Marketing's expilicit request for proposals on the project, or it may stem from another information obtained by R&D. There is usually much on-going between Marketing, Engineering and R&D activities or must be. These continuing relationships give R&D a fairly good idea of customer's and Marketing's position on, and need for, a potential product. As a

The initially held internal estimates are not necessarily the figures that appear in R&D's proposal to Marketing in a competitive situation. A basic influence upon the proposal is R&D's integrity. Many have masked the fundamental nature of this integrity influence by referring to the problem of assessing the competitive situation. By this, they mean that a company recognizes that the low bidder has greater likelihood of receiving the contracts. Therefore R&Ds attempt to assess what its competitors are likely to bid and, if at all possible, to justify and submit a bid lower than that of their competitors.

Some companies are more susceptible to practices of this sort than are others. We can describe the R&Ds as having lower integrity than the less susceptible type of R&D. The lower the integrity of the R&D, the more it will be willing to adjust or reassess its cost and effort estimates before submitting them to to Marketing.

This discussion about integrity is not for a try to attempt to find moral fault in R&D procedures for handling development. But it is an attempt to identify those factors that influence outcomes of NPD projects. The degree of integrity in the practices of R&D will have a bearing on the proposals submitted to Marketing and consequently on the contracts granted by customers. Therefore it is important to recognize the influence of the integrity factor in these bidding activities.

Under what conditions does R&D revise its submitted estimates of the dollar amount necessary to complete the job and change its requests for funds? During the early phase of study-contract activities, whenever R&D feels that the study project is worthy of more investment, it will request additional study funds and try to convince Marketing of the willingness) to support a project thus depends upon the estimated value-cost ratio.

During the early phases of a project life cycle, when R&D is merely requesting support for activities requiring small amounts of funds, Marketing will support such activities to the extent that it sees this area as having potential value.

The process of discussion and negotiation between Marketing and R&D provides Marketing with R&D's estimate of the cost and value of the proposed project. Marketing is affected by R&D's submitted estimates only to the extent to which it has confidence in R&D's abilities. A proposal from R&D may cause the Marketing to adjust its estimates of both cost and value to correspond more closely to those of R&D. New estimates determine the extent to which Marketing is willing to support the financial requirements of the project. Actual allocations to the project depend not only upon desired allocations but also upon the availability of sufficient funding authority. Marketing cannot exceed the authorization limits placed upon it; even within these limits, it will not allocate the full, desired amount immediately.

There is usually a lengthy delay encountered during which the request for funds and the requirements for the project are carefully considered, and Marketing decides whether or not it should allocate the necessary funds. This is a long delay, much of which may be spent in convincing the customers.

Despite the attractiveness of a proposed development, there is a minimum budgeting delay needed for processing the formal paper work and obtaining the minimal number of approvals. Additional delays beyond this expenditure rate of R&D, giving itself more time to see 'what is what' while not spending too much additional money. Marketing has more or less direct control over the expenditure of its own funds and therefore exercises strong but indirect control over the amount of effort put forth by R&D.

Marketing's evaluation of the funds incorporates not only the initiation of large scale activity but also the possibilty of cancellation of the project. Such cancellation can take place directly by gradually stretching out the project life and then gradually withdrawing funds from the project.

3.R&D's Investment Decisions

R&D's desire to invest in a project depends upon expectations of profitability of the resulting project and upon R&D's willingness to gamble its expected profits. As time evolves, and its estimates of product value and development - cost change, R&D also changes its estimate of the profitability that Marketing (in turn customers) will undertake large-scale development. Any actions taken by Marketing that show an increased(or decreased) willingness to support the project affect R&D's assessment of the situation.

R&D continuously decides upon the total amount it is willing to invest. It also decides upon a rate of expenditure of these funds, taking into account both the likely duration of its own required support and the availability of company funds. R&D continues to support the project effort at the rate its investment evaluation process deems appropriate , even after Marketing begins partial support. Once

Flow of Engineering Manpower:

The most critical productive project resource is engineering manpower. As all the engineers work, the activities of value perception, cost and effort estimation, and the provision of funds are being undertaken. As funds are obtained for work, R&D can begin hiring the manpower it needs or transfer more employees to the project.

Acquisition Policies:

First question is; What determines the number of engineers that R&D desires to have on the project?

An answer can be the financial support available to R&D determines the desired engineering employment level. But this raises another question: Does R&D have to wait for support on a specific project before beginning the recruiting process? If it recognizes the long lead time needed for hiring, R&D may begin to hire some engineers in anticipation of future funding. R&D must anticipate its needs far in advance and begin recruiting early. The delay in engineer recruiting can be greatly shortened when enough engineers are available for transfer from other parts of the company.

Another problem is whether R&D will hire up to maximum level supportable by available funds. Most engineering organizations are concerned with the problem of providing labor stability. Therefore they are unwilling to hire new engineers unless they feel certain that they will be able to use the new staff for a reasonable length of time.

After R&D decides how many engineers it wishes to acquire, it has to determine the rate of acquiring them. R&D cannot even attempt to hire

R&D is estimating the engineering effort required for a job. At the same time, they serve as the resource pool from which trainers are drawn to assist the new people and managers are selected to supervise the work.

Whether desired or not, the employment of a number of people requires supervisory, administrative and managerial personnel. Therefore the hiring and utilization of engineers require the transferring of other engineers from design and development work into activities that contribute less directly to the task objectives. Both types of functions are essential to the new product development process.

Transfer Policies:

As stated previously, most organizations consider the maintenance of engineering work stability an important part of their policy for hiring new engineers, and some companies do not hire any new engineers unless they are confident that they will be able to use these people for a long time. However, whatever the company policy toward acquisition is, most companies face a considerable problem when the services of some fraction of their engineering work force no longer required. This difficulty most often occurs during the final phase of new product development projects, when the job is coming to an end and fewer engineers are needed. First, because of the anticipated harmful effect on their later ability to hire, most companies are reluctant to lay off engineers. Second, R&D usually considers its greatest asset to be the productive ability of its engineering workforce, which is regarded as highly effective team only after it has worked as a unit for a number of years. Therefore most of the R&D Departments hesitate before laying off information with their professional colleagues. Also encouraging continuing education can aid bringing new know-how into R&D more quickly. Other means for accelerating information transfer are libraries, consultants, and professional meetings.

In addition, there is the additional delay of actually absorbing the information and making use of it. The time taken for absorption of outside discoveries and developments is lengthy. It constitutes the major portion of the delay between the discovery of new knowledge in one place and its utilization at some other time and place.

The Effect of Experience:

Changing state of the art and the delay in becoming aware of and utilizing this know-how form the basis for the potential productivity of an engineering team. However, many other factors affect the actual productivity achieved by a group of engineers. One of these is the effect of on-the job experience of the engineers. Productivity can be expected to increase as a result of increasing experience. In addition, increased productivity can be expected, as a result from the development of specific bits of know-how on a particular project, since many of the problems encountered throughout a project life cycle are similar in content or in the factors contributing to them. Therefore, as knowledge is built up during the earlier phases of the project, R&D's engineers are gathering information and new techniques that will be applicable to some parts of the later phases. Then, the productivity of the engineers working on the project tends to incraese as the job progresses.

Those engineers who have been made engineering managers also have their task-oriented productivity decreased substantially. This is a usual result of the job position change. The manager of an engineering organization applies himself to the task of laying out the direction on problem solving, clarifies the job requirements to save time and effort, provides systems coordination. All these activities are very much a part of the engineering task in NPD project. The capable managers stay close to the critical problems trough consultation with their engineers and through participation in the making of key design decisions. However, very few engineering managers have such effectiveness as a result of increase in their administrative activities.

The other category of workers whose effectiveness is diminished by the nature of their work situation includes the engineers who are in the process of leaving the R&D Department or project, either voluntarily or involuntarily. The time informally consumed by transfer activities, the loss of enthusiasm for the job being completed, the engineer's poor attitude toward the organization or project he is leaving, all contribute to a decreased technical efficiency of the engineer while he is working in this status.

Finally, we can consider the trained and full-time, on-the-job engineer. He has been selected as the standard engineering productivity who is supposedly able to manifest in his work the available and utilizable engineering productivity. However, the job experience effect also influences the full-time engineer, as it influences the effects of management ability.

R&D's management is responsible for establishing such policies and their effects on engineering productivity.

The Impact of Organization Size:

Another managerially related effect upon the productivity of engineers stems from the size of the engineering work force. The communications problem becomes particularly great as the size of the engineering team increases. Greater administrative problems come with organizational growth. The managers tend to spend more time on budget and personnel matters, and project control becomes more impersonal, responsive to periodic reports and artificial measures of achievement.

The ability of the manager can also affect the over-all productivity of the work force thru his decision to allocate engineering effort to the different types of work that have to be done on a project. From unwise decisions arise gross waste of scientific and engineering talent, caused in part by the use of engineers for jobs that could have been done more effectively and efficiently by another group of employees. More important waste comes from poor management decisions that provide engineering resources to a high percentage of projects which never result in satisfactory finished products.

All above stated factors combine to produce the over-all effectiveness of the engineers performing the project work. This effectiveness combined with the volume of applied engineering manpower, produces the progress rate on the job.

[References:1,2,7,8,12,13,31,34,39,40]

Problems of Project Planning and Control:

Problems involved in measuring and responding to progress in a new product development project are central to the management of R&D. These problems arise out of the inapplicability to research and development of existing control methods.

Attempts to apply standard control and evaluation techniques to the research program have proved very disappointing in many companies. The difficulties arise from control and evaluation procedures which are basically inadequate for any of the company's activities. But more frequently they come from applying procedures which are effective in other parts of the company bu not in R&D.

Intangibility:

Some distinctions that show up between the R&D Departmant and Manufacturing, for example, reflect the degree of tangibility of the outputs of the two organizations. In manufacturing, cost-accounting tools and physical counting of output usually serve the purpose of measurement of progress. Management somehow defines its output volume and cost goals and knows its degree of success in meeting these goals by simply looking at production records or accounting statements. Such things as product quality and customer satsfaction are also outputs of manufacturing. But despite quality control systems, the underlying aspects of these problems are seldom considered until they actually cause crises in the organization.

The R&D manager has a situation similar but certainly different in degree. He also needs measurements of his organization's progress, but

But as Marketing (so as customer(s)) and R&D get farher along in the NPD project, they begin more clearly to recognize the task content, including the specific requirements that must be met for effective project completion. Nevertheless, until the job is actually finished, the impressions of both Marketing and R&D may be highly uncertain. The ability to recognize specific job requirements depends upon the general managerial and technical skills of R&D and Marketing, and more particularly on how they use these capabilities in the initial project design.

Project managers continuously try to state what progress has been made, but no necessarily relevant measurements are available to verify or deny such statements. Therefore managers usually attempt to symbolize the uncertain and intangible aspects of R&D progress by the most certain and concrete things in the project. This is not a very good practise since the obvious concrete and measurable variables are often basically unrelated to the amount of effort required to get the job done.

Even worse is that in some R&D organizations no real attempt at control is being made. These include the many cases in which annual total budgets for R&D and annual budgets for individual projects are the rule.

Determinants of Progress Measurement:

The process of controlling R&D must take into account the real source of control-the individual engineer. If the engineer or manager is in a company environment that encourages initiative and integrity, then he will be more likely to supply the progress evaluation information the basic information inputs often lacking until most people think the job is just about over.

Fundementally, the engineers working on the job and the manager supervising it are continuously assessing the believed rate of project progress. They correctly assume that the application of time and effort gradually produces solutions to the numerous problems that confront them in the project undertaking. However the estimates of completion may completely differ from the real facts. During the later phases of NPD projects, when the assembled product is being tested, its operation and performance begin to reveal to the design team whether or not their previous estimates were correct. Often only after considerable testing has taken place, can both Marketing and R&D closely estimate the progress made.

On the other hand, at least the operating level of R&D Department often knows that things are not well with the project, even during the early phases.

To a great extent, progress measurement and evaluation involve the entire process whereby Marketing and R&D estimate the effort and cost required to complete the job. Such problems exist throughout the project life cycle, to its very end. Even when a job has in fact reached completion, the engineering test reports may not be so definitely conclusive.

The problems found in getting someone to admit completion of a job in the project that actually finishes its objective, lead to an overcompletion of the objective.

On the other hand, management policy might decree immediate response to any apparent error in the estimates as it shows up in the project review sessions. Management immediately begins to take actions to acquire more people and facilities.

Both examples, presented as the opposite poles of a situation, are really just points in the spectrum that describes how rapidly project management will respond to problems that are shown by the comparison of measured progress with previously expected progress. The Departments that have extremely long delay in responding to error indications are characterized by the fisrt example above, and a radical decrease in the delay produces the second example.

[References:3,4,5,7,8,10,12,13,14,16,17,18,20,21,22,23,25,26,28,30 32,34,36,38,39,40,41]

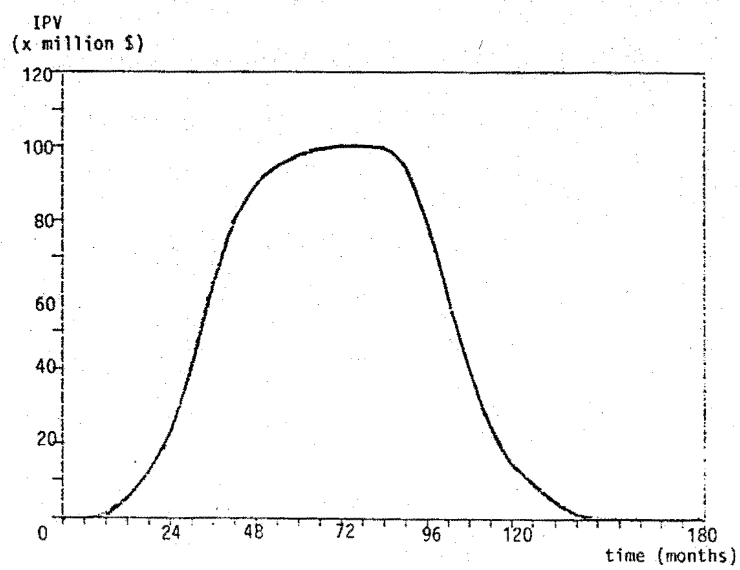
PLEASE REFER TO APPENDIX.A FOR A COMPLETE LIST OF VARIABLES AND PARAMETERS USED THROUGHOUT THIS CHAPTER.

The first equation is for a basic input to NPD model, the intrinsic product value. In a table of constants are stored the numbers that represent the intrinsic product value of the product under consideration over time. From one computer run to another, we may change this table to see what effect different product value situations have upon the project life cycle. The equation for selecting the product value from this table of stored numbers is:

```
A      IPV.K=TABLE(PVTAB,TIME.K,0,180,6)
```

This equation provides an exogenous input to the process; in other words it originates outside our closed system. I will take these market desires as given and adequately represented by the numerical values of IPV input.

The input values chosen for IPV do not reflect any particular product. They illustrate typical product life cycles.



I will use the above curve as reference and select the following points for determining the table of values of TDVR for the delay in recognizing product value:

```
A    DRPVF.K=TABHL(TDVR,KLEVF.K,0,60,5)

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
```

Over the period of DRPVF months, the unrecognized product value information is determined by R&D. The difference between the level of recognized value and the actual input product value is the information gap closed by RPVF equation. Following equations specify both the rate of recognition of product value and current level of accumulation of this rate of change:

```
R    RPVF.KL=(1/DRPVF.K)(IPV.K-LRPVF.K)
L    LRPVF.K=LRPVF.J+(DT)(RPVF.JK+0.0)
N    LRPVF=0
```

$r(t) = \frac{1}{d(t)} \left(i(t) - L(t) \right)$

$\frac{dL(t)}{dt} = r(t)$

$L_0 = 0$

The N-type equation shown for LRPVF provides the initial value for the level. I will assume that R&D is beginning from a state of absence of any perceived product value.

Over a period of time, R&D becomes aware of the average trend in its own recognition of product value. Usually, the engineers and scientists in R&D weigh more heavily the recent changes in their product value recognition and forget about changes that have taken place farther

Above statement does not imply that R&D recognizes changes in basic market value of product in so short time. That delay is shown in DRPVF equation and the corresponding graph. DSRPV constant indicates that whatever R&D recognizes soon causes it to change ~~its~~ beliefs for the future value expectations.

In order to be effective in NPD process, R&D must try to anticipate the future demands of customers. R&D will be assumed to project the trend in its own beliefs for the changing product value to form an initial projection of the future value using its perception of the current level of recognized value as a base line:

```
A       PFPVF.K=MAX(TPFVF.K,0)
A       TPFVF.K=LRPVF.K+(RPVSF.K)(PHF)      t(t) = L(t) + r(t) · h
```

The projection horizon will determine how far ahead R&D is willing to project this trend. This projection horizon may depend on two things:

1.)Normal Planning Period of R&D

2.)R&D's willingness to accept risk

So, R&D's willingness to accept risk determines the fraction of its maximum planning period which it will be using to project the recognized value changes.

```
N       PHF=(WARF)(PLPF)      h = w · f
```

As for the maximum planning period of R&D, I will firstly select a four year period, so:

For DAEVF, I will initially accept a value of:

```
C      DAEVF=6
```

$\alpha = 6$

Equations similar to previous ones also may describe the behaviour of Marketing Department. At the moment I will make the assumption that Marketing will reflect the preferences of customer(s). Therefore there is no reason to believe that customer(s)'s or Marketing's process of product value perception is very different from that of R&D.

The first aspect of Marketing perception, is the delay in recognition of the current product value. Like for R&D, this delay is a function of Marketing's (and also customer(s)'s) level of related product know-how. Therefore I will assume, at the moment, the same tabular values as listed for TDVR.

Following equation defines the relationship:

```
A      DRPVC.K=TABHL(TDVR,KLEVC.K,0,60,5)
```

Over the period of DRPVC months, the unrecognized product value information will be determined by customer and as a result by Marketing. Difference between Marketing's level of recognized current product value and the actual initial input product value is accepted to be the information gap that is assumed to be closed by the following RPVC equation:

```
C     PLPC=60
```

Of course Marketing may not be committing itself fully to programs that distant in time. Also its unwillingness to accept risk influences it to restrict its vision to nearer time. Therefore I will assume that Marketing is more conservative in accepting the risk so that:

```
C     WARC=.50
```

The projection of the trend in Marketing's rate of recognition will usually lead to a figure different than the previous estimate, as in the case of R&D. As a result, following equations can be written for Marketing:

```
L     EFPVC.K=EFPVC.J+(DT)(1/DAEVC)(PFPVC.J-EFPVC.J)
N     EFPVC=0
```

Due to difficulties and complexities dealing with the customer(s), Marketing's delay in adjusting value estimates may be somewhat longer than R&D, such as:

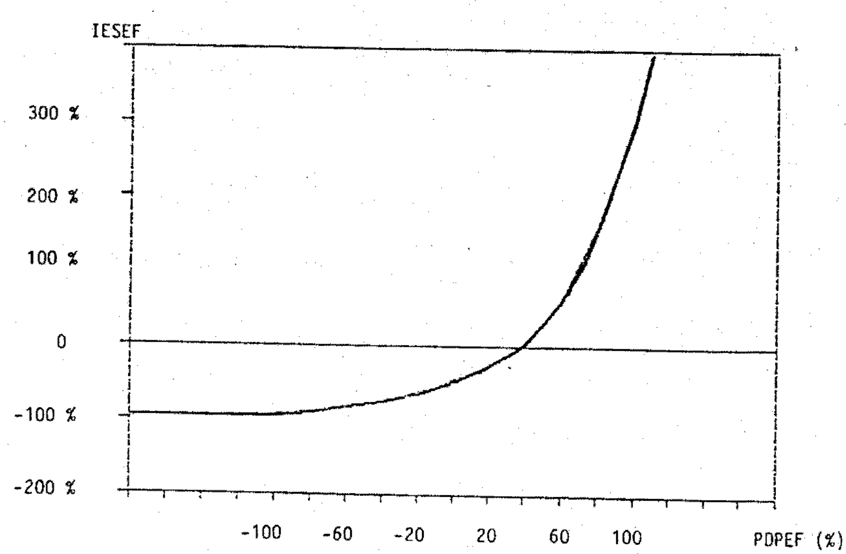
```
C     DAEVC=8
```

to complete the project will be five times NLKP. Initially, I will use a figure of 5500 effective man-months of engineering effort for NLKP.

It indicates that the past experience of companies (relative to the intrinsic size of present task) combine with a general tendency to underestimate job size so as to produce an influence on the companies' beliefs of the amount of know-how needed for projects. I will assume this will be also applicable for R&D. As a result, this influence will in turn be modified by over all ability of R&D, based on the theory that the more capable the organizations are, the smaller the error in their job size estimates. Experience and ability effects are included in:

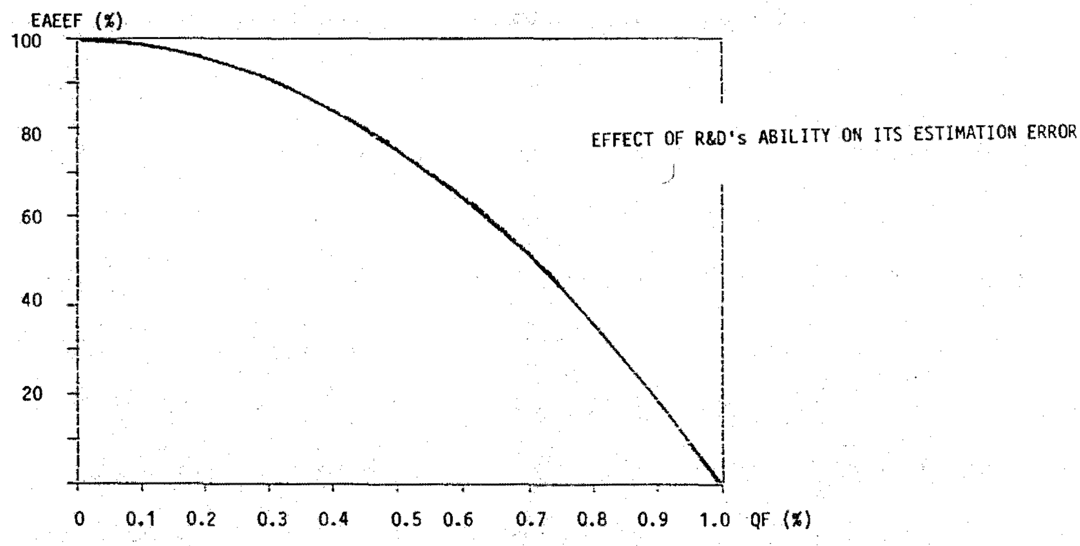
N MSEF=1+(EAEEF)(IESEF)

The influences on MSEF are assumed to be as included in the following graphs and equations:



INFLUENCE OF EXPERIENCE ON JOB SIZE ESTIMATE OF R&D

It is reasonable to think that R&D with more capable management will not err so greatly in its job size estimation as an R&D with poor managerial ability. The effect of the general quality of R&D is taken into account and assumed to be as in the following curve:



This curve represents the assumption that when the quality of R&D is at its maximum value, the previous size of job experience produces no additional tendency to err in its initial estiamtes of job-size. When the quality has an intermediate value between 0 and 1, a part of the effect of IESEF is felt as a modifier of the size estimate. The value is selected from above graph by use of a DYNAMO table look-up function in the equation:

```
N    EAEEF=TABLE(EAETB,QF,0,1,0.1)

C    EAETB*=1.0/.99/.96/.91/.84/.75/.64/.51/.36/.19/0
```

For the initial run I will assume R&D to be extremely able and will assign 100% quality measure:

since in general it gets very few indications of how the project is going. As the project nears physical completion, test results begin better to indicate to R&D the completion of job. Once the job is 100% completed and is actually working, it will take very short for R&D to realize it.

On the other hand, R&D's estimating procedure for determining the state of completion of job may begin to produce some estimates that appear to be nearing completion before the job finishes. This situation may have three aspects. First, if both estimated and real percentage progress are small, it is difficult for R&D to recognize an existing error in its estimate because it has almost no available measures of progress. Second, as the real progress approaches completion, with only the estimation lag, the tangible facts of product test performance will indicate the need to revise its completion estimate. Third, as the estimated progress approaches completion, but this time real progress lagging, same facts of product test performance will deny the previously estimated project completeness. Again R&D will recognize the need to revise its estimates.

These factors are incorporated into the following graph. The vertical axis shows the percentage estimation error recognized each month, and the horizontal axis is the indicator of progress status, that is the larger of the estimated or the real percentage completion of the project (in other words, dominant indicator). Fractional part of the error that is recognized each month is found by the DYNAMO table look-up function in the following equations:

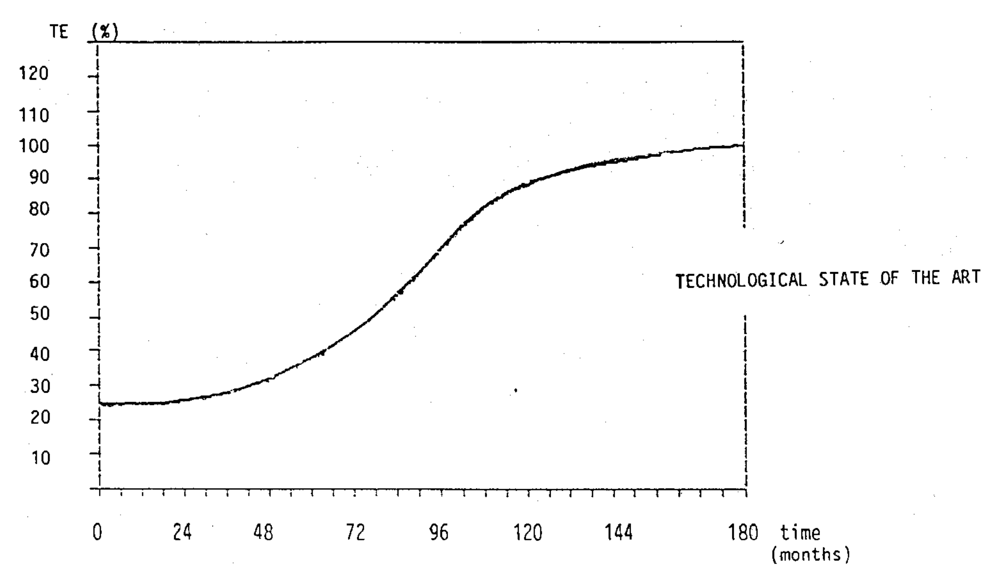
part of job. I will assume all these are also applicable and valid for R&D Department.

This extrapolated technological growth will be added to the basic estimate of current technical effectiveness, where it is merely the initial estimate plus changes and corrections in the initial estimate that have occurred as project technology evolves.

The higher the technical effectiveness at a time, the lower the effort required to complete work on the job. The technical effectiveness probable within the existing state of the art changes over time and will be assumed to be suppliable for this project as a basic input to the model. Therefore may be needed to be changed from one run to another to see the effects of changes. Following equation indicates that values for TE are stored in a table at six month intervals from time=0 to time=180:

```
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/
X1    .51/.57/.63/.70/.77/.82/.86/.89/.91/.93/.94/.95/.96/.97/.98
X2    /.99/.995/1.0
```

For the initial model simulation the state of the art will be assumed to change over time as shown in the following graph:



As shown in above graph and stated in the previous equation, initial rate of change of technology available to R&D is assumed to be zero. Delay in recognizing the technical progress rate is thought as being very short (in other words, R&D's opinion of technological growth changes rapidly as it gains knowledge about new breakthroughs). For this reason, I will use a two month lag in response:

```
C     DRTPF=2
```

The estimate of the current technological effectiveness made by R&D represents the summation of all the changes and corrections in the estimate since the beginning of project:

```
L     ETEF.K=ETEF.J+(DT)(RCEEF.JK+RCPEF.JK)
N     ETEF=(MTEF)(ENPRF)/ENAWF
```

Initially, estimate of the technical effectiveness represents a combination of the influences of actual effectiveness of R&D's engineers and the relative optimism of R&D as expressed in its estimating procedures. Relative optimism of R&D is assumed to be similar to R&D's willingness to accept risk.

Modifier in the following equations incorporate the effect of ability on the estimation error. The equation for IWARF uses a DYNAMO table look-up to combine the specific risk propensity effects with a general tendency for the conservative R&D to underestimate technical effectiveness.

shift takes place over a time of DRTEF months, where the delay in this opinion change is taken here as two months:

```
R     RCEEF.KL=(1/DRTEF)(RTEF.K-ETEF.K)

C     DRTEF=2
```

Realized technical effectiveness is defined as R&D's belief as to the current progress rate divided by the number of engineers who are actually at work during the given period:

```
A     RTEF.K=(PRBF.JK)(BNKPF.K)/ENAWF.K
```

Rate of correction of the previous effectiveness estimate is a fraction per month of the error magnitude indicated by the product of ETEF and the percentage error in project completion believed. Fraction recognized each month is specified by 1, divided by the delay in recognizing actual achievement at R&D. This indicates that the estimate error is corrected over a time period of DRAAF months:

```
R     RCPEF.KL=(PECBF.K)(ETEF.K)/DRAAF.K
```

Estimate of future technical effectiveness is based on the current estimate and on an extrapolation of the rate of technological growth that R&D has perceived. Linear extrapolation of the progress rate is used here:

Following equation for the estimate of effort required adds to the effort already expended, TEEF, the estimate of additional effort needed. The later one is found by multiplying the believed job-size by the percentage of the project believed incomplete. This in turn produces the estimated additional effective work needed, which in turn is divided by the expected future effectiveness of engineers and scientists to give the estimated additional effort.

```
A      EERF.K=(1/EFTEF.K)((TEEF.K)(EFTEF.K)+(BNKPF.K)(BPPIF.K))
```

Estimated additional project costs reflect the additional effort requirement and the cost per engineer, taking into account in the average cost factor the percentage of time the engineers usually spend on job. A monthly cost factor of $2500 seemed acceptable, so:

```
C      MESOH=2500
```

Average absenteeism of engineers including the effects of holidays and vacations is assumed to 11.5% of the scheduled work days during the year:

```
C      AVABS=0.115
```

Estimated total cost of the project is calculated to be equal to the cost that has been incurred upto now plus expected costs to complete the project:

```
N    MSEC=1+(EAEEC)(IESEC)

N    IESEC=TABLE(IETAB,PDPEC,-1,1,0.2)

N    EAEEC=TABLE(EAETB,QC,0,1,0.1)
```

Above PDPEC constant value can be changed in different runs. Marketing will be assigned a 60% quality measure.

```
C    QC=0.6
```

Following group of equations are the replicas of the previous ones written for R&D. They are for Marketing and are stated for the completeness of model:

```
A    GEAC.K=(1/BPPCC.K)(ESPCC.K-BPPCC.K)

R    RGEJC.KL=(FOGRC.K)(GEAC.K)(BNKPC.K)

A    ESPCC.K=(TEEF.K)(ETEC.K)/BNKPC.K

A    FOGRC.K=TABHL(IPPGR,DPPCC.K,0,1,.1)

A    DPPCC.K=MAX(PPC.K,BPPCC.K)
```

The process of Marketing estimation of the technical effectiveness of R&D's engineers are described by the following equations which are similar to R&D's:

```
L    ATEC.K=ATEC.J+(DT)(RCTAC.JK+0)

N    ATEC=TE

R    RCTAC.KL=(1/DTITC)(TE.K-ATEC.K)

L    STPRC.K=STPRC.J+(DT)(1/DRTPC)(RCTAC.JK-STPRC.J)

N    STPRC=0
```

Actual changes in Marketing's estimate of technical effectiveness are similar to R&D's. So:

```
R    RCEEC.KL=(1/DRTEC)(RTEC.K-ETEC.K)

A    RTEC.K=(PRBC.JK)(BNKPC.K)/ENAWF.K

R    RCPEC.KL=(PECBC.K)(ETEC.K)/DRAAC.K
```

Shift by Marketing to adopt its current realization of R&D's engineering effectiveness is assumed to take place relatively quickly. Therefore DRTEC has been chosen to be equal to 8 months:

```
C    DRTEC=8
```

Marketing also forms an estimate of the future technical effectiveness, taking into account the extrapolation period that depends upon its beliefs as to the percentage of project remaining to be completed:

```
A    EFTEC.K=ETEC.K+(XPTPC.K)(STPRC.K)

A    XPTPC.K=(BPPIC.K)(NPD)/2
```

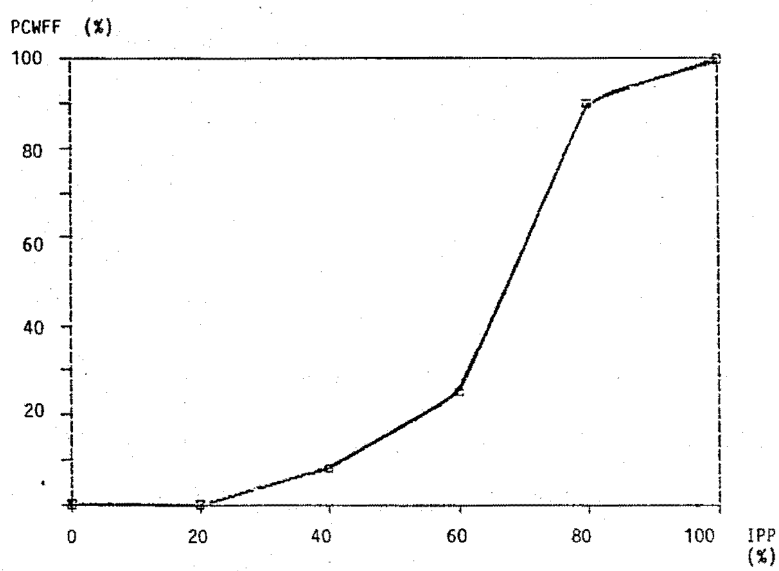
Combining these factors, Marketing comes up with its projection as to the estimated effort requirements of the project and as well the total cost and additional cost to complete the job. Following final three equations incorporate this process into the model:

The believed suitability of the project to customer indicates to Marketing and in turn to R&D the likelihood of the customer support. By combining this with the projected cost estimate of which the customer is aware, R&D arrives at an estimate of the funding expected to be made available by customer. In informing Marketing and customer of its cost expectations, R&D's relative integrity acts to change R&D's bid from its internal cost estimate. During the early phases of the project life, R&D may tend to request what it believes to be available from Marketing (so as from customer). As the project continues, pressures for full funding of the required project activities lead to increased requests for Marketing support.

In the following equations, rate of requesting changes in the project funding is recognized as the sum of the requested increases and decreases at any time. Equations represent the considerations leading to requests for money. The comparison between 'desired' and 'actual' total project funding is also shown below. Desired amount shows R&D's bidding strategy, and is the summation of level of project costs to date plus an additional amount which it believes it can request from customer. From this total, it subtracts the funds previously requested, to obtain the value of the additional funds it will request. But it does not immediately contact the Marketing to inform it of expected dollar change for costs. It is assumed to wait until the amount of money involved seems significant enough to relate the customer before changing the requested funding level:

```
A       PFFF.K=TABHL(TPFFF,BPPCF.K,0,1,0.2)

C       TPFFF*=0/0.2/1/1/1/1
```

In determining the funds that the customer is expected to make available, R&D and Marketing must use all their marketing intelligence about customer's attitudes and practices. Marketing and R&D takes into account both its own opinion and its information about customer's opinion of project's suitability. If R&D's opinion of the project is more favorable than Marketing's, R&D may assume that it can affect Marketing which in turn must be able to affect customer(s). Probability of Marketing support is highly depended on customer's beliefs and is tried to be shown below. As a result, probability of Marketing support is based on the indicated project suitability and R&D's beliefs as to Marketing responsiveness:



EXPECTED MKTG (CUSTOMER) FUNDING RESPONSE TO VARYING PROJECT SUITABILITY

Expected available Marketing funding is a fraction of the amount R&D is likely to request. Following equations define this process.

integrity coefficient of R&D and the full recognition of costs that R&D will concede as project develops:

```
C     IMTAB*=0/0/0/.60/1/1/1
```

Equations upto now, describes what happens when R&D thinks it has requested less funds than it needs. On the other hand, when R&D feels that it has requested more funds than it is going to need, it may notify Marketing for a revision in negative direction. This factor also is assumed to work in the same manner as discussed. Following equations showing expected underrun, is the difference between the current requested level of project funds and the expected total cost for the project. When this underrrun is greater than the breakpoint level at which R&D will make a change in its request for funds, R&D is assumed to make a request for a downward revision. This breakpoint is assumed to be fixed percentage of funds requested upto now:

```
A     RQDF.K=CLIP(RQRDF.K,0,EURFF.K,BPFRF.K)
A     RQRDF.K=-EURFF.K/DT
A     EURFF.K=RFPF.K-ETCPF.K
A     BPFRF.K=(BP)(RFPF.K)
```

Percentage expected overrun or underrun that R&D can tolerate before requesting more money is assumed to be an indicator of how rapidly it lets Marketing know of expected changes in project costs. I will initially take it as 5%. If BP=0, R&D will continuously inform Marketing of the expected cost changes.

Estimate of total cost accepted for use by Marketing combines Marketing's internally held cost estimate with the estimate reflected in R&D's funds request. First of the following equations indicates that cost estimate used by Marketing in its decision for the suitability of the project takes into account its own internal estimate, ETCPC, and some fraction of the difference between that and the estimate presented to it. The extent to which R&D's request is taken into account depends upon Marketing's confidence in R&D. This change will take place over a period indicated by the delay DRRFC in the equations. The difference which is indicated by the fourth equation below, which assumes that R&D's cost estimate is not in general considered relevant by Marketing unless it falls reasonably near Marketing's estimate. Outside the range, estimates are not considered wholly realistic.

```
A    ETCAC.K=ETCPC.K+(CNFC)(DECFC.K)

L    DECFC.K=DECFC.J+(DT)(1/DRRFC)(DECRC.JK-DECFC.J)

N    DECFC=0
```

the costs to complete the project, and determines the ratio of value to cost for the project. After comparing this to its investment criterion, a desired value-cost ratio, Marketing is supposed to decide how suitable the project appears to be for investment.

In the first of the following equations, it is assumed that value estimate is compared with the estimate of the cost to complete the project. This is based on the assumption that, Marketing or customer does not consider sunk costs in making its investment decision. Second and third equations take the ratio of value-cost relationship to the return on investment criterion. Final equation indicates that the probability of Marketing and customer support is a tabular function of the relationship among the values, costs, and investment criterion of customer:

```
A    VCRC.K=EVAUC.K/ECCPC.K
A    SPINC.K=MIN(TSPIC.K,1)
A    TSPIC.K=VCRC.K/ROICC
C    ROICC=2.00
A    WSCFC.K=TABHL(PCSF,SPINC.K,0,1,0.1)
C    PCSF*=0/0/0/0.1/.2/.3/.5/.75/.9/.95/1.0
```

The customer and Marketing are viewed here as being willing to take those projects in which they expect high return. Initially, Return on Investment Criterion for Marketing is set to 2, meaning that Marketing is assumed to desire projects whose expected value must at least equal twice the expected costs.

current request for funds and can consider the request in its allocation decision:

```
A    TFWCC.K=(WSCFC.K)(ETCAC.K)

A    MADC.K=MIN(TFWCC.K,RRFC.K)

L    RRFC.K=RRFC.J+(DT)(1/DRRFC)(RFPF.J-RRFC.J)

N    RRFC=0
```

Following level equations are introduced for keeping track of cumulative allocations and the funds available for additional allocation. Funds available are increased by new financial inputs to Marketing via customer support and are decreased by the rate of allocation to the project. Last equation shows financial input to Marketing by customer. This equation is initially set to provide a single pulse of an amount at the input time for Marketing. Financial restrictions can be easily considered by altering the value of dollar input of its timing. FRT provides periodic replenishment of Marketing funds.

```
L    AAC.K=AAC.J+(DT)(RFAC.JK+0)

N    AAC=0

L    FAC.K=FAC.J+(DT)(FINC.JK-RFAC.JK)

N    FAC=0

R    FINC.KL=PULSE(FINVC,INTMC,FRT)
```

funding support. These determine the maximum rate at which unspent Marketing allocations can be spent during the project life while also indicating the intended project schedule.

Following equation takes into account the fact that the funds desired to be allocated may not be available to customer (so as to Marketing) in its balance of unallocated funds. The trial allocation rate variable is described as the first equation of the next group:

```
R       RFAC.KL=MIN(TRFAC.K,MRFAC.K)

A       MRFAC.K=FAC.K/DT
```

Rate of allocation desired by Marketing represents its adjustment to the difference between its desired total allocation and the actual allocations made to date. Its delay in budgeting these funds depends on:

1.)Minimum delay in processing the paper work for these funds,

2.)The extent, to which it is enthusiastic about the project.

If it is enthusiastic, then it can push thru the allocation with the minimum delay. However, if not, it can be assumed that it will take a longer time for it to decide and allocate funds. It may sometimes feel that it has overextended itself and has allocated too much money. In such a situation, its allocation rate may be a cancellation rate, limited by the amount of allocations that have not yet been spent by R&D.

```
C       DMBFC=6.0

C       DBFTC=12
```

```
L    APC.K=APC.J+(DT)(BRC.JK-RECFF.JK)

N    APC=0
```

I will initially select a two month for the payments delay:

```
C    DPC=2
```

R&D's project billing rate is its current expenditure rate. Maximum expenditure rate is defined by the following equations. Here the scheduled project duration is used to control the outflow of Marketing funds.

```
R    BRC.KL=MIN(MREPC.K,TCEF.JK)

A    MREPC.K=CLIP(TMPER.K,0,TMPER.K,MRESC)

A    TMPER.K=UCAF.K/SPDC.K

N    MRESC=(1)(MESOH)
```

Scheduled project duration consists of two parts: the normal project completion time, which depends upon how much of the project is left to be done, and the changes in the scheduled completion time. Next graph, pictures this relationship. As Marketing's lack of satisfaction with the job increases, indicated by the percentage of expenditure in excess of project value expected by Marketing, Marketing is assumed to stretch out the job schedule as a pressure from the customer according

```
A      SPDC.K=MPCTC.K+ASPDC.K

A      MPCTC.K=MAX(MPCT1.K,DT)

A      MPCT1.K=(BPPIC.K)(.5)(NPD)
```

Following equation indicates that the additional scheduled project duration is aproximately exponentially related to the effect of expected overexpenditure on the project. Multiplier, EOESD, indicates the extent to which the customer responds to overexpenditure expectations.

```
A      ASPDC.K=(XPDC.K)(EXP(EXPD.K))
A      XPDC.K=NPD-MPCTC.K

A      EXPD.K=MIN(75,BEXPD.K)
A      BEXPD.K=(EOESD)(POEEC.K)
```

Multiplier that designates the amount of effect that overexpenditure expectations will have on the scheduling decision of Marketing is initially set to 20:

```
C      EOESD=20
```

Marketing continuously thinks about the cost versus value of project. Marketing may recognize that even if the product value were to drop to zero, there would still be something at least gained from the NPD activities performed. Percentage overexpenditure is determined by comparing the gap between the expected costs to complete the project and the expected value of the project, again ignoring the sunk costs, in the anticipation of project overexpenditure. So:

project and the expected total cost of the project. I will assume profit rate is 7%:

```
A     EXPRF.K=(EPRF)(EPCSF.K)(ETCPF.K)
C     EPRF=0.07
```

R&D will be willing to invest a certain fraction of its expected profits on the project, the fraction assumed to be determined by R&D's degree of conservatism, or in other words by its willingness to accept risk. R&D has to keep its allocation rate high enough to support a minimum research and development activity whose level can be determined by the policy of the Department. These are shown by the following equations. First equation expresses the maximum investment level desired. The maximum additional amount R&D wishes to invest is the difference between its desired and actual investment levels. R&D desires to invest this amount over the period, EPCTF. Third equation assumes that trial allocation rate does not drop below the basic rate needed to support the monthly engineering salary and overhead cost of LEI engineer:

```
A     MIDF.K=(WARF)(EXPRF.K)
A     MDRAF.K=(1/EPCTF.K)(MIDF.K-TAIF.K)
A     TRAF.K=MAX(MDRAF.K,BRAF)
N     BRAF=(MESOH)(LEI)
```

initially equals the base NPD budget, which in turn provides the basic monthly rate of allocation for the length of the budgeting period:

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

N    UIAF=BRBF

N    BRBF=(BPER)(BRAF)
```

R&D is assumed to review its budget periodically at semi-annual intervals:

```
C    BPER=6.0
```

Following equations add the possibility that at the end of each budgeting period, R&D can cancel the excess of the previously allocated funds. However it may not acquire sufficient engineers to cover these expenditures or it may have some of the expenditures supported by Marketing. In such a case, R&D is supposed not to accumulate the unused allocated funds indefinitely but to cancel the excess of funds and continue to review the investment budget on this periodic basis. Second equation determine the difference between the level of unspent funds and the base NPD budget where the first equation cancels this excess amount at the budget periods:

New engineers are recruited and join R&D as a result of recruiting activity. They go thru a formal training period during which their skills gradually increase to those of the average longer term employee of R&D. As the organizational growth takes place, some of the more experienced engineers are reassigned to training and supervisory roles. Similarly when services are no longer performed, some of the engineers are transferred to another job or laid off or fired. Those who are being transferred out require some period of time for paper work before they actually leave the project. This flow of engineers into and out produces two levels: the engineers actually on the project as well as those expected on the project.

These changes take place in response to R&D's efforts to adjust its engineering level to the desired number. The desired level is based on considerations both of maintenance of a stable engineering work force and of R&D's ability to support the engineering force profitably.

Level equation for the total number of engineers currently employed, regardless of their status is a continuous summation of the engineers joining, minus those leaving project group. This is denoted by the following equations:

```
L    ENGRF.K=ENGRF.J+(DT)(ENGJF.JK-ENGLF.JK)
N    ENGRF=LEI
```

Engineers desired, as contrasted to the actual ones, certainly cannot exceed those whom are expected to be able to be supported financially. However in some cases the project needs may restrict the to the recent changes in the available funding. Second equation states that the expenditure rate available is the larger of two amounts: that permitted by Marketing and customer and that being allocated by R&D.

```
A    EERAF.K=MAX(TEEAF.K,BRAF)
A    TEEAF.K=ERAF.K+(RCEAF.K)(TPEAF.K)
A    ERAF.K=MAX(MREPC.K,RFAF.JK)
```

In trying to estimate the funding that will be available, I assumed that R&D averages the funding that has been available over the recent past. The averaging, or smoothing, equations are shown below, and are supposed to take an exponential average of the expenditure rate available, ERAF, over the past DRCEA months:

```
L    SERAF.K=SERAF.J+(DT)(RCEAF.J+0.0)
N    SERAF=BRAF
A    RCEAF.K=(1/DRCEA)(ERAF.K-SERAF.K)
```

Since R&D is assumed to be very quick to take cognizance of any changes in the project funding available, DRCEA is estimated at 1 month:

```
C    DRCEA=1
```

Another variable taken into account is the time for projection of the changes in expenditure rate available. Following equation assumes that when funding is increasing, R&D projects ahead the duration of the hiring additional engineers, it tries to contemplate the duration of need for these engineers. The policy that sets the number of engineers desired tends to depend on the support level during the early project phases and gradually moves toward dependence on engineering work-force stability considerations as the project moves forward.

Following equation indicates that the weighted number of engineers desired takes into account both the stable work force level of engineers (SWENF) and the number of engineers supportable on the anticipated funds (SENGF). The weighting is assumed to depend on the stage of project progress. At the beginning of the job, the weighting is assumed to consider only the support level. As the project progresses, the weighting is supposed to depend more on considerations of a stable work force. By the time the project is completed, the weighted number of engineers desired is wholly dependent on work force stability factors:

```
A    WENGD.K=(BPPIF.K)(SENGF.K)+(WENG1.K)(SWENF.K)

A    WENG1.K=1-BPPIF.K
```

Following equation for the stable work force level of engineering, determines the expected man-months of effort remaining in the project and divides this by the expected time left for completion of the project. This determines the number of engineers who can be employed steadily until project completion, given the expected effort needed and the expected project scheduling:

```
A    SWENF.K=ECCPF.K/((MESOH)(EPCTF.K))
```

First of the following equations expresses this policy that the maximum number of new engineers desired at any time is limited by the number of experienced engineers, both those working full time on project tasks and those already partly engaged in training new engineers on the project. Number of recruits each experienced engineer can supervise effecively is expressed as the number each can handle (TPSF), multiplied by current training efficiency of staff (TEI). Higher the training efficiency, more new recruits are assumed to be absorbed. Last two equations say that the level of engineers expected in training is a continuous summation of R&D's hiring rate, minus the rate of engineering completions of training, minus R&D's transfers of new engineers from the project.

```
A    MEITF.K=(TPSDF)(ENFEF.K+ENATF.K)

N    TPSDF=(TEI)(TPSF)

L    EEITF.K=EEITF.J+(DT)(ENGHF.JK-ENLTF.JK-EITTF.J+0)

N    EEITF=0
```

Normal number of trainees that an engineer can supervise is assumed to be 2.5 men:

```
C    TEI=1

C    TPSF=2.5
```

Maximum hiring rate permitted under this policy is the rate that would bring the expected number of trainees upto the specified limit.

being transferred out of training are not available for the normal completion of training that is treated by ENLTF:

```
L    ENBRF.K=ENBRF.J+(DT)(ENGHF.JK-ENGJF.JK)

N    ENBRF=0

R    ENGJF.KL=DELAY3(ENGHF.JK,DRCE)

L    ENITF.K=ENITF.J+(DT)(ENGJF.JK-ENLTF.JK-EITTF.J+0)

N    ENITF=0

A    ENRTF.K=ENITF.K+(DT)(-EITTF.K)

R    ENLTF.KL=ENRTF.K/DETF

L    ENFEF.K=ENFEF.J+(DT)(ENLTF.JK-ENFTF.J-ENREF.JK+0)

N    ENFEF=LEI
```

As an initial compromise, DETF is set at one and a half years:

```
C    DETF=18
```

Following equations give the actual number of engineers engaged in training or supervisory work, or both, as a resultant of reassignments to and from the full time engineering category; this also takes into account the transfers of some of the trainers out of the project. Actual level is denoted by the third equation, which states that the number of engineers desired as trainers equals the number of new engineers expected, divided by the number of recruits each experienced engineer is expected to train:

assumed one month is required to arrange for and accomplish the reassignment of the engineers:

```
C    DRET=1.0
```

Total available for transfer are those experienced engineers who are currently employed full time on the project task, those who are assigned as trainers, and those new recruits still in training. Those employed as trainers are assumed to be transfered from the project first. If more transfers are needed, engineers still in training will be transfered. Finally, if still more engineers should be removed from the project, some of the full time experienced engineers are transferred out of the project.

Following equations say respectively that;

1.)when R&D expects more engineers than it desires, R&D transfers at the rate of ENGTD engineers per month

2.)the transfer rate is ENGPF/DT unless sufficient engineers are not available for transfer. This quantity is the amount needed to adjust the engineering gap, ENGPF, immediately:

```
A    ENTDF.K=CLIP(ENGTD.K,0,0,ENGPF.K)
A    ENGTD.K=MIN(-ENTRF.K,TEATF.K)
A    ENTRF.K=ENGPF.K/DT
```

Total engineers available for immediate transfer are those assigned as trainers, plus those in training, plus the fully experienced engineers who are working directly on the project effort. Following nominal notification period is usually given. These factors cause notified engineers to remain in the project for an additional short period of time while they are being transferred. ENGLF represents the engineers leaving only the project, as well as those departing from R&D. Then:

```
L    ENBTF.K=ENBTF.J+(DT)(ENGTF.JK-ENGLF.JK)
N    ENBTF=0
R    ENGLF.KL=ENBTF.K/DTRE
```

Utilized tecnological effectiveness was said to depend upon both available technology and the competence of R&D. Initially, this quality factor was equaled to 100%:

```
A    UTEF.K=(QF)(ATEF.K)
```

Whatever the know-how developed in solving NPD project problems, some time is required for it to be adequately absorbed. Then R&D's engineers supplement their nonproject skills with these new, more specific insights and approaches to the task. Increments to the engineering effectiveness are larger initially than they are later, since the number of engineering problems yet unsolved on the project decreases as the project progresses. This lessens the likelihood that new project accomplishments made late in the life cycle will find further use on this project. Therefore the multiplicative effect on the engineering productivity of the project achievements may look like the

```
C      TMEPK*=1/1.16/1.27/1.36/1.42/1.47/1.50/1.53/1.55/1.56/1.57
```

Several months go before the engineers on the project are able to utilize effectively their newly found know-how on other project problems. DCKN is assumed to be 6 months period:

```
C      DCKN=6
```

Basic relative productivity of the engineers employed on the project is given by the following equation. This equation recognizes the different degrees of effectiveness of the less trained from the more experienced, of those fully employed on engineering from those busy with handling administrative tasks or preparing to transfer out of the project:

```
A      REPRF.K=(PRIT)(ENITF.K)+(PRAT)(ENATF.K)+(PREBT)(ENBTF.K)+(1.
X1     )(ENFEF.K)
```

Constants used in above equation are all defined relative to the base productivity of the fully experienced engineers, ENFEF. New engineers are assumed to have some relevant experiences gained elsewhere, and they increase their effectiveness during their training period. Therefore PRIT, productivity of engineers in training, is set to represent 40% of the effectiveness of the more experienced engineers. More experienced engineers assigned to training devote only part of their efforts to the indirect training work, to the extent that their

This rate of productivity adds to the previous job accomplishments to produce the level of real progress on the job, which has been identified here as the level of really relevant know-how of R&D. Continuous accumulation of the increments of progress will complete the job when the required tasks (NLKP) are finished. Thru its communications with Marketing, R&D transmits a certain fraction of this acquired technological know-how to Marketing:

```
L    KLEVF.K=KLEVF.J+(DT)(ENPRF.JK+0)
N    KLEVF=0.0001
A    KLEVC.K=(PKFTC)(KLEVF.K)
```

R&D's initial project know-how is set equal to very small number so that all project tasks will require completion during the simulation. I will assume that R&D is effective in communicating to Marketing 80% of the project know-how developed. This know-how effects Marketing's and customer's value estimating process.

```
C    PKFTC=0.80
```

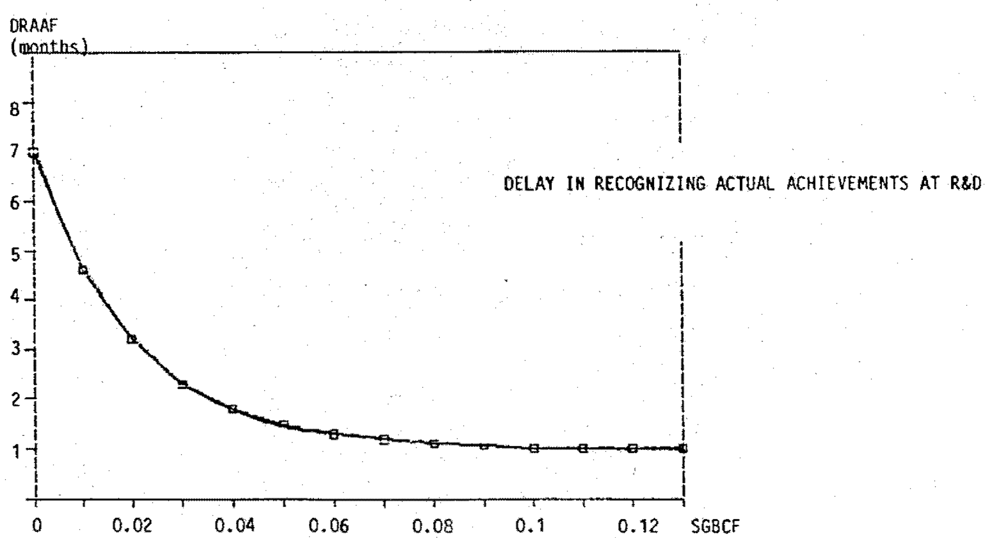
First of the following equations shows that the current engineering expenditure rate is determined by the number of engineers in R&D and the average monthly cost per engineer. Second and third equations cumulate this rate into the level of total engineering costs. Fourth equation indicates that the number of engineers actually working can be represented by the total number of engineers in R&D multiplied by the factor that accounts for the average absenteeism from work. Fifth and sixth equations cumulate this expended effort to date. Finally, last two equations, compute the total costs to Marketing (so to customer) as the sum of the changing rate of company expenditures of customer funds on the project.

```
R    TCEF.KL=(MESOH)(ENGRF.K)

L    TECF.K=TECF.J+(DT)(TCEF.JK+0)

N    TECF=(TEEF)(MESOH)

A    ENAWF.K=(PWAW)(ENGRF.K)

L    TEEF.K=TEEF.J+(DT)(ENAWF.J+0)

N    TEEF=KLEVF/UTEF

L    TECC.K=TECC.J+(DT)(RECFF.JK+0.0)

N    TECC=0
```

Beliefs form the basis of decision making in the project. First I will consider the believed level of project completion, composed of the previous completion estimate plus revisions due to changed beliefs as to the stage of progress and beliefs about new progress. Believed rate of new progress is assumed to be the ratio of the amount of effort being

```
A    MGBCF.K=MAX(GBPCF.K,-GBPCF.K)

A    DRAAF.K=TABHL(TDRAF,SGBCF.K,0,.10,.01)

C    TDRAF*=7/4.6/3.2/2.3/1.8/1.5/1.3/1.2/1.1/1.07/1.0

R    RCBPF.KL=GBPCF.K/DRAAF.K

A    GBPCF.K=PPC.K-BPPCF.K

A    SGBCF.K=(FOGRF.K)(MGBCF.K)
```

I will assume that it is unlikely that the progress estimate revision will take effect in any less than one month after the cause for revision exists. This minimum delay is assumed to exist only when the job is almost or actually completed. This may suggest a lower bound of one month for TDRAF table. On the other hand, if the work was stopped prior to completion, an additional six months may be required to recognize what has really been achieved on the job. Following graph is produced by incorporating boundary figures and assuming decreasing delay time.



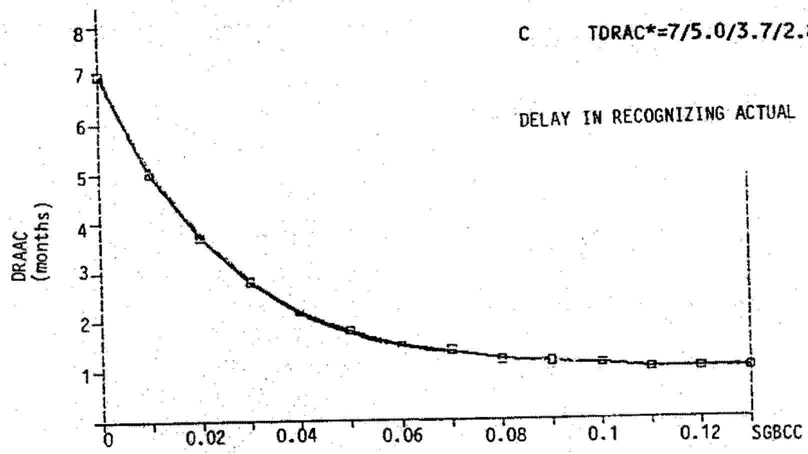
Recognition of this error in the earlier progress estimate may also tend to produce a revision in the previous estimate of job progress with effect on the technological effectiveness. Resulting modification

```
A     SGBCC.K=(FOGRC.K)(MGBCC.K)

A     MGBCC.K=MAX(GBPCC.K,-GBPCC.K)

A     DRAAC.K=TABHL(TDRAC,SGBCC.K,0,.10,.01)
```

The delay in achievement recognition by Marketing or Customer is shown below by the graph and values.

```
C     TDRAC*=7/5.0/3.7/2.8/2.2/1.8/1.5/1.4/1.2/1.16/1.1
```

DELAY IN RECOGNIZING ACTUAL ACHIEVEMENTS AT MKTG.



Customer's or Marketing's modification of their previous progress estimate also assumed to follow R&D's description:

```
A     PECBC.K=GBPCC.K/BPPCC.K
```

Finally I will provide the equation for Marketing's or Customer's estimate of the percentage of job yet undone.

```
A     BPPIC.K=MAX(TBPIC.K,0)

A     TBPIC.K=1-BPPCC.K
```

To provide extra information for use in studying various simulation results, following equations will be introduced.

First profit rate to R&D is the percentage of profit allowed on the project billings times the expenditures covered by Cutomer or

Simulated time history of an example NPD project is represented in this chapter. Equations and constants that represent the project are the ones used and explained in Chapter.6. (Complete output for this Chapter is supplemented in Appendix.B) This example project requires from 5500 to 27500 man-months of engineering effort, depending on the state of the art technology and overall ability of R&D's and Marketing's management and engineers. This effort requirement indicates project costs between $14 million and $70 million.

History of this example NPD project began with a single engineer, supported by R&D's own funs, working in area technically related to an potential future product. Engineer continues to work in this field, accumulating technical know-how relevant to the product development efforts.

R&D pays the costs incurred by the engineer out of its general funds, feeling that it must support this one-man activity in this new technical area. If R&D or the engineer could envision the eventual project at this time, they may estimate its cost to be very high. R&D estimates effort at about 22000 man-months of applied engineering, or costs of about $62 million. This is based on figuring the job at an average cost of $30000 per engineering man-year and by adding on the extras needed to cover the absenteeism time spent away from the task. With its zero-value estimate of product worth at the moment, such a cost estimate gives R&D no hope of getting any Marketing support which in turn would expect from potential customer(s).

Marketing is also experienced in related technological areas as well as R&D. In this example, Marketing is aware of R&D's efforts, but

At this time, R&D and Marketing begin to collect some information that suggest there may be some value to the product area. Two trends aid this perception. First; the underlying worth of product area is increasing. Second, R&D's continuing exploratory work in the area is increasing. Improvement of R&D's know-how is placing it in a better position for sensing opportunities and technical possibilities in the area.

At the end of twenty-third month, product's perceived present value is $1 million and R&D's estimate of future product value is almost $3.5 million. Advance of perceived current product value influences R&D and Marketing to expect the trend continue.

About the nineteenth month, cost of accomplishing the job starts decreasing. Main reason for the decrease is the increasing technical knowledge in the related areas for the development and production of the product.

Within few months, R&D and Marketing perceive more of these technological improvements in the product related areas. As a result, Marketing and R&D rely more and more for their cost estimates on forecasts of a future technology.

Following three forces;

1.)Rising of perceived current value and future product value projections

2.)Accelerating changes in technology and the future cost expectations by these changes

3.)Marketing's changing opinion for R&D's success as a result of the above two, begin to improve the overall suitability of the project.

than $25 million. R&D's future product value approaches $75 million where Marketing still foresees a value of only $45 million. Cost estimates are $47 and $55 million for R&D and Marketing. Although the two Departments see the product area as a high potential, especially Marketing's conservatism prevents it from entering into the area very soon. It waits for a more convincing product-need-product-cost relationship before committing its own and customers funds.

These factors are shown in Appendix.A (graphically and with a complete output).

By the fifty-first month, Marketing is almost spending $9000 a month (either self budget or by the customer funds it has found) on the project and R&D is adding $1000 a month out of its own funds. Both R&D and Marketing (and also the customer) now think that future worth of the product is greater than the development cost of the product, but Marketing is not yet convinced that it should support a major program in the area. Marketing's and customer's are limited and they want to invest in the most attractive opportunities.

R&D is confident that Marketing will soon be willing to support the project and therefore it submits a proposal with an accompanying estimate of costs. R&D believes that project will cost about $53.5 million, but cuts this by 10% in its communication to customer. Therefore R&D requests about $48.4 million for this job for which it really expects the cost will be $5 million more.

By this time R&D has four engineers on the job and is continuing to recruit, hire and train more as fast as its existing group can at $192 million and from then on begins declining, slowly first and rapidly later. Marketing's value estimate undergo a similar process.

By the seventy-eighth month, R&D has 27 people at work and has 13 more near the point of joining the group. Despite the technological advantages accruing from new breakthroughs outside R&D's own work, its project accomplishment is still small. Main reasons for this can be:

1.)Lack of effectiveness of the new engineers, most of whom are inexperienced

2.)Utilization of the most of the experienced project engineers to train, organize and supervise their new colleagues on the job.

Upto the hundredth month, real value keeps dropping and estimated costs continue a slow decline as technological improvements are discovered, communicated, recognized and interpreted. By the hundredth month, engineering group is at a level of 125 engineers plus supporting staff, with an anticipated increase of 50% within the next months. Taking into account the project duration, R&D would like to have almost four times as many engineers. But it is unable to reassign or to recruit and train that much in a short period of time.

By the hundredth month, the ratio of Marketing's perception of future value to its estimate of cost has fallen to four. R&D whose value estimate has fallen more rapidly and which also estimates higher costs than Marketing now, thinks that the project is even more marginal and is beginning to worry that Marketing may cut the funds.

As R&D grows in size, it increases its basis for further expansion, because of the number of people already in the Department and also because of their greatly increased average experience. As a result, convinced that NPD project is finished. Momentum of the project causes a few extras to be done during the final month, such as additional product testing.

But the work has been done, Marketing stops reimbursing the costs of R&D, and R&D shifts its engineers as quickly as possible to other work within the company.

Total cycle of the product value phenomenon is visible: intrinsic product value grows, levels, falls and disappears; estimated current value lags in recognition all along; estimated future value of both R&D and Marketing initially lags in its growth, then accelerates and overshoots the real-value, and then falls rapidly for R&D and less quickly for Marketing toward zero.

Another characteristic is the behavior of the perceived product-cost curve. Starting very high relative to product worth at that time, estimated effort and cost on the project fall under the influence of a rising technological state of the art. Cost estimate rises as a result of the feeling that the basic scope and complexity of the project is bigger than anticipated.

Curve of engineering employment on the project also shows the rise and fall of the life cycle. For a long time, only a single engineer is working in the product area within R&D. This effort level is so small relative to the later engineering activity on the project that it dose not show up in the graph.

Final curve drawn on the graph shows the real percentage completion of work needed for the project. This curve is invisible for many months of project (almost upto fiftieth month). Then on, project

Although the outputs of the simulation runs corresponding to project time histories for the current model seem satisfactory within my understanding, many parameters used in the simulation model are 100% hypothetical. Therefore main concern for the future studies can be focused on the measurement of these parameters. Accomplishment of this future possible step may also enable the verification and validation of the current model via use of some particular projects. Once the validation can be done, for example, we may study the very different shapes of intrinsic value inputs.

Some of the parameters are selected and used as constant throughout the simulation runs. This may not be the general situation. Parameters chosen to be constants may also be changing with time.

Once the accomplishment of satisfactory data gathering is done exploration of NPD management can be performed. For example, we can examine the effects of changes in the characteristics of product (such as size of job and/or intrinsic product value) or characteristics of R&D Department (such as quality of R&D and/or willingness to accept risk and/or previous job-size experience and/or resource limitations) or characteristics of Marketing Department (such as quality of Marketing Department and/or risk propensity and/or previous experience and/or Marketing's confidence in R&D and/or resource limitations of Marketing) or both, on project outcomes. Also examining of above stated points (sensitivity analysis in a sense) may brought into scene additional characteristics which may worth to study.