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ENGINEER DYNAMICS AND PRODUCTIVITY IN R AND D PROJECTS

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ABSTRACT

The dynamic process of engineer acquisition and utilization in R and D projects is diagrammed and described. Policies for engineer acquisition, training, and transfer are discussed. The bases for engineer productivity are defined and organized into a structural representation that includes effects of technology, experience, management, and organizational factors. Some results of computer simulations of an R and D project model are presented, indicating the sensitivity of project outcomes to various training times, initial staff sizes and other factors affecting productivity.

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by

Edward B. Roberts

Of the many productive resources needed for a research and development project the most critical element is engineering manpower. The research and development process requires the organization of a sufficient number of persons with the breadth of technical competences needed to carry out the task. Government-sponsored R and D, in particular, often demands a growth in project staff from the few engineers who undertake exploratory studies to the several hundred men needed to complete the job. In any area of new technology, or of significant departure from a firm's previous work specialities, the firm's ability to expand its technical organization is inherently limited by its existing capabilities. Initially, a great deal of time will be needed to recruit, train, and supervise the new men entering the project. This type of problem, the transfer of know-how from one person to another, the translation of objectives and technical approaches conceived by a few engineers--or even, perhaps, by one man--into goals and methods mutually understood by a much larger staff, is inherent in the research and development process.

This paper discusses engineer dynamics and productivity, that is the policies and activities related to acquiring, training, and then utilizing engineers in the pursuit of project objectives. The paper is divided into three parts, discussing first the flow of engineering manpower into and out of a research and development project, and second, the factors influencing the productivity of the engineers during the life of the project. The influences described in these two sections are incorporated into a general model of research and development projects, some results of which are presented in part three of this paper.

THE FLOW OF ENGINEERING MANPOWER

The flow diagram of Figure 1 presents a dynamic closed-circuit view of engineer acquisition and utilization. The blocks indicate the various categories into which an engineer moves during his job cycle on a research and development project. The arrowhead symbols (⇨) indicate the decisions that shift the engineer from one category of work to another. Some of the information used in these decisions is pictured by the dotted lines.

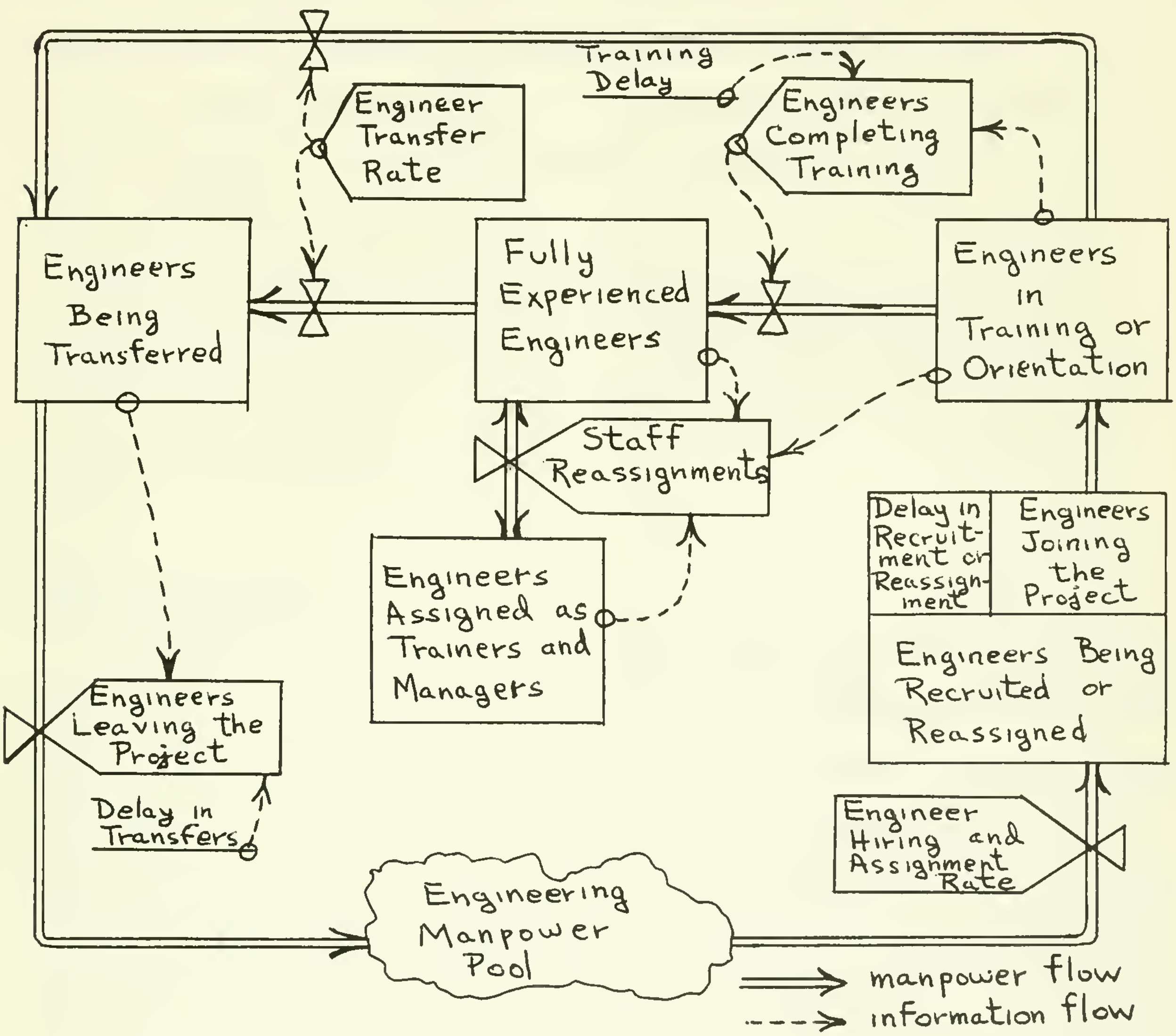

Figure 1. The Flow of Engineering Manpower

Briefly, starting in the lower right-hand corner of the diagram, the symbols show that as a result of recruiting or reassignment by the company, new engineers join the project team. They go through a period of formal training or informal indoctrination, varying in length dependent upon needs, during which their skills increase gradually toward the level of those of the average longer-term employee on the project. As organizational growth takes place, some of the more experienced engineers are reassigned to training and supervisory roles. Similarly, when their services are no longer required on the project, some engineers are transferred to other jobs, or occasionally laid off or fired. Some time is required for paperwork before those who are being transferred actually leave the project.

The flow diagram illustrates the process of acquiring and utilizing engineers during the life of the project. The indicated changes take place as a result of the project manager's efforts to adjust the actual number of engineers to the number desired.

Acquisition Policies

What determines the number of engineers that the firm desires to have on the project? An obvious answer is that the level is determined by the financial support available to the firm. But this raises another question: Should the firm wait for support before beginning the recruiting process? If it recognizes the long lead time needed for hiring, the company may well begin to hire some engineers in anticipation of future funding. Most new engineers and scientists are recruited directly from college. Companies must anticipate their needs far in advance and start recruiting early in the school year, several months prior to graduation time. In many cases firms start recruiting prospective engineers while they are still sophomores or juniors, offering plant

visits or summer jobs. These activities clearly indicate that the delay in hiring new engineers may be so lengthy that the firm which awaits funding before seeking recruits will lose much valuable time. The delay in engineer acquisition for a new project is greatly shortened when enough engineers are available for transfer from other parts of the company.

It is questionable whether firms do actually hire up to the maximum level supportable by available funds. Most engineering firms are concerned with the problem of providing labor stability, especially to their professional employees. Therefore they are unwilling to hire new engineers unless they feel fairly certain that they will be able to utilize the men for a reasonable length of time. Most firms adopt a mid-road policy taking into account not only the amount of support currently available (or expected to become available soon) but also the anticipated duration of such support.

Once a firm has decided how many engineers it wishes to acquire, it still has to determine the rate of recruiting. In all likelihood, the firm cannot even attempt to hire immediately all the people it needs. First of all, the personnel department in the usual research and development firm is limited in size. This restricts recruiting and interviewing activities. Experienced engineers often have to be taken off their current jobs in order to go to colleges or other prime sources of trained manpower for the purpose of recruiting. Some firms, unwilling to take their employees away from other productive duties, may therefore limit their rate of acquiring new engineers. For these reasons, at any given time a firm is probably actively recruiting only a fraction of the total additional manpower it desires to have.

Training Policies

Another influence upon the hiring rate is the firm's training policy. Most firms recognize a need for orienting and training new employees, whether they are fresh from college or obtained after much experience with another

company. In order to train the recruits, more experienced personnel must be diverted from their current activities. Companies vary greatly in their attitudes toward the value of training programs for new employees. Some severely restrict their rate of hiring in order to indoctrinate new personnel fully under the available number of experienced and particularly competent engineers. Other companies train more casually and are not concerned with providing extra coaching or on-the-job instruction to their recruits. For example, among twenty-three selected laboratories surveyed by the management consulting firm of Booz, Allen, and Hamilton, "in the best lab circumstance, about a third of the personnel seldom or never were given on-the-job instruction, and in the poorest, almost two-thirds did not receive it. In view of the relative youth and immaturity of lab personnel, this would appear to be severe neglect of an expected supervisory function" (Randle, 1959, p. 134).

The basic problem in determining a company's training program policy is the "double-edged sword" nature of the situation. On the one hand, if the firm does not provide adequate training to its new people, their long-run ability will be decreased. On the other hand, a very thorough training program removes some of the most effective people from work directly oriented toward the firm's product. Different firms try to solve this enigma in different ways; some bury their heads in the sand and ignore the existence of the problem. Whatever policy is finally adopted by the company determines both the future productivity of the firm's engineers and the current availability for project work of the experienced personnel.

At the completion of their training program, regardless of its brevity or length, the new engineers become available on a full-time basis for research and development work. These full-time people are the ones usually considered when the firm 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 recruits and managers are selected to supervise the project.

While the number of people engaged in training activities depends largely on an overt policy decision by the firm, the need for managers does not. Whether desired or not, the employment of a number of people requires supervisory, administrative, and managerial personnel. "The supervisory structure of engineering organizations, according to a survey of 395 laboratories, requires at least 25 per cent of all the engineers in the organization" (Hirsch, et al., 1958, p. 94). Thus, the very hiring and utilization of engineers requires the transferring of other engineers from design and development work into activities that contribute less directly to task objectives. Both types of function are essential to the research and development project.

<u>Transfer Policies</u>

Whatever their policy toward the acquisition of engineers, most companies face a considerable problem when the services of some fraction of their engineering staff are no longer required. This difficulty most often occurs 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, research and development companies usually consider their greatest asset to be the productive ability of their engineering work force which they often regard as a team that has required a number of years to build to high effectiveness. Such companies, therefore, hesitate before laying off an individual whose technological knowledge can contribute to further profitable ventures for the firm. Should the firm hire and fire R and D people in the short run, it would soon be totally unable to obtain and retain the competences necessary for initiating and completing successful development projects.

These difficulties often influence the amount of funds that the firm appropriates for what amounts to company-sponsored research efforts. These efforts,

when instituted under such pressures, are really stop-gap measures to maintain the employment of the company's engineers. In many situations, however, if the firm has done a good job of planning and has made its plans materialize, the engineers being freed from one project can be transferred to another without much delay. Some inefficiencies usually occur in such a transfer process because of the time necessary for the firm to recognize that the engineer is no longer needed on the old project and to arrange for his transfer or, if necessary, to given him reasonable notice of lay-off.

Voluntary leaving by individuals, rather than company-instituted lay-offs, dominates engineer turnover. A detailed study of one laboratory found that technical staff members are rarely discharged, but voluntary movements are such that about half of the laboratory's staff turns over every five years (Marcson, 1960, p. 83). Even higher rates of turnover were found in a broader sample of R and D organizations, the survey results showing that the average engineer changes jobs once in every 3.3 years (Hirsch, et al., 1958, p. 86). Financial considerations are usually important in an engineer's decision to leave an organization, though other factors, such as prestige, family desires, dissatisfaction with the job, and personal aspirations may also be influential.

ENGINEERING PRODUCTIVITY

Progress on project tasks is accomplished by the engineers employed as a result of the process just described, and it is to the production of this progress that we shall now turn our attention. Any discussion of engineering productivity tends to become highly complex, because the influences at work are numerous and highly unstructured.

The Technological Basis of Productivity

In attempting to focus upon these influences, we first observe that the basis of productivity is the level of technical knowledge applicable to the project's problem area. As technology grows over a period of time, the potential effectiveness of the engineering staff also grows. We shall not here attempt to delve deeply into the nature of technological evolution but shall mention a few important points regarding the utilization of technology.

First, there is a lengthy delay before new contributions to technology become known within the firm. The extent of the delay depends upon the effort the firm is putting forth in the relevant technological area and upon the firm's policy of obtaining and transferring to its own use knowledge that is being developed outside the firm. Many different factors influence the delay in bringing outside information into the firm. The most obvious of these is the extent to which the firm's engineers exchange technical information with their professional colleagues. Perhaps one of the less obvious factors is the number of years members of the staff have been away from college. The younger people have been taught new techniques at college and often bring these methods into the firm. Encouraging continuing education can aid in bringing new know-how into the firm more quickly, as can effective use of technical libraries, outside consultants, attendance at technical conferences, and the like.

Even after the staff members become aware of new techniques, there is an additional delay in actually absorbing the information and making use of it. The time taken for absorption of outside developments is quite lengthy. It constitutes the major portion of the delay between the discovery of new knowledge in one place and its actual utilization at some other time and location.

The Effect of Experience

The changing state of the art and the firm's ability to become aware of and to utilize new knowledge forms the basis for the potential productivity of an engineering firm. Many other factors, however, affect the actual productivity achieved by a group of engineers. One of these is the effect of on-the-job experience on the abilities of the engineers. Some observers regard the increased productivity resulting from experience as analogous to the "learning curves" that have been applied to efficiencies in manufacturing organizations.

> The engineer, whose job is much more complex than that of a production worker, becomes more proficient when he knows the company procedures and policies; has learned the important formal and informal communication channels; has determined where he can obtain assistance in solving critical problems; is familiar with the technical aspects of the company's products; and has learned the technical errors which were made previously so that he can avoid the same pitfalls. This learning process continues [but] at a diminishing rate as long as the engineer is associated with the company. (Hirsch, et al., 1958, p. 96).

Of course, some companies have already learned that this diminishing rate of growth need not set in. Through symposia, seminars, attendance at university "short courses," and graduate and post-graduate education, many companies, large and small, seek to maintain the rate of personal development of their employees.

In addition to these general benefits attributed to lengthy experience with the company, increased productivity tends to result from the development of specific bits of know-how on a given project. To a high degree, many of the problems encountered during the life cycle of a project are similar in content or in the factors contributing to them. Thus, as knowledge is built up during the earlier phases of the project, the firm's engineers are gathering information and new techniques that will be applicable to some parts of the later phases. In the aggregate, then, the productivity of the engineers working on the job tends to increase as the job progresses.

Job Category Effects

In addition to the effect of job experience on engineering productivity, one should also consider the effects associated with the various worker categories. There are basically four categories of engineering employees: engineers being trained; those doing the training and managing; those who are more or less experienced and are working full time on the project's engineering tasks; and, finally, those men who are in the process of quitting, being laid off, transferred, or fired. The work category of the engineer is a good indicator of his relative average productivity.

As our standard, we can take the experienced engineer who devotes his full time to product-oriented work. On the average he is supposedly able to manifest in his work the available and utilizable engineering productivity discussed previously.

The average new recruit cannot be expected to be nearly as effective. This is not due merely to a difference in over-all engineering experience, since new recruits may very well come from other firms after many years of service. The process of indoctrination and orientation itself requires several months before the new employee becomes effective.

In general, those engineers who are working as trainers or managers also have their direct job productivity decreased substantially. Looking first at the trainer, few can question the necessity or importance of his role in the organization. In the long run his contributions to the project show up in the enhanced productivity of the engineers whom he helps to develop. In the short run, however, the trainer's direct contributions to the solution of the design and development problems of the project are substantially reduced because of the smaller portion of his time available for this work. The amount of effective engineering (rather than training) work that the trainer is able to do depends to a large extent on the number of trainees who have been placed under his guidance.

The task-oriented productivity of those engineers who have been made engineering managers is also usually decreased markedly. This is not necessary, but it is a common result of the change in job position. The highly effective manager of an engineering organization applies himself to laying out the direction of attack on the problem, clarifies the job requirements to save the time and effort of others, provides systems coordination, and so on. All of these functions are very much a part of the engineering task in a research and development project. The capable manager stays close to the critical job problems through consultation with his engineers and sometimes through participation in the making of key design decisions. Very few engineering managers have such high effectiveness, however. Most of them do not manage at all. Instead they administer. They typically spend much time on rating the performance of their engineers, on pay-raise evaluations, and on other paper-shuffling activities. They prepare multiple budgets that serve not for job-planning but rather for organization-accounting purposes. They entertain customer visitors, attend higher-level staff meetings, file and collect reports in such numbers and in such detail that the meaningfulness of the data to the real management of the project seems only a remote possibility. Those who express concern for the underutilization of engineers might more profitably examine the underutilization of engineering managers who waste much time and talent on such administrative trivia. To be sure, the functions performed may well be necessary to the organization, but they have little direct relevance to the project task. Thus, except for the few who do perform the needed managerial role, engineering managers find their task-oriented productivity severely curtailed by their administrative activities.

The third 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 company or the project, whether for voluntary or involuntary reasons. The time informally consumed by transfer activities, the loss of enthusiasm for the job being completed, and very often the poor attitude toward the organization or project, all contribute to the decreased technical efficiency of the engineers working in this status.

One can also recognize another category of engineers who, because of sickness, vacations, holidays, or for incidental personal reasons, are temporarily not on the job. Although this category appears basically as random noise in the project system, it does have a strong seasonal component due to vacations. An earlier study by the author in an engineering department of a large company showed that this off-the-job time amounted to an average of about 12 per cent of the year's total potential workdays.

Managerial Influences

The quality of engineering management is probably the most important single factor influencing the full and effective utilization of engineering potential. It is easy to see that problems resulting from the poor organization of work, the hiring of less competent personnel, the lack of proper use of outside technological resources--and from many other factors--are all attributable to poor managerial ability within a firm that can lead to lower technological effectiveness than the firm could potentially achieve. Thus:

> Good supervision is basic to high R and D effectiveness. In this respect, research does not differ materially from other company areas. Yet management often excuses poor supervision on the basis that R and D work does not lend itself to direction, that the scientist works better when unrestricted, or that the experience and education of the scientist poorly fit him for handling others. Here is where many companies run into trouble (Randle, 1959, p. 134).

The quality of management influences the effectiveness of the engineering work team in many ways. A good example is afforded by decisions as to the allocation of engineering effort among the different types of work that have to be done on a project. From unwise decisions of this class arises gross waste of scientific and engineering talent, in part by the use of engineers for jobs that could be done more effectively by someone else. More important, however, is the waste that comes from devoting engineering resources to the vast number of projects that never result in satisfactory final products. In the same vein, the engineering manager's allocation of his own time can have a great effect on the productivity of his group.

Able management effects policies that enable group leaders and working engineers to see their particular tasks in the perspective of an over-all organizational objective. This assists everyone in the project to see the forest as well as the trees, thus providing a more intelligent basis for individual engineering decisions. The capable management also establishes a penalty-reward system which encourages initiative and creativity, not for their own sakes, but toward defining and accomplishing project goals. The well-designed system will also foster the objectivity and organizational integrity that permit quick recognition and communication of project problems and bottlenecks. It fosters a set of attitudes that allows the people of the organization to <u>be</u> the communication and control system needed for effective project management. It is then not necessary to depend solely on the artificial and ineffective devices for project evaluation and review whose proponents currently clutter both the management literature and the mailbag.

Such an environment facilitates the development of good leaders and effective working engineers and scientists. It provides the worker with motivations that derive from pride and involvement in the work group. Effective performance

results from such motivations, and through policies that enhance these characteristics management can have an important effect on engineering productivity.

The Impact of Organization Size

The size of the engineering work force in itself has an important influence on the productivity of the engineers in a firm. One author has said: "Above a certain level, the assignment of additional personnel to a large project may not only not reduce total time proportionately, but in fact may increase total time to accomplishment, and...many organizations today engaged in complex engineering tasks are operating at a level in which this fact is true....They could speed up the accomplishment of their tasks by reduction of engineering personnel" (Kershner, 1958, p. 35). With organizational growth come greater administrative problems. The communications problem, in particular, is intensified. In the small organization, the director of research or the manager of engineering knows about and exercises personal influence on the several projects of the firm. As the size of the engineering team increases, however, the manager spends more time on budget and personnel matters and project control becomes more impersonal, responsive to periodic reports and artificial measures of achievement. Also with increased size comes decreased flexibility in the organization; in short, inertia sets in.

There is strong reason to believe that the tight organization--that is, one that has a meager budget and small staff--can accomplish objectives significantly out of proportion to its size. Notable among the major programs that have been successfully carried out in this way is the development of the Sidewinder missile.

> This program, with a tiny engineering staff at NOTS [Naval Ordnance Testing Station], led to an extremely successful guided missile. The group was small enough that the approach could be kept completely coordinated and all major technical decisions were made by one man, William McLean. Mr. McLean was recently awarded a special Civil Service prize for his accomplishment in this program and richly deserved it. But in addition to being a testament to the brilliance of one individual, the program serves also as a striking illustration of the efficiency achievable with a small engineering staff (Kershner, 1958, p. 38).

Another relatively recent example of the ability of a tightly organized team to perform efficiently is the feat of the Von Braun rocket group at Huntsville, Alabama, while it was still part of the Army Ordnance organization. After a long development program had failed in its first two attempts to launch the Vanguard satellite, the Von Braun group was given the go-ahead to make an attempt. Eighty-four days after receiving this authorization they successfully launched the United States' first satellite, the Pioneer I. To be sure, neither the satellite nor the rocket was developed in this brief period. The organization had many years of experience in related areas, had previously developed a launch vehicle, and had thought about and done preliminary work on the problems of earth satellites. But this type of background is exactly what is necessary for an effective project team. The people involved need deep understanding of each other, of the technical problems, of the related science, and, more important, of the required art. When this understanding exists, a group such as Von Braun's, once given an opportunity, is able to run with the ball. Like the Sidewinder, Pioneer I provides a good example of the effectiveness of a small work team with top-notch managerial capability and strong motivation for accomplishment.

A Structural View of Engineering Productivity

All of the factors previously discussed--the acquisition and use of technical knowledge, on-the-job experience, the relative productivity of workers in various job categories, managerial competence, the motivations of employees, the size of the work force--combine to determine the effectiveness of the engineers on the project. This effectiveness, together with the amount of engineering manpower applied, governs the rate of progress on the job. In Figure 2 the various elements involved in engineering productivity are organized in a flow graph. To be sure, the progress of research and development projects is affected

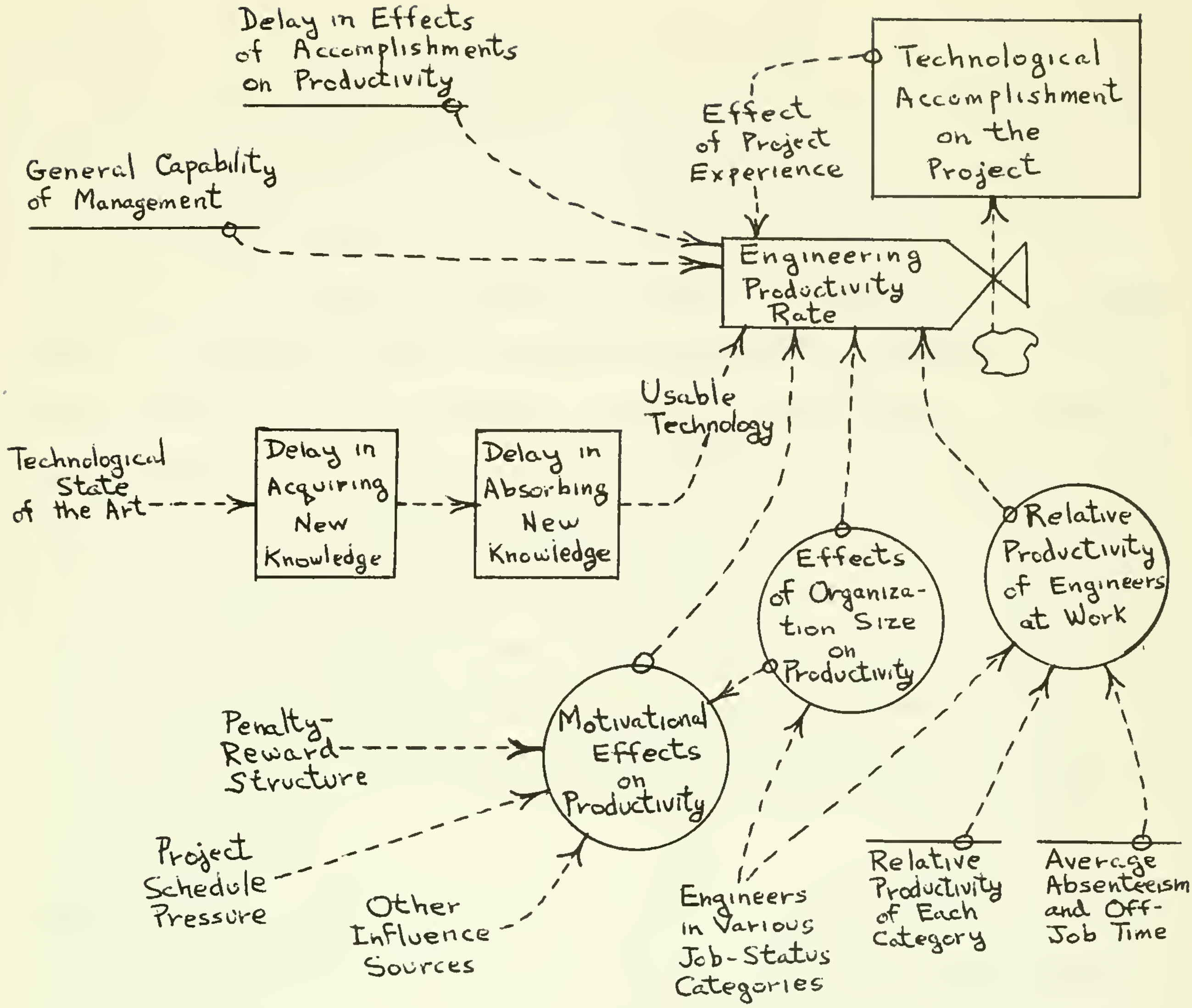

Figure 2. Influences upon Engineering Productivity

by other influences as well--for example, the policy aspects of engineer acquisition treated in the early portion of this paper. But the structure illustrated in the diagram and our general inderstanding of its components present many possibilities for more thorough treatment of R and D management problems.

RESULTS OF THE R AND D PROJECT MODEL

The foregoing general description of the many influences upon engineer acquisition and productivity can be incorporated into a general model of research and development projects. Such a model requires the addition of several sectors including, as examples, those representing company and customer financial decisions, progress evaluation activities, and procedures for estimating effort and cost requirements. This model has already been developed and its full details are available elsewhere (Roberts, 1964). The results of investigation of this model through use of computer simulation techniques present some quantitative insights to the qualitative descriptions of the engineering process. By making simple changes in the value of the particular characteristic under study and then producing new simulated project life cycles, we can readily identify the effect of each variable separately on the outcome of research and development projects.

Effects of Training Time

One of the first factors mentioned in this paper was the importance of the engineer acquisition and training process. Yet even when we look for definitive quantitative evidence on the duration of this acquisition and training period, we find wide divergence of opinion. Various studies have suggested that this period lasts anywhere from six months to five years. Certainly the different experiences of different organizations working in different technological environments can readily explain wide estimate variation. It is more important to discover the differences in R and D project outcomes which would result from the various assumptions.

Figure 3 gives the results on the typical project model of various assumptions regarding the required training time. These results are taken from simulation

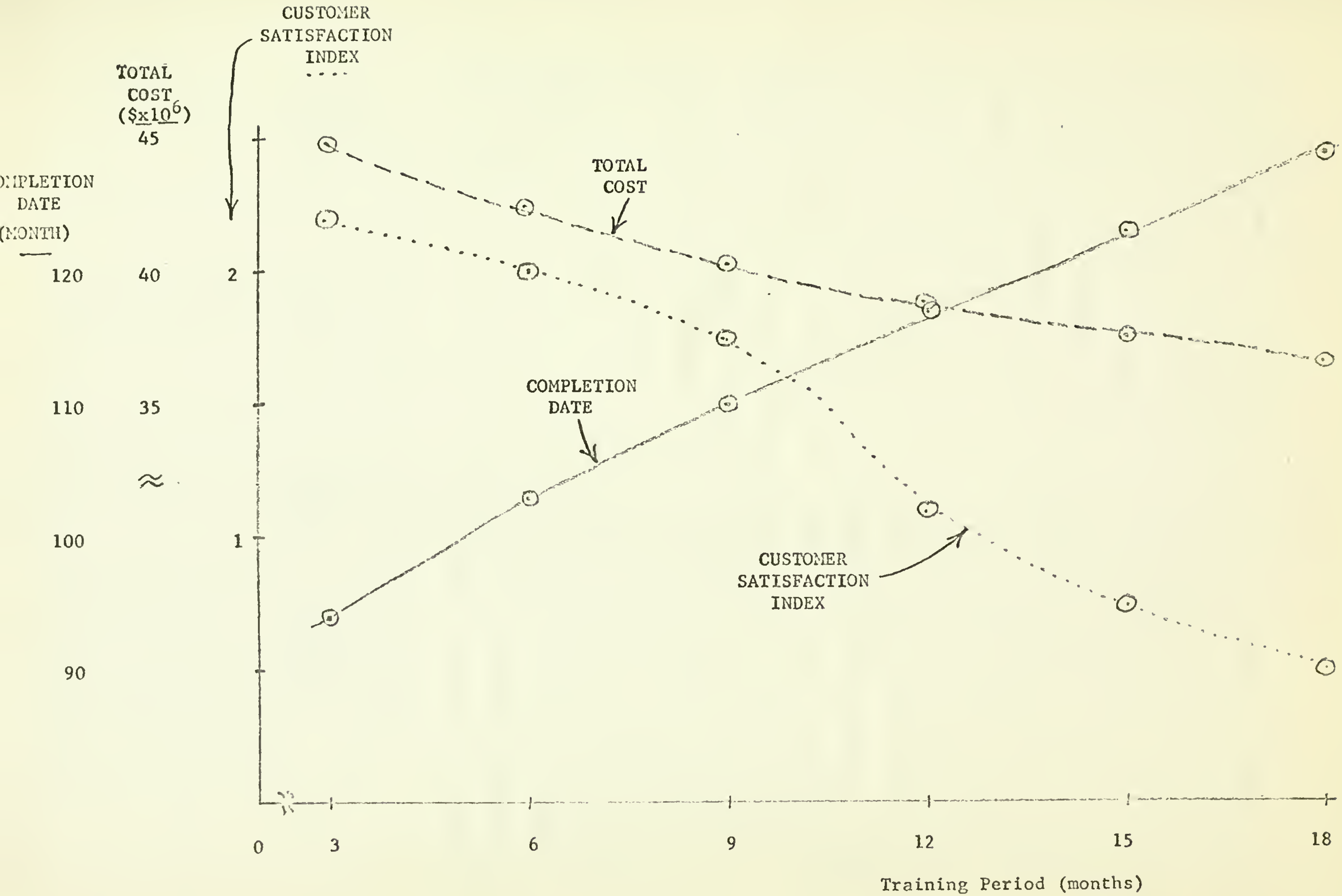

Figure 3. Effects on Project of Various Training Requirements

studies performed on an IBM 7090 computer using the Industrial Dynamics approach (Forrester, 1961). The curves show that the resulting outcomes of R and D projects are extremely sensitive to the time needed to develop the new engineers effectively. The date of completion is prolonged increasingly as the necessary training period is lengthened. Total project cost, however, decreases somewhat as the delay in completion permits the firm to take advantage of the steadily increasing technological state of the art. The delayed project completion overrides the lower cost in influencing the customer and his satisfaction with the project declines as training time increases. These results demonstrate that the many months needed to develop new professional talents constitute a vital influence upon R and D project behavior. Companies working on research and development activities should obviously strive to reduce this time period.

The potential danger of attempting to implement such a policy is that diminished productivity of the trainees is likely to accompany reduced training time. If this occurs, the results may be disappointing, as indicated in Table 1. For our simulated project, a 21-month training period results in only partial completion of the job. If the training period could be reduced to eighteen months without lowering its effectiveness, the project would be completed successfully. However, should lowered trainee effectiveness accompany this reduction in

Table 1 Changed Training Time and Trainee Effectiveness

Training Time (months)	Effectiveness of Trainees	Project Cost ($ x 10^6)	Project Completion Status
21	Normal	22.6	only 61% complete
18	Normal	36.7	100% at month 129
18	Lowered	24.2	only 41% complete
9	Normal	40.3	100% at month 110
9	Lowered	48.5	100% at month 113

training time, more harm than good could occur, causing greater costs and even less job progress. The tabulated simulation data indicate that a substantial decrease in training time must take place for any given change in effectiveness, before desirable project outcomes result.

Effects of Initial Staff Size

One possible way of ensuring needed organization expansion in an R and D project is for the firm to staff initial study groups with more engineers. A larger nucleus exploring the problem area, developing a mutual understanding of the difficulties involved and of the means to accomplish project objectives, will ultimately result in more rapid project expansion. The curves of Figure 4 show that a greater initial staff size can benefit a project to a surprising degree. Rapid completion is greatly enhanced by an intially bigger "push" and, despite higher costs resulting from use of a less-developed technology, customer satisfaction also rises. The greatest effects take place for the first few increments in staffing above the nominal effort of one engineer or scientist. Bringing the initial staff to two men causes project results in which the customer's perceived value about equals his total project expenditures, while also reducing project duration by ten months. Adding one more engineer to the initial group size makes the project results clearly satisfactory to the customer. These simulation results demonstrate the "critical mass effect" of an initial threshold level of engineering effort concentration that is needed to "get the ball rolling" adequately. Beyond this number, further increases in initial staff size cause more benefits, but at a gradually decreasing rate.

Especially when viewed in a practical light, the outcome of these tests seems encouraging. For example, staffing a project study group with four men initially stead of one produces results nearly comparable (in terms of completion

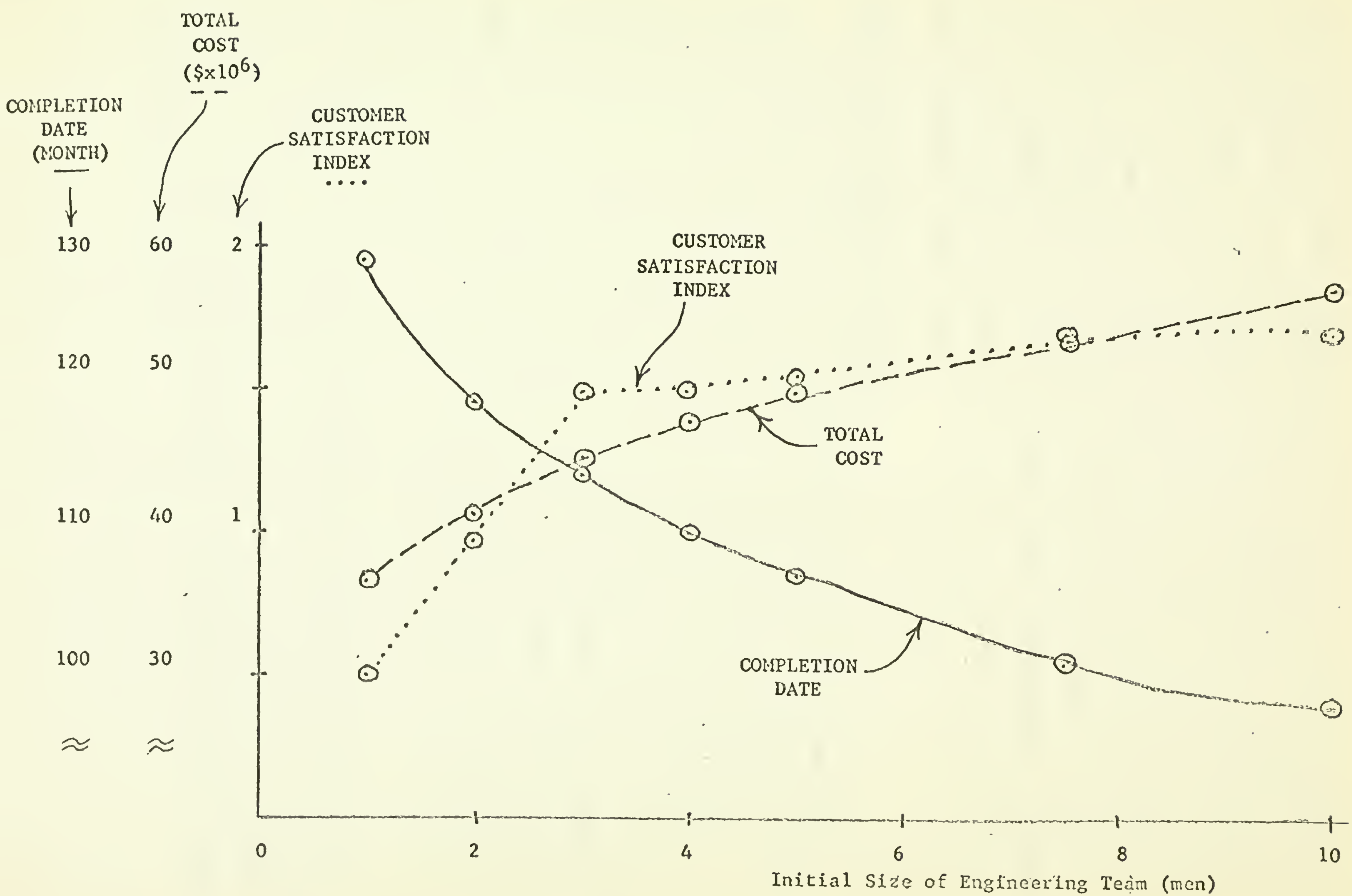

Figure 4. Effects on Project of Various Initial Staff Sizes

date, cost, and customer satisfaction) with cutting the overall training time to nine months while avoiding any decreased effectiveness. The higher initial staffing, however, can reasonably be accomplished, given the initial availability of more money and manpower, whereas the severely reduced training period is highly unlikely, particularly without a serious counterbalancing decrease in engineering productivity. Again, from a practical viewpoint, the results bear upon management policy on the number of men to be assigned to preliminary study contracts, or on the number of different projects a limited engineering staff should try to keep active.

Other Factors Affecting Productivity

Computer simulation investigations have been performed in many other areas described in the earlier portions of this paper. One series of results (Roberts, 1964, chap. 9) establishes that bringing the new engineers on a project up to full competence level amounts to an 82 - 84% addition to the optimum project cost. Other research results (Roberts, 1964, chap. 10) show that the long delays in acquiring and absorbing information on new technologies can doom a project to failure. Still other studies (Roberts, 1964, chap. 12) demonstrate that as the project organization grows in size, the decreased efficiency that occurs causes increased cost, delayed completion, and decreased customer satisfaction.

Research along the lines indicated has been under way for several years and is continuing. Its potential value is indicated by the Hirsch study, which was based on a detailed examination of many R and D organizations with regard to many of the factors under discussion here. The authors of the study summed up their findings in this way:

Our best estimates at this time indicate that improved utilization of the scientific manpower available could result in increased yields by a factor up to 100 times--with a more probable increase of about 10 times! This would mean that by improving utilization methods alone, i.e., without increasing the supply, about ten times as much output could be obtained from our scientific supply (Hirsch, et al., 1958, p. 88).

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