VORSTEG, Jr., Joseph Vincent, 1929—
THE SELECTION, PERIODIC REVIEW, AND POST-
APPRAISAL OF RESEARCH AND DEVELOPMENT
PROJECTS IN AMERICAN INDUSTRY.

The Ohio State University, Ph.D., 1966
Business Administration

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1967
THE SELECTION, PERIODIC REVIEW, AND POST-APPRaisal
OF RESEARCH AND DEVELOPMENT PROJECTS
IN AMERICAN INDUSTRY

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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***************

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ACKNOWLEDGMENTS

I would like to express my appreciation for the encouragement and invaluable assistance which I have received from many persons throughout this study. Without their support the completion of this dissertation would not have been possible.

I wish to thank the corporate executives who completed the questionnaire which provided the principal source of primary research data. A special tribute is offered to those executives who provided time from their busy schedules for interviews.

Appreciation is expressed to a friend and fellow student, Arthur L. Holt, for the ideas and suggestions which he contributed during the formulative phase of this study and for his help in the reproduction and distribution of the questionnaire.

My gratitude is given to another friend, Bessie F. Shriner, whose secretarial ability is reflected throughout this report.

I would also like to acknowledge my appreciation to Dr. Ronald S. Foster and Dr. Ralph M. Stogdill who gave generously of their time to serve as members of my committee and who provided council in the development of this study.

A special note of appreciation is extended to Dr. Charles B. Hicks, my adviser during my doctoral studies at The Ohio State University. He skillfully guided me around the pitfalls which beset
an inexperienced person undertaking a study of this nature. His faith and encouragement provided much motivation.

Finally, my heartfelt gratitude is given to my family. Without complaint they endured my mental preoccupation and extended periods of absence and at the same time provided the basic purpose for it all.
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CHAPTER I

SCOPE AND IMPORTANCE OF THE PROBLEM

The challenge of research and development

Today, as never before in history, research and development activities are playing a role of ever-increasing importance in the daily lives of everyone. The walk in space of the astronauts, the Soviet soft landing on the moon, and the twenty-one photographs of the surface of Mars transmitted to earth by Mariner IV after a 325,000,000 mile flight through space are only a few examples of the numerous and varied products of research and development undertakings. The various branches of the armed forces maintain research laboratories and development facilities all over the country, where highly trained personnel are constantly striving to develop adequate defensive weapons to protect this nation and its people against potential enemy attack and, further, to develop superior offensive weapons which will enable immediate retaliation with a devastating force against any aggressor. Indeed, the very future of our country as a free and sovereign state appears to be dependent on the ability of our scientists and engineers to maintain scientific and technological supremacy.

Of equal importance to our national life are the contributions made by the industrial research and development activities in a form
having more direct significance to the average person. The development of the artificial heart, which has enabled physicians to correct conditions in patients through open heart surgery which only a few years ago would have been fatal, the laser scalpel, used experimentally just this year to remove a malignant growth, and the many antibiotics and serums which have been developed are a few examples of the things which research in the area of medical science has provided to ease suffering and pain and prolong the life span. Color television sets which are rapidly appearing in many households, nutritionally enriched foods and new food-processing techniques such as dry freezing, which has done much to increase our flexibility and enjoyment of a variety in eating, the application of teflon to ovens, skillets, and irons for lightening the burden of the housewives, and the many synthetic fibers which provide a permanent crease or a wash-and-wear capability that are now in everyday use represent but a few of the countless products that research and development programs have contributed towards making our lives more enjoyable. Not only have research efforts led to the development of such items but they have given us the systems of mass production and automatic processing which make it possible to manufacture and sell these products at a price the average family can afford.

Further, the present and, more important, the potential contribution of research to our economic stability is most promising. As early as 1942 the statement was made by Francis R. Bichowsky that

It is really hard to find a modern manufacturing business whose product, or at
least whose manufacturing or operating method, is not the result of invention. Research, therefore, in some sense, produces wealth and is of value both in a financial and in a social sense.¹

This astute observation of twenty-four years ago is even more dramatically applicable to the highly technologically oriented industrial environment of the sixties. Dexter M. Keezer has noted that today's research will change the way a family lives tomorrow—how people communicate, where and how they travel, and what they eat and wear. He states that industrial research is unlocking new sources of energy, revolutionizing methods of production, and changing the very structure of industry itself. For the economy as a whole, it is pointed out that research on today's massive scale moves the traditional limits on economic growth.² However, research not only provides new products and practices to be used when business is good and profits are high, but it frequently enables diversification of business and aids industrial enterprises to come out of a slump and return to even greater prosperity. The International Business Machines Corporation and The DuPont Company built a large portion of their great industrial empires on millions that were spent for research during the depth of the depression. In today's highly technological age research is essential to any company which hopes to survive its competitor's efforts. It is


inevitable that the continuous exploration of the vast scientific frontiers bring with it a promising period of wealth and prosperity.

Research and development, in the very basic sense, is not really new, for man has been solving problems of one type or another and increasing his degree of sophistication as far back in history as his efforts can be traced. The discovery of fire, the utilization of weapons for defense against animals and later for the hunting of food, the invention of the lever and the wheel, of weaving and of planting and harvesting crops represent some of the earlier successful attempts of man to better himself. There was, of course, no scientific approach behind these early developments, and they were evolved primarily out of necessity. However, it is not difficult to draw an analogy to today's modern industrial research environment where man strives for advancement and demonstrates a willingness to try new things to satisfy a need. Not until men had collected a great deal of information about the natural world, had improved their processes of pure reasoning, and had developed a thirst for knowledge could their methods become scientific.

Progress through many generations is marked by such things as the printing press, the steam engine, the cotton gin, and the electric generator. Furnas pointed out

For many generations science and invention evolved along parallel paths, with few crossovers. When the paths finally merged to an effective degree the inevitable result was an industrial revolution which is probably, even now, only well started. Inevitable, too, as industry became larger and its technology more complex, was the organization of
groups assigned the task of applying their full efforts towards welding scientific knowledge and inventiveness into new and better products and processes. Thus arose modern industrial research.\(^3\)

The day of the lone researcher, or inventor if you prefer, of men such as Samuel Morris, Alexander Bell, and Thomas Edison who gave us the telegraph, the telephone, and the electric light, appears to be essentially over. For the highly technological and scientific industrial complex of the sixties generally requires more knowledge and experience, more sophisticated and accurate equipment, and more financial backing than one man could ordinarily be expected to acquire. Thus, in the research laboratories which have evolved throughout the country, areas of specialization have developed in which one man or a group acting as a team handles only the problems in a particular field.

Complex research and development activities, as we know them today, began during the 1890's. When the Colgate Palmolive Company established a department for research in 1897, under Dr. Martin Ittner, it was only the seventh such industrial research laboratory in existence in the United States.\(^4\) In 1900 the General Electric Company and the United States Steel Corporation both established research laboratories for investigations into their company's areas


of interest. Since that time the growth of research has been phenomenal, with World War II contributing much toward the realization of its importance. Research and development expenditures in this country went from approximately $345,000,000 per year in 1940 to an average of $600,000,000 per year for the period of 1941 through 1945, excluding expenditures on atomic energy investigations. By 1955 the annual expenditure for research and development has increased to 4.64 billion dollars. However, even that amount is dwarfed by the estimated 21.3 billion dollars spent during 1965, and the projected eight per cent increase to an expenditure of 23 billion dollars for research and development during 1966. Of this amount, it is estimated that the government will supply 15.1 billion; that industry will finance approximately 7.3 billion; and that universities and other non-profit institutions will furnish the nearly 600,000,000 remaining, with industry contracting for approximately 9.2 billion of the government expenditures.

The continuous exploration of the vast scientific phenomenon holds the promise of many new and as yet unidentified discoveries which

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9 Ibid.
will provide greater productivity, a healthier existence and a longer life span, and more convenient and enjoyable living for everyone. The fulfillment of this promise rests in the hands of our industrial research and development laboratories. However, the real challenge which faces industry is the effective utilization of the resources being made available—the maximum possible return for each research and development dollar spent. Only in this way, can the true promise of our technological age be fully realized.

Statement of the problem

Dr. C. G. Suits, Vice President and Director of Research, General Electric Company (retired), expressed the philosophy that in today's competitive market you cannot have profitability in the long run without an effective research program. He noted that the research laboratory is no longer a status symbol in industry. He cautions, however, that great care is required to assure achieving the right match between the corporate objectives and the over-all research and development efforts, pointing out that just doing research, for the sake of research, can quickly lead a going company into bankruptcy. Dr. Suits points out that this is true not only because of the cost of the research effort itself but because of the technological loss to competition that a company will experience if its research and development program is not adequately pursued.\(^\text{10}\)

\(^{10}\) Keynote address given by Dr. C. G. Suits at the First Annual National Conference on Industrial Research, Purdue University, January 10 and 11, 1966.
That research and development is an essential for industrial survival in this technological environment is widely acknowledged and appropriately reflected in current writings. An editorial in Steel Magazine, for example, states: "Wise and intensive research is the best, if not the only, long run competitive weapon available." However, as Dr. Suits has warned, research for the sake of research alone can be an expensive if not fatal luxury. W. R. Hainsworth, Vice President, Servel, Inc., points out that

The ultimate goal of most industrial research is factory production. Success here means that the effort has accomplished its purpose; failure means that the time and material invested in the work have probably been lost. The modern industrial corporation, when it carries on research, expects eventually to profit from it in some way.

The above is a basic and underlying premise of this report. It is one that is reflected in much of the current writings which indicate that one of the more promising paths to increased profits and corporate growth is through the pursuit of research and development activities. Carl E. Barnes points out there is increasing concern on the part of security analysts and many investors, as well as corporate management, at the apparent large waste of research dollars and the general poor


12 Furnas, op. cit., p. 395.
return being recognized on this investment.¹³ David C. Minton, Jr. notes that research and development in the industrial complex is maturing, and, as associated with any degree of maturity, there is an increase in sophistication regarding the knowledge and attitude applied to different projects. He states that while management today is not as vague as it was only a few years ago, it still sometimes strays from the prime goals of the firm or government agency. He points out that it is still often difficult to convince someone that a particular project should not be undertaken, that it would not contribute to more efficient operation, expanded markets, or greater profit for the company.¹⁴

Within the framework of objectives established for the corporate research and development program, management can realize the desired results only through the careful selection of the projects which are undertaken. C. E. K. Mees wrote in 1920, "Healthy laboratories have more ideas than the company can possibly develop. The problem is one of selection and not of origination."¹⁵

A critical problem today remains that of selecting projects which, if properly pursued, will yield the desired results. The effectiveness of any research and development program in achieving the stated corporate objectives is only as good as the criterion


employed to screen, evaluate, and select individual projects for undertaking and the adequacy of the techniques or tools used in accomplishing this. However, selection is only the first step. Once effort on a project has been initiated, it is necessary to evaluate continuously and frequently the progress being made and to determine if the original benefits anticipated will still be provided by successful project conclusion.

**Purpose of the study**

The primary purpose of this study was to gather information relative to the current industrial practices in the evaluation and selection of individual research and development projects, with the objective of providing a better insight and understanding of this management decision process. In accomplishing this, an attempt has been made to gather information regarding the relative emphasis that is given the various objectives of research and development projects; to determining the general methods of project funding; and to establishing the degree to which the evaluation process is formalized or preplanned, as well as to specify the major parameters considered in the research and development project selection and to identify the frequency and methods used in assessing project progress. Limited consideration has been given to special situations which cause deviations to normal procedures and to the frequency of evaluation of the over-all research and development program. In examining the body of criteria used to screen and evaluate individual projects for incorporation into the company research and development program
portfolio, emphasis has been placed on the extent to which potential profit (return on the required investment) is utilized in the evaluation process. The factors considered essential for incorporation into a meaningful research and development project profitability analysis have also been identified and analyzed. Applications of this concept to periodic progress reviews and re-evaluations to decide whether a project should be continued or abandoned has also been explored. As a part of the over-all study, a review of some of the approaches that are available for conducting a profitability analysis has been included.

Although much of the recent literature supports increased planning and control of research and development undertakings, there still exists a strong school of thought that maintains to do so would ruin the freedom of the individual researcher and stifle the creativity which is so essential to project success.16 The objective of such planning and control is, of course, to increase the probability of selecting and pursuing those projects which will provide the desired results that are both useful and profitable to the corporation. However, these research and development management functions are both time consuming and expensive, varying in degree in accordance with the depth to which they are conducted. They, like the research effort, should pay for themselves. Therefore, a secondary purpose of this research study was to determine the degree of predictability of research and development in those companies whose management policy profile requires

that they plan their research undertakings, conduct a profitability analysis, and perform project post-appraisals versus those who do not meet this criterion.

**Hypotheses of the study**

Although primary emphasis of the study was given to an identification of the contemporary management practices regarding the evaluation and selection of research and development projects within American industry, the following specific hypotheses were investigated during the course of the study:

1. Within the framework of objectives established by the corporate long-range plan (or company policy, whichever is appropriate) potential project profitability is the major single factor in determining whether a research and development project will be undertaken.

2. Current practices for assessing the potential profitability of research and development projects are completely diversified within industry, varying from the use of quantitative and highly sophisticated models which allow the treatment of many pertinent factors, to the subjective or qualitative evaluation of a few selected factors with reliance primarily on composite management judgment.

3. Even in the cases where models, representing a conjectural explanation of the research and development project situation, are used for identification of desirability or profitability, the executive composite judgment is always made and plays a significant part in the final selection.
4. Techniques are available to permit the development of a general approach to research and development project profitability analysis which allows the incorporation of the essential factors necessary for a meaningful evaluation. However, published models to date are inadequate in terms of their treatment of all the necessary factors or are not sufficiently adaptable to specific industrial situations.

5. Those industrial concerns which select research and development projects in accordance with a written plan, conduct quantitative profitability analyses before the project is undertaken, and perform post-appraisal of the results obtained at the project level have results which are more predictable than those which do not, in terms of estimated cost and anticipated returns versus actual cost and actual returns.

Importance of the study

The rapid exploitation of the state of the art developments into industrial products and processes has made technology a factor of major significance in our competitive market. James R. Bright believes that technological change is the most powerful factor in the business environment today and that it is a power that seems to be continuously growing. He notes the following:

Unquestionably, our era of dynamic business change is based on technological progress. In this mercurial environment, traditional products, materials, skills, and production facilities are made obsolete in a few years and, in some cases, a few months. At the same time, new findings of science and achievements of
technology offer opportunities equally great. The cause for new technological advances seems endless. Thousands of businesses are going to rise or fall on the ability of their managers to respond effectively.\(^17\)

The competitive market forces resulting from research and development activities are of major importance to the individual companies which must operate in the environment and survive by assuring that they meet the challenge through their own corporate research and development program. There is, however, an even broader aspect of the importance of the subject which must be acknowledged—the influence of industrial research and development on the economic growth and stability of a nation. The impact of technological change would not be nearly so great if it involved only those companies whose competitive existence depended upon their research and development results. Viewed in this sense, one company's new product could simply be written off as its competitor's loss. However, it is the total aggregate impact of the ever increasing advancements of all industrial firms that represents a continued economic growth and stability for the future. Research and development not only influences the demand for goods and services through the creation of new products that serve as alternative means for satisfying general demand, but it creates products that often satisfy previously unknown demands.

The ramifications of industrial research are not limited to those companies which aggressively pursue their own program. There

are influences on suppliers as well as customers, on small businesses which do not maintain their own research facilities, and very frequently on other industries. It is this filtration of the effects of technology through all levels of economic activity that represents the key ingredients to future growth and stability. Since the end of World War II many of our basic industries which helped build the nation to the state that it is today, such as steel, glass, and forestry, have matured. Although they will continue to expand and to develop new products and new uses for existing products, as well as to increase the productivity of their current processing methods, it is unlikely that they will change drastically. However, many newer industries have developed and are rapidly growing as a result of modern research and development. Some, still only in the stage of infancy, owe their existence to more recent research and development activities such as cryogenics, nucleonics, and new material technology.

The late President John F. Kennedy, in his economic report of January, 1963, expressed a definite interest in the stimulation of industrial research and development. He indicated that research and development provides essential sources of increased productivity and that rising productivity is a major source of economic growth. He said that the federal government must now begin to adjust the imbalance in the use of scientific skills, and he proposed a number of measures to encourage civilian research and development in order to speed the application of science and technology throughout the civilian economy.\(^{18}\)

The large expenditures which have been made for research and development in recent years are by themselves significant to our national economy. However, such expenditures are dwarfed when viewed in the light of the "multiplier effect" which research and development has had in terms of technological change in products, processes, and industries. Unfortunately, the expenditure of large sums of money does not necessarily mean that it is being used effectively, particularly in view of the quotes that are given for the ratio of successful projects to unsuccessful ones. These vary from one in forty to one in ten. Dr. Charles H. Moore, Executive Vice President of the International Copper Research Association, warns that the biggest fallacy is that more research dollars buy more results. He states that until you are reasonably certain that you can obtain results, you should not commit your money, since research must pay for itself in terms of accomplishment.19

In order for the national economy (as well as the individual company) to recognize maximum benefits and growth from research and development expenditures, it is necessary for those concerned with industrial research management to ascertain whether the investments being made in individual projects are worthwhile and whether the total scientific effort is proceeding with maximum effectiveness. In discussing the effect of research and development on the economy and its social productivity one writer noted that there is a need for the

nation and for the individual companies to direct the research and
development effort to projects of greatest urgency and to achieve
optimum progress.\textsuperscript{20}

It should be readily obvious that for our national economy,
and society in general, to realize maximum benefits from the research
and development expenditures of our technological age, industry itself
must first grow and prosper from such undertakings. The responsibility
for this lies, of course, with those who manage their corporation's
technical efforts and shape and guide the direction which it takes.
The industrial research managers of today are perhaps administering
the most powerful factor of growth the world has ever known, exceeding
by far the early contributions of technology and science and that of
the vast land frontiers which once existed. Dr. Raymond Villers stated
the following

All decisions made by research people have
an effect upon the profit of the enterprise. The
wrong decision means lower earnings; the right
decision means higher earnings. The most
significant decisions deal with the selection of
projects, and the determination of the amount of
research time allotted to them.\textsuperscript{21}

This study is concerned with the identification and understanding
of the pertinent decision factors of concern to industry in the selection
of individual research and development projects for the accomplishment of
specified company objectives. This could provide assistance and direction

\textsuperscript{20} D. M. Mack-Forlist, "R&D ... and Industry?" Mechanical
Engineering (December, 1964), p. 17.

\textsuperscript{21} Raymond Villers, Research and Development: Planning and
in greatly increasing the efficiency of the corporate research and
development investment, lead to even more rapid realization of desired
technological advancements, and enhance competitive effectiveness.
Increased stimulation of economic growth and prosperity would naturally
follow.

Limitations of the study

The broadness of the subject of industrial research and
development, involving as it does many disciplines and all organic
functions of business operation, necessitates as much limitation as
possible. Therefore, the scope of this study has been essentially
limited to an investigation of the management functions of research
and development project selection and progress evaluation in profit
motivated industrial enterprises. Although the growing importance of
research work performed under government contract (an estimated 55
per cent of the total industrial research and development expenditures
for 1966) is acknowledged, the primary purpose of the study is
concerned with those organizations performing research and development
for internal corporate use. Therefore, consideration of projects
pursued under a contractual arrangement has been excluded.

In order to define a universe which would provide both
meaningful and significant study results, the 500 top industrial
corporations, as listed in the July, 1964, issue of Fortune Magazine,
were selected. This selection was not arbitrary but was based on logic
and the findings of previous studies. To start with, the fact that
large companies are likely to do most of the research spending is a
simple matter of economics. Research and development usually involves a large research staff, heavy capital outlay, with special production and marketing costs (and risks) that go with a really new product or process. In addition, it can reasonably be assumed that such organizations have a larger research and development staff and have been performing such activities for a longer period of time than some of the smaller industrial concerns. It seems a logical consequence that such organizations would have evolved more sophisticated research and development management procedures as a result of their experience with time and the inherent problems of size. A study conducted by the National Science Foundation indicated that out of an estimated 11,800 industrial firms performing research and development, 300 manufacturing companies, with the largest research and development programs in terms of dollars, accounted for 91% of the funds for industrial research and development performance. The same 300 companies reported 61% of the net sales, and 60% of the employment of manufacturing companies with research and development programs.22

A determination of what the corporate basic policy or long-range planning objectives should be in relation to the scope and goals of their research and development program is considered outside the scope of this paper. This will depend entirely on the nature of the business, its willingness to expand and make capital investments, and its ability to utilize effectively the results of successful research

22 "Funds for Research ....", loc. cit.
and development efforts. The relative emphasis given various research and development factors within this framework has been investigated, since it directly influences the selection process.

The organization of an industrial research and development laboratory and its relation to the over-all corporate structure was not a prime area of study. Although the subject is discussed briefly in Chapter III, it is primarily for the purpose of orientation and to show its relative insignificance to the selection and progress evaluation functions.

The subject of the hiring, training, and utilization of scientific and technical personnel, together with human relation aspects of operations in the laboratory, have been excluded from this paper, even though they are certainly of significance in the over-all research management perspective.

The techniques and goals for obtaining over-all corporate research and development program balance in terms of high-risk versus low-risk projects, short-run versus long-run projects, product innovation versus new product line projects, pure research versus applied research versus development projects, have not been investigated. It can reasonably be assumed that management strives to have the over-all objectives the corporation desires to achieve through its research and development program represented by a cross section of the individual projects at any given time and to adequately reflect the balance that is required by the long-range plan. The areas for which the over-all program balance is reviewed have been given limited treatment, since they can also directly influence project selection.
The study is limited to industrial research as it pertains to the physical sciences; other areas such as marketing research are excluded.

The study has been limited to the management aspects of the subject. These are to be differentiated from, although they are related to and depend on, the methods and techniques used in actually conducting the scientific and technical evaluation of proposed research and development projects. The judgment process by which such technical decisions are made would be difficult to cover in one scientific discipline, let alone throughout the entire spectrum of physical sciences with which the selected universe is concerned.

Fundamentally, the study relates to the evaluation and selection of research and development undertakings at the project level. It will deal with other considerations only as they influence, and are influenced by, the major area of study.

Methodology used in developing this study

Both secondary and primary data were gathered during the course of the study, with an analysis and synthesis of the latter being the most important in development of the final report. However, the first major step was to conduct a comprehensive review of existing literature on the subject of industrial research. A prime purpose of this review was to become knowledgeable in the area and to provide a frame of reference for the author to enable development of the concept and philosophies under which the study was to be continued. Another
important aspect of the literature review was to reveal what had already been accomplished in the area of this study and to identify current thinking and philosophies as they had evolved over the years.

Library card catalogues were searched and abstracting bulletins were reviewed in order to obtain references to appropriate material. The review was initiated with broad readings in the general area of industrial research and development management and administration in order to gain the over-all background required. Later the review was narrowed to those areas of particular interest to the subject. Here, the periodicals proved most valuable, especially in reflecting current thinking and the actions that were being taken in different industrial concerns. In addition to the above, the theory presented in general management textbooks was also reviewed. Through this approach, a better understanding of the subject was developed and an indication of the originality of the area of investigation and the approach that had been outlined was provided.

As stated previously, primary research was the main method of data collection utilized in the study. Three approaches were employed in essentially a concurrent manner: (1) intensive interviews were conducted with corporate executives in the vanguard of research and development management activities, (2) a conference on industrial research was attended, and (3) a comprehensive questionnaire was prepared and distributed to a random sample selected from the universe under study. As a part of the planned interview approach, the author personally visited the research and development laboratories of eight
different corporations selected from the universe and conducted intensive interviews with 35 top research and operating executives in these concerns. The positions of the persons interviewed varied according to the specific corporation but in general included the following:

- Vice President, Research and Development
- Vice President, Long Range Planning
- Director of Corporate Research and Development
- Director of Research
- Director of Development
- Director of Product Planning
- Director of Marketing Research
- Controller

The selection of corporations to be visited for on-site investigation and data collection was not random but rather quite purposeful. The author's fourteen years of experience in applied research and development engineering, in positions ranging from project engineer to section chief and head of a staff office for research and development planning, had led to the conclusion that the management functions of primary interest to the study were independent of the type of industry or technical field of interest. The literature review also tended to confirm this. Dr. Villers, for example, concluded that, contrary to general belief, the fundamental problems of research management are not related to the kind of industry, the type of product, or the size of the
company but are related to the special characteristics of research and development operations. It was, nevertheless, considered highly desirable to validate this conclusion as a part of the interview process if it could be accomplished without compromising other objectives.

In order to maximize the variety of situations about which data were collected, it was considered desirable to visit those companies conducting research and development under government contract as well as those conducting such activities for their own internal use and profits. Another selection objective was that of visiting companies where, because of the nature of their industry, it was required that they undertake a relatively large amount of pure or basic research. The final selection criterion related to the desire to study companies conducting research and development at the division level as well as those performing this function at a centralized corporate facility.

The companies visited were selected from fundamentally different types of industry in such a manner as to satisfy the above objectives. Their primary areas of interest may be generally classified as follows:

- Appliances and industrial equipment
- Chemical products
- Food products
- Glass products

23 Villers, op. cit., p. viii.
Office machinery and computers
Packaging products
Paper products
Pharmaceutical products

A great deal of the information discussed was considered company confidential and a promise was made not to reveal any sources of data. In order to preclude an identification of specific organizations from the discussions contained in subsequent chapters, the corporations visited are included in an alphabetical listing of all participating companies as found in Appendix A. The companies at which interviews were conducted lose their identity when combined with a listing of the questionnaire respondents.

In establishing interview appointments the initial contact was made by a person-to-person telephone call to the principal corporate research and development executive. If a meeting was agreed to, a time and date were established and a follow-up confirmation letter was mailed to the individual contacted, together with a one-page prospectus which outlined the purpose and approach of the study. It was felt that the advanced receipt of this prospectus would enable the company to understand better the purpose of the study and to be more prepared for the meeting and have the appropriate people available. If an individual contacted by telephone did not agree to a personal interview (three refused on the basis of company policy), as much information was obtained during the telephone conversation as could be. This, as appropriate, has been incorporated into the report.
The interview was opened with a review of the purpose and objectives of the study, together with questioning aimed at reaching common ground from the viewpoint of semantics. A line of questioning was pursued which led from the general aspects of research and development management to the specific area of interest to the study. The interviews followed a non-structured non-disguised pattern, with the interviewee being encouraged to discuss freely all aspects of the subject which he considered to be significant. To ensure that all aspects were adequately covered, a 52-question interview guide was also employed. Extensive notes were taken and were tape recorded immediately after the interview for subsequent typing. An attempt was made to complete the interview with one corporation in a single day; however, three organizations had to be revisited because of the lack of availability of key individuals.

In order to obtain additional first-hand information, the author attended the First Annual National Conference on Industrial Research, co-sponsored by Industrial Research Magazine and Purdue's Krannert Graduate School of Industrial Administration, held at Purdue University on January 10 and 11, 1966. The central theme of this conference was "Corporate Research and Profitability." This enabled first-hand observation of the areas of interest and current concern, as expressed in the papers delivered and the questions asked. Three

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case histories were presented on corporations from the universe being studied as follows:

1. Westinghouse Electric, represented by —
   M. K. Evans, Vice President, Operations Services
   W. E. Shoupp, Vice President, Research
   G. G. Main, Vice President, Finance

2. B. F. Goodrich Company, represented by —
   Arthur Kelly, Executive Vice President
   F. K. Schoenfeld, Vice President, Research & Development
   J. N. Hart, Vice President and Controller

3. Xerox Corporation, represented by —
   J. H. Dessauer, Executive Vice President, Research and Engineering
   E. K. Damon, Vice President, Finance
   M. J. Kami, Vice President, Planning

In addition to the above, attendance at the conference gave the author an opportunity to participate in discussions between persons from various corporations who were concerned with research and development administration and to question these individuals in regard to their opinions and company practices. After the conference adjourned, an extra day was spent on the Purdue campus in order to obtain the thoughts and ideas of members of Krannert school faculty. Of particular significance, were discussions held with Professor E. A. Pessemier regarding pertinent aspects of a new book he has just
completed and a computer program he is working on that utilizes cash flow techniques to provide an estimate of potential project profitability.25

The primary data collected during company interviews, augmented by the valuable information obtained at the Purdue Conference, have been analyzed and synthesized into discussions, which will be presented in subsequent chapters.

Development of the questionnaire

The first step in the development of a suitable questionnaire, to which considerable time and effort were ultimately devoted, was a review of the extensive notes taken during the literature survey. As this was accomplished, a full realization of the magnitude of the problem being undertaken clearly unfolded. Not only did the question of semantics have to be overcome, but the questionnaire had to be sufficiently challenging and short enough to solicit a favorable response yet provide meaningful and significant information for use in the study.

Originally 72 questions were compiled as potential candidates for incorporation into the questionnaire. These were screened and evaluated to eliminate duplications and overlap, combined where appropriate, and grouped into a logical order to form the initial draft, which was obviously far too long. This initial draft was

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discussed in detail with a fellow student and with professional associates. In addition, a meeting was arranged where the questionnaire approach, format, length, and specific questions were discussed and reviewed with Dr. J. C. Yocum, Director, Bureau of Business Research, and Dr. R. M. Stogdill, of the Bureau of Business Research, The Ohio State University.

As a result of the constructive criticism and valuable guidance received at the above meeting, together with the many meaningful comments and suggestions received elsewhere, the questionnaire was reconstructed. After several additional revisions, the questionnaire had been reduced to 15 key questions and was considered to be in a form suitable for field testing.

A pre-test mailing of 35 questionnaires was made to corporations selected at random, using the cover letter intended for use in the final distribution. Seventeen replies were received in slightly over five weeks. The field test indicated that some revisions were required and the questionnaire was subsequently restructured. In the pre-test questionnaire several questions had been combined in the interest of brevity. Comments provided with the returned test questionnaire, together with some complete blanks, indicated that two questions had been very poorly stated and were confusing to the recipients. From the viewpoint of clarity and ability of the respondents to provide the information requested, it was decided that several questions should have been used instead of one. Therefore, at the sacrifice of some brevity, the questions were reworked. Also, two additional questions were added.
The proposed changes were discussed with the author's program committee and final validation of the questionnaire acceptability was accomplished by working closely with three industrial research and development administrators. Before the questionnaire evolved to its final form, as reflected in Appendix B, the author had the opportunity to incorporate the experience gained from four company interviews and attendance at the Purdue Industrial Research Conference, as well as the literature search upon which the initial draft was predicated.

The questionnaires were dispatched to 165 American corporations selected from the "500 Largest Industrials." The corporations in this listing are categorized on the basis of total sales. For those companies selected, a questionnaire was sent, marked personal, to the principal corporate research and development officer. In the majority of cases this was the company Vice President for Research and Development, although in several instances it was to the Director of Corporate Research (and Development) and in two instances, where a principal research and development officer's name could not be obtained, it was sent to an Executive Vice President. It is felt that this technique solicited a more favorable response than would have resulted in simply sending the questionnaire to the selected companies without specific direction to any one corporate official. Appropriate company executive's names for the selected corporations were obtained from

Poor's Register of Executives and The Decision/Job Directory, although in a few cases other sources had to also be utilized.\footnote{Poor's Register of Executive's and The Decision/Job Directory, (New York: Standard and Poor's Corporation, 1965), selected pages. Decision/Job Directory (Cincinnati, Ohio: Decision, Inc., 1965), selected pages.}

Statistical exactness was not required or necessarily desired for a major portion of the study because of the nebulous nature of research and development management activities, the myriad alternatives of possible critical project selection and evaluation criteria, and the specific long-range objectives and requirements of the different corporations which require the tailoring of individual research and development planning and programming to fit the situation. Rather, it was intended to gather information from an adequate number of large American industrials to determine such things as the general objectives and goals expected from a research and development program, the degree to which projects are selected in accordance with a plan, the factors used in the selection process, and the parameters considered important in conducting a profitability analysis, if one is made. It is well accepted that the subject is difficult and controversial in nature and that many varied opinions and different experiences would be encountered.

However, in investigating the fifth hypothesis regarding project profit predictability, a determination of the statistically significant difference between the two groups seemed to be the most valid way of approaching the subject. The corporations solicited, therefore, were selected from the population by a random sampling technique. The
respondents were classified in one or the other groups to be studied in accordance with the manner in which they answered certain questions. Group A and Group B were established in order to permit the above investigation and each individual questionnaire was placed in the appropriate group. The mandatory requirements for entrance into Group A were as follows:

1. Selection of proposed individual research and development projects in accordance with a written plan (A. GENERAL INFORMATION).

2. Utilization of some type of quantitative method in estimating potential project profitability, at least on a selected project basis (Question number 4).

3. Comparison of estimated costs and returns with actuals through project level post appraisal for at least a limited number of selected projects (Question number 18).

Group B includes all respondents not meeting the criteria for classification into Group A. Group B respondents may, therefore, possess none, one, or a combination of any two of the above characteristics. No attempt was made, however, to analyze the Group B replies in accordance with this level of detail, since the investigation was concerned primarily with the study of those companies having a complete management policy profile as defined versus those which are incomplete.

It was assumed at the time of distribution of the final questionnaire that at least 40% of the businesses solicited would

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28 See Appendix B, "Questionnaire Summary."
respond favorably and provide information suitable for use in the study. Based on this assumption, a final questionnaire mailing of 165 was made, in expectation of a minimum response of 66. In addition, a one-page supplemental questionnaire was prepared which, if completed, would augment the pre-test format and bring it up to an equivalent of the information requested in the final questionnaire. These were mailed to the nineteen pre-test questionnaire respondents with a letter of explanation. From the total 200 questionnaires that were mailed, 107 usable replies were received out of an over-all response of 130, not including letters of refusal. From the 107 usable questionnaires, 51 were classified in Group A and 56 were placed in Group B. An alphabetical listing of all companies participating in the study is presented in Appendix A.

Each of the four sources of gathering information employed in this study has its own limitations. Obviously, the principal limitation of the interview approach is that insufficient different situations can be explored in a reasonable period of time to permit over-all generalizations on how prevalent a certain practice or concept may be. The conference attendance, while being broader in scope from the viewpoint of the number of contacts, suffered from the limitation of available time with certain specific individuals. Also, the cases presented while pertinent in many aspects did not cover all areas of the study. Obviously, the questionnaire has the disadvantage of written communication while at the same time being limited to a relatively few questions which can be answered definitely and
objectively. The literature has the ever present problems of relevancy and objectivity, including contents which present only what the author elects to discuss and then from his viewpoint.

Nevertheless, an attempt was made in this study to utilize the different sources of information in such a manner as to enable them to complement one another. For example, the answers to the questionnaire indicate the number of organizations which perform a profitability analysis as a part of the selection process; the interviews and the discussions held at the Purdue Conference provide an insight as to how specific companies prepare these and use them, and how significant or insignificant they are in the opinion of the persons who have final authority; and published articles frequently describe the use of such techniques in organizations not visited.

In order to present the research results in as objective a manner as possible, all of the tables shown in the subsequent chapters were developed solely on the basis of the questionnaire replies. No attempt was made to incorporate the interview findings into the data given in any tables.

Definitions

Throughout the course of this study a general lack of accepted terminology regarding the various aspects of the industrial research and development activities became obvious. Although there have been many attempts to develop standard definitions, including a set issued by the National Science Foundation, the terminology continues to have slightly different meanings to different people and varies from company
to company. In fact, in two companies visited it was found that the terminology carried a different connotation at the Vice President level and at the level immediately below. The problem of clean-cut differentiation is attributed, of course, to the fact that between what is clearly one type of effort or another lies a large grey area, which in practice is continuously penetrated in both directions.

While it is not the intent of this study to resolve the terminology problem which exists, several of the important terms that are employed require specific definition as they are used in this study in order to provide a frame of reference for the reader.

Research and development. Basic and applied research in the sciences and engineering as well as the design and development of prototypes and processes. Excluded from this definition are routine product testing, market research, sales promotion, sales service, research in the social sciences or psychology, or other non-technical activities or technical services.29

Industrial research (and development). The myriad of activities included under the above definition, as they are performed in the industrial complex, either under contract or for the internal corporate use.

The differentiation between industrial research and institutional research is a matter of motive. Mees and Leermakers state that the

29 "Funds for Research ...," loc. cit.
distinguishing feature of an industrial research laboratory is one of intention and not one of method with the intention being to apply the research results.\textsuperscript{30} C. C. Furnas, in stating the same thing, notes that an industrial research laboratory has its objectives directly connected with the future welfare of the specific company which supports it, particularly in regard to ultimate profits.\textsuperscript{31}

\textbf{Research.} The application of human intelligence and reasoning, aided by modern equipment, to a systematic process of critical and exhaustive investigation of a problem whose solution is not immediately available or to a study and understanding of fundamental scientific relationships. Research may be performed in an attempt to gain knowledge or to discover new and better ways of doing things. It is generally accepted that research may fall into one of two categories: basic and applied.

\textbf{Basic research.} Original investigations, studies, and experimentations of the fundamental laws and phenomena of nature in an attempt to gain new knowledge or achieve additional information about the basic relationships in the various sciences. Attempts have been made in some of the literature to differentiate between pure research, basic research, and fundamental research. Although certain

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\textsuperscript{30} Mees and Leermakers, \textit{op. cit.}, p. 7.  \\
\textsuperscript{31} Furnas, \textit{op. cit.}, p. 2.  
\end{flushleft}
fine points of difference can be identified, such classifications would serve no useful purpose in this report. Therefore, the terminology may be considered as synonymous.

**Applied research.** Investigations that utilize available basic information and established scientific principles and techniques in an attempt to solve a practical, predetermined problem. While basic research indicates that a certain result may be possible, applied research moves the obtaining of that result from the realm of possibility to high probability or accomplishment. Successful efforts in applied research result in new and improved ways of doing things. Within the industrial laboratories, applied research efforts could be directed towards new or improved products or processes, presumably undertaken in expectation of a profit, a cost reduction, or a valuable intangible.

The classic distinction which appears to be drawn between basic and applied research is one of purpose, with basic research being conducted primarily to advance knowledge and applied research being undertaken in order to apply to some practical end the technology evolved. Killeffer states that the most important difference is that the researcher in pure science is free to explore any by-paths that may attract him; while the worker in applied science must continually direct his attention and confine his energies to achieving his specified objectives. He further notes that in applied research questions of
time and expense continually limit the freedom of the worker to follow his fancy into side issues.\textsuperscript{32}

It is considered extremely unlikely that industrial laboratories allow any sizable number of researchers, even those working solely in the basic science area, to pursue any investigation which may strike their fancy. Basic research is sponsored by industrial corporations because of the necessity to keep abreast of the state of the art in the fields of their present or potential technological interest and with the expectation that such knowledge as may be obtained will ultimately have valuable application—it is certainly not what could be considered the seeking of knowledge merely for the sake of knowledge. It is not uncommon, however, to encounter a situation involving a predetermined problem or specified objective having commercial application but for which the required scientific knowledge is not available. The question must be asked, therefore, whether any research activity undertaken on the basis of a specified objective or predetermined commercial application can be classified as "pure." To reply in the negative would be to deny the existence of pure research within industry. This is not felt to be the case since a large body of fundamental knowledge is continuously being evolved by industrial research activities. The author feels that emphasis should be placed on whether the basic information, scientific principles, or techniques were available at the outset of the research effort or

had to be evolved as a necessary prerequisite to fruition. The latter, of course, constitutes basic research types of investigations.

**Development.** The technical activity required to convert applied research results, or other available scientific knowledge, to the point where it has practical application and usefulness. For example, if applied research was carried to the point of a first successful working model, the series of successive refinements required to translate the working model into a marketable product that could be economically produced is considered as development. It is the last phase of effort prior to release for full-scale production and includes the nonroutine testing required to ensure that the desired function, reliability, and quality are inherent.

The ability to identify clearly the end of an applied research phase and the initiation of the development effort is frequently found to be as hazy as the difference between basic and applied research. One research director pointed out the critical time lag between the start of a project and the introduction of the resulting product into the market or the derived process into factory production. He stated that in attempts to shorten this time span, his company has integrated the various research phases to the maximum practical extent. For example, when reasonable confidence is obtained that a working product model can be constructed, it is built with all production and marketing factors in mind. Styling, materials, and production tolerances are all considered, with the process specification and inspection procedures being developed simultaneously. He admitted that this approach lengthens
the time required to obtain the first model but stated that it tends to shorten the over-all cycle because production redesign is all but eliminated (some minor changes are not uncommon), it enables life and reliability testing to start earlier, and it facilitates debugging. Also, on larger projects it is frequently found that different phases of effort involve concurrent activity at different levels of research.

Exploratory or feasibility study. That activity necessary to determine whether an adequate baseline of scientific and technical knowledge is available to warrant undertaking a proposed project and, if appropriate, to estimate the probability of technical success and determine time, manpower, and other resource requirements. Although no distinction is made in this report, the author considers an exploratory study as being preliminary to an applied research undertaking and a feasibility study preliminary to a development effort.

Engineering trouble shooting. The post development support activity provided to other operating divisions of the company or customers by technical personnel assigned to the research and development organization in order to assist in solving problems of production or use after the development phase has been completed and the project results released for full-scale operation. Pilot plant setup and operation are excluded and would normally be considered a part of the development effort. Also, routine technical services, such as equipment installation or maintenance, are excluded.
Once again, however, the terminology employed does not enjoy universal acceptance or even recognition as a separate phase of effort. It was pointed out in one company visited that the company does not consider the development phase complete until all of the "bugs" have been worked out—if problems arise after the books have been closed, it only serves to illustrate that an error in judgment had been made.

**Project.** A distinct unit of research or development effort which is undertaken to accomplish a specified scientific or technical objective. Such an objective may involve problems the solutions to which are not readily obvious or may seek to acquire information or knowledge which is unknown, inconclusive, or uncertain at the outset. A project may involve a single experiment or investigation that can be accomplished in a relatively short period of time or it may involve extensive study, numerous experiments, and testing taking place over an extensive period of time.

**Project task.** A separate unit of technical activity accomplished as a part of the over-all project effort to achieve a subordinate objective which supports the primary project objective and without which the project could not be successfully completed. Project tasks may be undertaken sequentially or concurrently; they may be large or small in terms of the time and effort required; and they may relate to any level of research and development action. The task objective
may be such as to have no independent value except to support the project objective or it may possess value of its own such as a component which could be used on other products.

**Task element.** A distinct unit of technical effort which must be completed in order to conclude the task which it supports. It may be defined the same as a task, except that elements relate to the task level of activity rather than the project level. Such task elements may, of course, be further broken down into one or more subordinate tiers or subelements.

**Research and development program.** The aggregate of approved scientific and technical effort, including all projects, engineering trouble shooting, and study activity (or time allotted for studies). If the company allows free time (and funds) to the scientists and engineers to investigate and experiment in areas of their particular interests, this should also be considered as a part of the over-all program.
CHAPTER II

CONCEPTS OF INDUSTRIAL RESEARCH MANAGEMENT

Introduction

In examining the current research and development management practices in American industry several preliminary concepts and factors must be briefly investigated in order to develop a proper conceptual framework of reference. This chapter will acquaint the reader with areas of the process of industrial research management that are pertinent to the study undertaken and will provide a background for a review of the findings that are presented in subsequent chapters. Source material for this chapter was derived primarily from a review of related research and the existing body of contemporary literature.

One of the hypotheses investigated during the study states that techniques are available to permit the development of a general research and development project profitability model which allows the incorporation of the factors essential for a meaningful evaluation, but that published models are inadequate in their treatment of all the necessary factors or are not sufficiently adaptable to specific industrial situations.
An appropriate heuristic model would represent a conjectural explanation of the situation and would enable pertinent factors to be quantified for mathematical synthesis. However, before an analysis of the above hypothesis can be pursued it is necessary to define the functions of the model and to identify the factors which it must accommodate. A criteria for model selection has therefore been developed and included in this chapter.

Conclusions regarding the adequacy of existing quantitative profitability models can be derived by comparing the capability of such models to the selection criteria. A discussion of such comparisons is presented. In addition, a summary of selected models which have been proposed for estimating project profitability has been included for the information and convenience of the reader and to provide a better insight of the research findings which are presented in Chapter V.

Planning the selection procedure

One of the major problems that confronts every industry engaged in research and development activities is that of selecting the projects to be undertaken. Indeed, the success or failure of the research and development department, and perhaps ultimately of the company itself, will depend to a large degree upon the wisdom of the selections that are made. Quinn states

Proper selection of research projects is the key to research success. Unless researchers are working on the right problems, even the most outstanding research personnel,
motivated, organized, and controlled in the best fashion, will not make a maximum contribution to the sponsoring concern.¹

Research and development projects should, in general, support the corporate objectives, and a cross section of the over-all program should represent a balance of the desires and achievements that management expects from its laboratory. However, most research and development organizations have more ideas presented which conform to the above broad screening criteria than can possibly be undertaken. In establishing the research and development program, therefore, every means possible must be taken in determining the relative merits of proposed projects in order to optimize the selection between the many alternatives. Of course, it must be recognized that the amount of information required to complete an evaluation will vary from project proposal to project proposal. Some of the projects presented may be immediately recognized as undesirable for a particular company to undertake. On the other hand, a few projects presented may be approved just as readily, not only because the idea may be a good one, but often because they are absolutely essential if the company is to meet competition and stay in business. When talking in terms of extreme cases, it is not always good to talk in terms of generalities. However, it is believed that the majority of the projects submitted for evaluation fall somewhere between the two extremes and will, therefore, require more careful study.

The significance of project evaluation and the importance of considering all pertinent aspects of proposed undertakings are clearly acknowledged in most of the current literature. Hertz, for example, states that project proposals made to management should include all information available on which a decision may be based, as well as the opinions of those concerned as to its merits, and that all who have an interest are required to give a consensus as to the organizational attitude.² Killeffer states:

Clearly, all the facts that one can muster plus every bit of experience, whether his own or someone else's, that can be brought to bear upon the problem of evaluation are seldom quite enough to take all the gamble out of the future, even the future of a research based project.³

Obviously, in accomplishing an evaluation there should be a predetermined method of attack and some yardstick upon which to base a decision. Equally apparent to the writer is that this can be most effectively accomplished in a consistent, repetitive manner by adherence to a written plan which is to be followed in the evaluation and selection process. Not everyone, however, subscribes to the philosophy of having a written plan. Mees and Leermaker, for example, while they acknowledge that a successful system of evaluation would be desirable and would greatly simplify the assignment of work priority, state that such formal systems are usually inadequate in their flexibility and create


a restrictive environment. They warn that "...excessive screening by some formal means may have a tendency to eliminate all but the mediocre and relative sure projects."^4

Anthony, on the other hand, states, "An advantage of considering a project proposal in terms of a standard pattern, such as a check list, is that such a process tends to assure that all relevant factors are brought out. Without such a device, the evidence may be limited to the often over-enthusiastic opinion of the originator of the idea."^5 William B. Reynolds, Vice President for Research and Engineering, General Mills, Inc., favors the subjective executive judgment approach to the selection of research and development projects. He states, "The basic fallacy of the quantitative check list approach is the fact that often a single factor is so compellingly important that a 'go' or 'no-go' decision must be based upon that one factor alone." He maintains that the check list approach leads to relatively sure but highly conventional results, pointing out that post analysis of projects which have led to major breakthroughs have shown that (by applying the method of analysis) they had everything wrong and should never have been undertaken.^6

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5 Robert N. Anthony, Management Controls in Industrial Research Organizations (Harvard University Graduate School of Business Administration, 1952), p. 119.

Furnas, who fundamentally favors following a plan as a guide to the project evaluation and selection process, acknowledges the fact that research, by its very nature, cannot be tailored to any set pattern and that methods for selecting research projects will present different problems in different organizations. He states:

The lack of complete adherence to the proposed plan is an earmark of sound judgment. Any plan proposed for choosing research projects must be broad enough and possess sufficient freedom to permit functioning in various types of emergencies. It is probably with good reason that some organizations become opposed to rigid and unyielding plans for selecting research projects.7

The author strongly feels that the establishment and general adherence to a comprehensive, well formulated plan for project selection can provide significant benefits to an organization. The fact that some evaluation plans are inflexible and have resulted in a restrictive environment is not a basic fault of having an established plan, but rather it is due to the inadequacies of the plan itself and to the management group which has allowed its thinking and operations to be too closely bound by such a plan. It is acknowledged that in certain cases it will be readily apparent that some projects should (or must) be pursued and in other cases they should not be undertaken. However, as previously pointed out, the large majority of projects proposed are not nearly so clear-cut. A carefully formulated plan assures that all

significant aspects of proposed candidate projects are given proper consideration and that any information having a pertinent bearing on the situation is obtained from knowledgeable people within the organization or, if required, from outside sources such as consultants.

The flexibility required for efficient laboratory operation can and should be incorporated into any research and development evaluation plan. It would be foolish, for example, to attempt to conduct a detailed market profitability analysis for a basic research project where at best only general results can be foreseen. Similarly, where a development project result has a known application, a high probability of success, and is of relatively short duration with correspondingly low cost, it would be equally as foolish to expend almost as much manpower in a formal evaluation and review as would be required to pursue the effort to a conclusion. Provisions in the selection plan which allow for approval at various organizational levels and which reflect appropriate variance in the extent and degree of detail required for approval can easily provide the required flexibility. This is usually a function of the level of research activity involved, the project duration, manpower requirements, costs, and the ultimate significance of the project to other operating aspects of the corporation.

References to an established evaluation plan resulting in the selection of relatively sure, but highly conventional, projects reflect a lack of appreciation for the real benefits to be derived from having such a plan. Examples are given of highly successful projects which,
when subjected to an after-the-fact type of planning analysis, have been shown to be proposals that would have been rejected. It is suggested that something is basically wrong with the method of analysis, the information which was used, or in the management policy regarding the acceptable level of risk. Any plan will only give an indication of a greater or smaller probability of success based on the knowledge available. If management rejects five projects because they have only a 20% probability of success, it is still likely that one of these could be successful. The question must be asked as to whether intuition alone is a sufficient substitute for thorough analysis. The rejection of a potentially profitable project can be just as undesirable as the approval of a project which turns sour at a later date.

It should not be the purpose of an evaluation plan to eliminate risks. Rather, such a plan should aid in the identification and proper assessment of the risks involved in order to minimize unwise efforts and to assist in selective risk taking. The amount of risk assumed should, of course, be proportional to the potential profitability and may well be a matter of corporate policy. Over-all program balance in terms of the various project risks can be established accordingly.

The desirability of preparing a written project proposal to be submitted and reviewed for approval has long been recognized. Hertz, for example, maintained that the information which should be included in a proposal submitted to management for undertaking a research and development project should include (1) estimates of the personnel and material resources required for its solution, (2) the feasibility
of obtaining a solution, and (3) the results to be anticipated if the problem is solved. Bush and Hattery state that the various projects should be described in concise but comprehensive terms, preferably by following an outline consisting of a suitable short title, a brief statement of objectives, a plan of attack, a description of the related aspects of the work on other projects or in other organizations, and an estimate of the manpower requirements. Anthony also advocates the utilization of written research and development project proposals, but recognizes that depending on the level of research activity (end of the research spectrum as he phrases it) different consideration should be provided for and different types of information should be included in the proposal.

While there is general agreement that a written proposal for projects at the development end of the spectrum is desirable, this approach is not nearly so uniformly endorsed in the basic research area. Furnas maintains that once a broad area of investigation has been defined, the remaining activity is up to the individual scientist who is conducting the project and is largely a matter of inspirational guidance. That this is a significant factor in the successful pursuit.

8 Hertz, loc. cit.
10 Anthony, op. cit., pp. 112-126.
11 Furnas, loc. cit.
of basic research will not be disputed in this paper. However, the question must be asked as to what type of planning, in terms of specific objectives, time, and money, will assist in effectively accomplishing basic research undertakings. On this point too, there is significant disagreement.

Mees and Leermaker go so far as to say that any attempts to select basic research projects by methods similar to those used for applied research and development projects (defining objectives and planning in terms of time and money) are not only useless but in fact harmful. ¹² E. S. Hiscocks states that he is not nearly so certain that the planning of basic research projects is useless, and, in fact, he proposes an approach for its accomplishment. ¹³ Bush and Hattery maintain, "It is not far fetched to state that, even in the case of purely fundamental research, there is room for improvement in the selection and guidance of projects." ¹⁴ Anthony acknowledges that the cost or time required to carry a basic research investigation through to a successful conclusion usually cannot be predicted. However, he states, "It would be incorrect, and dangerous, to infer that it is impossible to do any planning for basic research projects." He maintains

¹² Mees and Leermaker, op. cit., p. 214.


¹⁴ Bush and Hattery, op. cit., p. 51.
that useful statements can be made about the general objectives of
the investigation, the magnitude of the attack that is proposed,
and the time required to complete the various phases of this attack.\textsuperscript{15}

There is also a difference of opinion reflected within the
literature as to the manner in which the selection between alternative
projects, all of which meet minimum criteria, should be made.
Strasburg points out: "... generally the selection decision is
revolved in favor of the proposal with the greatest economic potential
in the long run, expressed by a return on investment index."\textsuperscript{16} Some
favor the development of a preference rating through quantitative
methods, while others maintain that executive judgment is the only
basis upon which the decision can be reasonably based. It seems important
to the writer that such a decision process should be resolved on the
basis of a soundly developed rationale.

\textbf{Criteria for model selection}

Planning provides a basis for economical and effective action
in the achievement of specified objectives. It considers the factors,
forces, effects, and relationships that enter into and are required
for the solution of a problem and determines such things as what should

\textsuperscript{15} Anthony, \textit{op. cit.}, p. 65.

\textsuperscript{16} Louis Strasburg, \textit{Project Design In The Process of Research
Management} (The Ohio State University, 1962), doctoral dissertation,
p. 72.
be done, how it should be done, where action should take place, who should be responsible for it, and why. In this light, the evaluation and selection of individual research and development projects are obviously planning functions. As such, the performance of these functions require the development of planning premises and the use of these premises within an integrated framework of management policies, as they relate to the goals and objectives which it is desired to achieve from the research and development program. However, development of the planning premises is characterized by a lack of specifically pertinent historical information, the evaluation of periods of greater futurity than those involved in ordinary planning decisions, and the appraisal of events of uncertain or probabilistic materialization in the somewhat distant future. In a general yet very practical sense, planning premises for the evaluation of individual projects can be viewed as forecasts of the technical feasibility, cost, and returns which can be expected if a given course of action is adopted. The process of forecasting has been summarized in the following steps to show that the forecasting technique in dealing with a paucity of factual information must itself be evaluated and refined:

1. Developing the ground work—which in the case of research and development project evaluation


involves an appraisal of the current technological environment and the study of the company's present and future position with respect to such technology.

2. Estimating future business—development of a prediction regarding the anticipated income and cost associated with proposed individual projects. It should be noted that Redfield's original treatment of the forecast process considered future business in the sense of the income resulting from sales. His approach is extended into the area of cost projections for this application.

3. Comparing actual with estimated results—the measurement of unanticipated gains and losses based on the forecast as a benchmark. These comparisons permit an identification of variances from predicted values as well as accurate forecasts in order that cause and effect relationships can be analyzed.

4. Refining the forecast process—improving the accuracy with which technological success, cost, and income can be predicted during individual research and development project evaluation. Improvement in predictability over time is more important than the initial precision of the estimate.

Since the forecast process is confronted with many risks and uncertainties in the evaluation of individual research and development projects, it benefits materially from the application of operations research methods. Operations research can be considered as "the application of scientific method to the study of alternatives in a problem situation, with a view to providing a quantitative basis for arriving at an optimal solution in terms of the goals sought."19 This approach to project evaluation is characterized by the use of models, with primary emphasis on objectives, development of figures of merit,

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treatment of problem elements as quantified variables, and the use of a variety of applicable computational techniques including probability statistics. Viewed as an operations research activity the forecast process would take on the following form:

1. Formulation of the problem—statement of all of the known and estimated factors influencing the decision such as cost, risks, and expected incomes.

2. Construction of a model, presumably mathematical in nature—designed in such a way as to include all of the problem elements in a manner representative of their function or behavior relative to one another.

3. Provision of controls for the model and its solution—such as the establishment of limits for expenditures in specific time periods, and the identification of progress review points and the procedures for accomplishing this.

4. Testing of the model—including determining the accuracy of the results provided by the actual use of the model, or equivalent models, on other projects for which the input data relationships are known.

5. Derivation of a solution from the model—usually some index or other figure of merit concerning the desirability of the individual research and development project being evaluated.

6. Placing the solution into effect—involving the actual assignment of an approval status to the proposed projects evaluated under the model.

The growing emphasis which has been placed on use of models since Redfield's description of the forecast process has resulted in the proliferation of designs and formulations. Even in single industry groups or fields of technology, reviews of comparative modeling techniques are being published. One recent article reviews seven major formulations commonly recognized as useful in the chemical industry for the evaluation and selection of individual research and development
projects.\textsuperscript{20} Within the bibliography reported for this study innumerable significant variations of the forecasting model for use in individual research and development project evaluation are reported. These models differ widely with respect to the kind and level of details required for their operation, the degree of sophistication with respect to time adjustment, and the extent to which factors of risk and uncertainty are brought within quantitative estimates such as probabilities. Many of these require several pages to develop and others vary only in minor aspects. It is impossible and, in fact, not really purposeful to review them all. However, some of the more widely known and general purpose models will be subsequently discussed.

For the planning purposes of the top administrative management group, it seems that some broader basis than method or technique alone is needed for a meaningful evaluation of the numerous models as suitable tools for estimating potential individual project profitability or desirability. Admittedly, the computational method is important and must as a minimum be valid and representative. However, some of the considerations that are more general than the computational method but which should also be considered are the alignment of the model with respect to the objectives of management, the comprehensiveness of its scope with respect to the planning or commitment period, the acceptance by the model of various levels of detail corresponding to appropriate

policies on such matters as recovery period and patent desires, and the operability of the model as a user of, and guide for, the preparation of actual operating statistics and accounting records. General criteria for the selection of a model to be used in the evaluation of individual research and development projects can be formulated through a review of the principles relating to the planning process. Equivalent criteria would be derived from review of almost any of the presentations of planning principles available in current management textbooks. The principles listed in the following tabulation are taken from a leading text representing the process school of management thought; they lead to a set of criteria which are felt to be entirely compatible with all other management texts which have been reviewed or surveyed by the author.21

The general criteria developed for selecting or constructing a model for use in the evaluation and selection of individual research and development projects will be meaningful in the long run if the principles of the process of management are in fact valid. Computational methods and refinements will come and go depending upon availability of accurate data and rapid processing equipment, as well as the procedures in vogue for management planning and control purposes. Thus, a review of modeling techniques in terms of their meaning to administrative management, rather than their efficiency as arithmetic processes, is considered to be more significant in this study.

21 Koontz and O'Donnell, op. cit., p. 201.
<table>
<thead>
<tr>
<th>PLANNING PRINCIPLE</th>
<th>CRITERIA FOR MODEL CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Contribution to objectives</td>
<td>The model should use long-term profitability as a major determinant in arriving at individual R&amp;D project desirability. Profitability may be expressed as a return on some base, a per cent of sales, or any other basis which appropriately reflects the corporate goals.</td>
</tr>
<tr>
<td>2. Efficiency of plans.</td>
<td>The model should reflect explicitly each of the additional costs which will be incurred through both the investment and productive life of the project, as well as the timing thereof. These costs should be expressed in a manner suitable for direct magnitude comparison with the benefits to be realized from the project.</td>
</tr>
<tr>
<td>3. Primacy of planning</td>
<td>The model should be so designed and administered that it is applied universally and uniformly to all proposed R&amp;D projects and automatically handles the different levels of confidence associated with different inputs. Since the duration of many projects is longer than the term of the individual planning cycle, the model should be capable of being reapplied in the process of project progress evaluation during each successive planning cycle, or at intermediate points as may be desired.</td>
</tr>
<tr>
<td>4. Planning premises</td>
<td>A uniform method should be prescribed for data acquisition and computation in the development of model inputs, as well as the operation of the model itself. All assumptions and guidelines used should be fully coordinated and stated explicitly.</td>
</tr>
<tr>
<td>5. Policy framework</td>
<td>Each term of the model, and its general computational method(s), should be tested against the company's over-all statement of objectives and planning procedure for the R&amp;D project evaluation and selection process.</td>
</tr>
</tbody>
</table>
6. Timing

a. The future time span considered by the model should be adequate with respect to the commitment involved.

b. The factors comprising the model should be expressed in a manner permitting time adjustment of all values to a common base point.

c. The planning cycle period within which the model is to be used should provide for adequate flow of routine information, sufficiency of review prior to projected major expenditures, and adequate freedom of action with respect to the performance period through which the project and perhaps the R&D managers are evaluated.

7. Planning communication

The model, its supporting input procedures, and its computational results, should be expressed in written form and this information should be available to the managers affected.

8. Alternatives

The output of the model should describe the proposed individual R&D projects in such a way that they can be ranked as a meaningful alternative to any and all other individual R&D projects. The ranking of alternatives may be according to more than one criterion, e.g. profitability, magnitude of commitment, or recovery period.

9. Limiting factors

Terms of the model must be sufficiently detailed that individual limiting factors such as cost magnitude, risk of technological success, waiting period for recovery of investment, or importance of intangibles can be applied as individual pass or fail tests.

10. Commitment

As a minimum, the model must look forward through the payback or recovery period and to the point of minimum acceptable profitability.
11. Flexibility

a. The amount and duration of all cost phases must be shown so that reviews and decision points can be established between successive major increments if desired.

b. The model should be suitable for providing a sensitivity analysis so that all factors can be ranked according to their significance with respect to principle number 9.

12. Navigational change

Each successive review of project progress through the use of the model should result in a new decision to continue or abandon, accelerate, or deemphasize, based on expectations at that time.

13. Strategic planning

Market performance, in the light of both total demand and expected competition, must be included as an income forecast in the model.

Review of selected models

The check list. The check list probably represents the most elementary level of a model for individual project evaluation. Indeed, the elementary nature of its structure would cause many analysts to reject it as a model, since it is inherently descriptive rather than computational and generally fails to provide quantified index ratings on key criteria. An example of a simplified approach of this type is shown as Figure 1. An examination of the components of the check list, however, indicates that certain calculations were necessary to arrive at the assigned ratings in the financial section; various ratios and return rates must be derived and compared to some desired standard.

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22 Kiefer, op. cit., p. 95.
<table>
<thead>
<tr>
<th>FINANCIAL</th>
<th>MARKETING</th>
<th>CORPORATE POSITION</th>
<th>OTHER FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated annual sales of new product</td>
<td>Product advantage</td>
<td>Relation to company objectives</td>
<td>* By-product outlets</td>
</tr>
<tr>
<td>Time to reach estimated sales volume</td>
<td>Product competition</td>
<td>Required corporate size</td>
<td>Waste disposal</td>
</tr>
<tr>
<td>Ratio of annual sales: R&amp;D costs</td>
<td>Market size</td>
<td>Advertising or prestige value</td>
<td>Corrosion potential</td>
</tr>
<tr>
<td>Ratio of total costs: annual savings</td>
<td>Market stability</td>
<td>Effect on purchasing other materials</td>
<td>Hazard potential</td>
</tr>
<tr>
<td>Return on sales</td>
<td>Market permanence</td>
<td>Effect on present customers</td>
<td>Freight position</td>
</tr>
<tr>
<td>Return on fixed capital</td>
<td>Cyclical and seasonal demand</td>
<td>Operating departments’ desire</td>
<td></td>
</tr>
<tr>
<td>Return on total investment</td>
<td>Company known in potential markets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D investment payout time</td>
<td>Compatibility with present products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed capital investment payout time</td>
<td>Suitable marketing organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit in first year of production</td>
<td>Market development requirements</td>
<td></td>
<td></td>
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</tbody>
</table>

RESEARCH AND DEVELOPMENT

<table>
<thead>
<tr>
<th>Chance of technical success</th>
<th>Promotional requirements</th>
<th>Technical service requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical novelty</td>
<td>Time required to become established</td>
<td></td>
</tr>
<tr>
<td>Potential know-how gain</td>
<td>Product variations and modifications</td>
<td></td>
</tr>
<tr>
<td>Relation to company's present know-how</td>
<td>Difficulty of copying or substituting</td>
<td></td>
</tr>
<tr>
<td>Time to develop product</td>
<td>Export potential</td>
<td></td>
</tr>
<tr>
<td>Manpower needed</td>
<td>Possibility of a captive market</td>
<td></td>
</tr>
<tr>
<td>Lab and pilot plant equipment needed</td>
<td>Licensing potential</td>
<td></td>
</tr>
<tr>
<td>Competitive technical activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patent status</td>
<td></td>
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</tbody>
</table>

PRODUCTION

| Process advantage | | |
| Process versatility | | |
| Process familiarity | | |
| Compatibility with present operations | | |
| Equipment availability | | |
| Raw material availability | | |
| By-product outlets | | |
| Waste disposal | | |
| Corrosion potential | | |
| Hazard potential | | |
| Freight position | | |

Figure 1 - A sample composite check list.
Other sections include both calculated values and subjective evaluations. The checklist does require, therefore, some of the processes necessary in the use of a model and these processes are intermingled with subjective or intangible factors. The main characteristics of this approach which are desirable for inclusion in the construction of a suitable model are as follows:

1. A standard approach for every project is used.
2. Quantitative estimates are provided in key areas.
3. A written record is provided as to all evaluations and decisions made.
4. An effort is made to evaluate some of the uncertainties quantitatively.
5. An attempt is made to orient the checklist to alignment of individual research and development projects with company objectives.

Major shortcomings of the checklist approach for evaluation of individual research and development project proposals can be summarized as follows:

1. Indexes as to profitability, desirability, preference ranking, and other major factors are not readily provided per se, although scores can be assigned and totaled.
2. The input values, assumptions, and computational processes are not documented as a general rule.
3. Time adjustment is not provided.
4. No attempt is made at segmentation in order to provide the decision points required prior to major successive expenditures.
5. Individual attitudes and differences on the part of managers are likely to cause different scores for the same project when reviewed by different people.
Charles I. Sullivan proposed a method of quantifying a checklist for project evaluation which contains thirty-eight items, to each of which he assigns a point value on a one-to-six scale. Each item is then evaluated as to "favorability" on a zero to one hundred scale. The product of the point value and the favorability rating gives a numerical rating for each item on the checklist. The over-all project rating, expressed as a percentage, is then the total rating multiplied by one hundred and divided by the total assigned points. Sullivan emphasizes that this system is intended primarily for projects in the applied research and development end of the spectrum.  

Barry M. Richman (Columbia Graduate School of Business) proposed a very similar procedure for corporate decisions relative to new product development and marketing. Richman utilizes the more erudite term of "evaluation matrix" for his model but arrives in essentially the same way at a final project rating.  

An approach to project evaluation which is similar to the above has been presented by Mottley and Newton of Charles Pfizer and Company. They propose a numerical rating system but recognize its limitation in the absolute sense. It is offered for consideration as a practical temporary means for enhancing the judgment of research.

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management. Basically, they propose five criteria for project evaluation: (1) promise of success, (2) time to completion, (3) cost of the project, (4) strategic needs, and (5) potential market gain. The authors proposed the assignment of numerical ratings to these five parameters and suggested the product of these five ratings as a numerical value for the project. They present their justification for this approach as follows:

When a research manager makes up his program and defends the budget that he is requesting for its support, he is forced to fall back upon intuitive judgment as to which lines of investigation will succeed and eventually pay-off. However, we do feel that it is possible to help him clarify his intuitive judgment by refining certain criteria that, although they are only indirectly related to the company's future profit position, will provide an objective basis for the comparison and selection of projects.25

John Magee of Arthur D. Little, Inc., developed the concept of a tree of decisions for the treatment of alternatives in progressing past various decision points to a final outcome. This concept essentially described a means of formalizing the course of a project evaluation and selection to assure that all important alternatives are considered.26


Rather than rely on check lists as such, the criteria proposed by this study for selecting a model take advantage of the check list method outside of the model itself. For example, any classification system for organizing a chart of accounts, technical area description or segmentation, or analysis of the business environment is essentially a check list. So is a set of detailed steps in the planning process. A check list becomes a useful tool for organizing and compiling information, but they do not represent operable models suitable for evaluation of proposed individual research and development projects.

Return on investment curves. One of the earliest, although still elementary, models which can be given serious consideration for evaluating the investment relating to proposed research and development projects was reported by L. V. Redman in 1928.27 Redman provided curves of investment values with and without reinvestment for competitive and noncompetitive industries. He presented a baseline comparison by providing a curve for a conservative 5% per annum investment. These curves can be used as a graphic model, requiring that the user formulate the necessary assumptions to identify the location of the individual research and development project being considered on the graphic projection. Because of their historical interest and continuing importance as an integral function consumed within other models which were subsequently derived, Redman's curves are presented in Figures 2 and 3. This approach has the advantage

Figure 2. - Redman's Investment Curves

Figure 3. - Redman's Investment Curves With Liquidation Values.
of recognizing that the important individual factors to be considered in evaluating any research project are in the future rather than in the past, and it provides quantitative values for future performance by adding curves for liquidation. Redman also furnishes a basis for the appraisal of sunk costs to be incurred in the event of project termination. By treating Curve A—the noncompetitive industry—as the proposed venture, Redman shows the drop in cash availability during the investment period, followed by the recovery of funds during profitable production. He admonishes managers to feel their way carefully into the manufacture phase, indicating an awareness of the desirability for a decision point review prior to each successive expenditure. In fact, Redman warns that before new phases are undertaken, which usually involves the commitment of a larger sum of money, a reevaluation of the future outlook should be accomplished. He states that if the project doesn't look promising it should be abandoned immediately and continues by quoting, "commit your blunders on a small scale and make your profits on a large scale." Redman's clear understanding and statement of the problem of research and development project evaluation was such that any model which is derived today for that purpose will probably conceptually incorporate much of his thinking. Some of his points to be carried forward are adapted for the following:

1. Using return on investment as a principle criterion.
2. Calculating future values, including compounding.
3. Comparison of expected research project income with that of other alternatives.
4. Acknowledgment of the requirement for periodic reappraisals.

5. Standardization of the evaluation criteria.

It was almost inevitable, of course, that any early attempt at the scientific evaluation of proposed research and development projects would be improved with the continuing application of refinements and new knowledge. Advances have been made which reveal some of the shortcomings of Redman's technique:

1. The fact that the principal expressions of the model are in graphic terms, with the result that the process of formulating and applying assumptions of other data are not explicit.

2. The plotting of the resultant of cost and income rather than separate series for each of these two prime determinants.

3. Inadequate provision for varying time estimates and periods considered for investment and income without complete new sets of curves.

4. A failure to provide specific index values by which projects will be ranked for desirability.

5. General assumption as to availability of input information without regard to operating realities.

Discounted cash flow analysis. A more recent milestone in the development of a model for evaluation of proposed projects is
represented by the work of James Brian Quinn. In discussing the measurement of the direct products of industrial research, Quinn considers several approaches to estimating future income. He then provides a method for matching cost against income and concludes with the derivation of a "research return ratio." By making minor changes in the symbols selected by Quinn to represent factors in his models, the following summary can be developed showing different methods of evaluating expected results:

1. The unadjusted income basis:

\[ V = V_1 + \sum_{i=0}^{n} (I_i) \]

2. The capitalized earnings approach:

\[ V = V_1 + y(I_n) \]

3. The calculated risk basis:

\[ V = V_1 + \sum_{i=0}^{n} (P(I_i) \]

4. The present value approach:

\[ V = V_1 + \sum_{i=0}^{n} C_i(1 + R)^{-i} \]

where:

- \( V \) = the value of the opportunity
- \( V_1 \) = the present liquidation value of the resource on a non-income-producing basis
- \( I_i \) = the net income in each \( i \)th year
- \( n \) = the total number of years hence that the last income is expected

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y = the number of years earnings appropriate for this class of risk  
Ia = the average annual net income from exploitation during period y  
P = the probability of receipt of the income (I_i) in year i  
i = the number of years hence that income I_i is expected  
C_i = the net cash flow in each i th year  
R = the expected rate of return on this class of risk

Quinn then recommends that the present value approach be used for appraising the value of future returns from research expenditure, for such reasons as these:

1. Expected cash flows are discounted on the basis of inherent risk.

2. Expected cash flows are discounted on the basis of their expected timing.

3. The technique normalizes all proposed projects with respect to each other regardless of duration and amount involved.

Prior to developing his method further, Quinn points out that the summation of the factors of the net cash flows in each i th year, the expected rate of return, and the present value of the venture should be available for use at successive project reviews. He then discusses the detailed introduction of cost considerations as they relate to the time factor, and he quotes an unnamed executive as making the following statement

I prefer a comparison of the profitability of a particular product with the cost of obtaining that product. We have made occasional studies of the new product introduced in a period with the total research cost of that period. I do not believe that these figures have a high degree of utility for my purposes.\(^{29}\)

\(^{29}\) Ibid, p. 125.
These considerations lead Quinn to the statement of a research return ratio:

\[
\text{Research Return Ratio} = \frac{A + P}{I_a(T)}
\]

where:

- \(A\) = the actual profits from exploitation to date
- \(P\) = the present value of future profits
- \(I_a\) = the average research investment in this product area from the inception of research to the last significant discounted future revenue
- \(T\) = the length of time \(I_a\) is invested

Quinn points out that the advantage of this method over other techniques is that the formula adjusts for the most important factors in computing a return on research expenditures. He notes that it allows for the length of time during which the R&D investment is sunk, for discounting future profits on a risk basis and thereby providing an automatic cutoff date for revenues, and for a proper consideration of both past and future revenues as they relate to the research cost which made them possible.

In general, the approach presented by Quinn requires only that it be extended in a few areas to become a reasonably acceptable model for individual R&D project evaluation in accordance with the criteria developed. These areas can be summarized as follows:

1. The cost projection techniques should be strengthened to show incremental future cost and their present values.

2. The cost period should be broken down into incremental phases such as research, production, and marketing, with a decision point review prior to successive major expenditures.
3. Time increments should be selected matching the normal cash flow projection phasing used by the company for financial planning generally.

4. Provision should be made for the consideration of a variety of different risk and uncertainty factors.

5. A variable cost of future capital should be considered.

Other contemporary thinking. Since the end of World War II numerous formulas and ratios have been devised and offered for use in selecting research and development projects or evaluating the productivity of research programs. For the most part the various writers attempt to compare the value or benefits obtained from research and development projects with the cost of successfully completing the project and exploiting the results. The techniques proposed vary significantly in their levels of complexity, particularly from the viewpoint of the detail required for calculations and the manner in which the time adjustment factor is handled.

Philip Marvin discusses two approaches introduced in 1950. The first presented by R. E. Wilson, is an appraisal ratio which was suggested as a guide in estimating the value of a research project to the firm. It is formulated as follows

\[
\frac{\text{Estimated value to the firm of a successful completion of the research project}}{\text{Estimated cost of the research project}} \times \frac{\text{Probable chance of successful completion of the project}}{1}
\]

The second, formulated by Dr. C. L. Kemp, Jr., offers a means of evaluation on the basis of a so-called Index of Return. Although

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appearing at first glance to be somewhat complicated, it deals really with a very simple relationship:

\[ \frac{V (MP - C + CM)}{RC \times T + MF} \frac{PS + MF}{NP} = \text{Index of Return} \]

or since the factor \((MP - C + CM) = NP\) (Net Profit) and since the PS factor can be taken as one for the completed development, the elimination of the MF factors which can be taken into account in the actual calculation of NP, the equation can be reduced to:

\[ \frac{V \times NP}{RC} = \text{Index of Return}. \]

where:

\[ V = \text{volume sold per unit of time} \]
\[ MP = \text{market price of the product} \]
\[ CM = \text{marketing cost of the product} \]
\[ C = \text{cost of manufacturing the product} \]
\[ T = \text{time for development (years)} \]
\[ RC = \text{development costs per year} \]
\[ PS = \text{probability of success factor} \]
\[ MF = \text{miscellaneous factors (royalties, special payments)} \]

More recently, Francis X. Lamb proposed an evaluation formula to assist in the decision process which resulted in a Project Rating.\textsuperscript{31}

It is as follows:

\[ \frac{\text{Estimated Income}}{\text{Estimated Expense}} = \text{Project Rating} \]

which is equal to the following:

\[
\text{Probability of Engineering Success} \times \text{Probability of Sales Success} \times \text{Annual Volume} \times \text{Units} \times \frac{	ext{Net SP}}{	ext{F.C.K}} \times \text{Life in Years}
\]

\[
\text{Engineering Expense} + \text{Mfg. Eng. Expense} + \text{Sales Expense} + \text{Lab. App. Expense} + \text{Inventory}
\]

* Net selling price minus the factory cost multiplied by a constant for overhead.

H. I. Ansoff presented a proposed method for the evaluation of applied research projects which, he maintains, is designed to allow for the uncertainties and lack of knowledge usually present at the inception of applied research projects. He proposes ranking competing projects on an arbitrary scale in accordance with two figures of merit— one for profit and one for risk: The figure of merit for profit is:

\[
FM_p = \frac{(M_t + M_b) \times E \times Ps \times P_p}{C_d \times J} \times S
\]

Considering the risk involved in undertaking a proposed project to be an important yardstick, Ansoff offers the following additional figure of merit as a rough approximation of the dollar cost at risk in applied research as a per cent of the eventual return on the investment.

\[
FM_r = \frac{C_{ar}}{FM_p}
\]

The symbols used in the above are:

\[ P = \text{Profit Potential} \]
\[ E = \text{Estimate of total sales (earnings) over lifetime} \]
\[ M_t = \text{Technological Merit} \]
\[ M_b = \text{Business Merit} \]
\[ P_s = \text{Probability of success of project} \]
\[ P_p = \text{Probability of successful market penetration} \]
\[ S = \text{Strategic fit of proposed project with other projects, products, and markets of the company} \]
\[ C_d = \text{Direct Investment} (C_{ar} + C_{pr} + C_{pd} + C_{pe} + WC + F) \]
\[ C_{ar} = \text{Total cost of applied research effort} \]
\[ C_{pr} = \text{Total cost of product research effort (exclusive of applied research)} \]
\[ C_{pd} = \text{Total cost of product development effort} \]
\[ C_{pe} = \text{Total cost of product engineering effort} \]
\[ WC = \text{Working capital required} \]
\[ F = \text{Total cost of extra facilities required such as staff, buildings, etc.} \]
\[ J = \text{Savings factor in direct investment resulting from use or sharing of existing facilities and capabilities} \]

The following example reflects an uncomplicated but meaningful use of return on investment and payout time as an evaluation criteria which is derived by a straightforward arithmetic process.\(^{33}\)

Data:

Investment required:

New-plant investment* .................. $300,000
Working capital ......................... 200,000

Income and expense statement (per year)

Predicted sales—1,000,000 lb./yr. @$0.75/lb. $750,000

Manufacturing costs ................. $400,000
Sales + distribution costs .......... 100,000
General overhead expenses .......... 150,000

Total costs .............................. 650,000

Net (pre-tax) ............................. $100,000
Net (after 52% tax) ...................... 48,000

Return on Original Investment (R.O.I.):

Return on investment = \frac{\text{Average Profit per year}}{\text{Investment}} x 100

R.O.I = \frac{$48,000}{\$300,000 + 200,000} = 9.6\%/yr.

Payout Time (P.O.T.):

Payout time = \frac{\text{Fixed capital investment}}{\text{Annual net profit} + \text{Annual depreciation}}

P.O.T = \frac{$300,000}{\$48,000 + $30,000} = 3.8 \text{ yr.}

* Depreciated at 10%/yr. based on 10-yr. plant life and no salvage value.

The author continues by pointing out the significance of a sensitivity analysis in the evaluation of proposed R&D projects and presents charts showing variation relationships. Elaboration of the basic model by the addition of networking and probability estimates has been recently reported.\textsuperscript{24} This particular approach links probability components

through the network (a version of PERT) to arrive at outcome
probabilities. Although the report is not sufficiently detailed to
indicate all of the factors and operations involved in use of the
model, this approach appears to be closely related to the main line
of development started by Redman and expanded by Quinn and others.
One of the best summaries of model, variation in current literature
covers seven significant calculations.\(^2^5\) The first of these is an
index of return attributed to Fred Olsen and defined as follows:

\[
\text{Value of research} = \frac{(\text{Estimated I.R.}) \times (\text{Probability of Success})}{\text{Estimated Cost of Research}}
\]

I.R. = Value of process savings for one year or 3% of the sales value
of new products each year for five years or 2% of the sales
value of improved products each year for two years.

This approach sets arbitrary values on the benefits of research and
involves a criterion of three or greater as indicating a worthwhile
project. Basically this may be a useful rule-of-thumb approach for
cases where it is applicable, although it is primarily intended for
evaluating the contribution realized from past research. A somewhat
more involved index is the project number developed by Carl Pacifico
calculated as follows:

\[
\text{Project Number} = \frac{R_c \times R_t \times (P-C) \times V \times L}{\text{Total Costs}}
\]

\(R_c\) = Chance of commercial success (on a scale of 0.1 to 1.0)
\(R_t\) = Chance of technical success (on a scale 0.1 to 1.0)
\(P\) = Price of the product, dollars per pound
\(C\) = Manufacturing and selling cost of the product, dollars per pound

\(^{3^5}\) Kiefer, loc. cit.
\[ V = \text{Sales volume, pounds per year} \]

\[ L = \text{Commercial life of the product, in years} \]

Total costs include costs for research, engineering, plant, market development, working capital, and the like.

A figure of merit of two is used for interpretation of the results of this calculation. As in the case of the Olsen Index, all costs are lumped together in a single figure whether research, engineering, plant expenditures, market development, working capital or other. Perhaps these simple guidelines may be of some useful value in determining whether a project should be submitted to full evaluation by a more complex model, thereby eliminating some time and effort if in the gross sense they do not appear to be worthwhile. The third computation reported is a formula contributed to Solomon Disman, which indicates how much can be spent on a project, as well as its relative priority. This computation is described as follows:

\[
\text{MEJ} = R_c \times R_t \frac{I_1}{1 + r} + \frac{I_2}{(1 + r)^2} + \cdots + \frac{I_n}{(1 + r)^n}
\]

\[ \text{MEJ} = \text{Maximum expenditure justified, in dollars.} \]

\[ R_c = \text{Risk of commercial success} \]

\[ R_t = \text{Risk of technical success} \]

\[ r = \text{Rate of return desired on the R&D expenditure} \]

\[ n = \text{Commercial life of product or cost saving, in years} \]

\[ I_1 = \text{Estimated net income or cost saving in first year, in dollars} \]

\[ I_2 = \text{Estimated net income or cost saving in second year, in dollars} \]

\[ I_n = \text{Estimated net income or cost saving in n-th year, in dollars} \]

To set project priorities:

\[
\text{Project number} = \frac{\text{MEJ}}{\text{Total Estimated R&D Costs (discounted)}}
\]
Another approach to quick evaluation is provided by the Index of Research developed by Gorden K. Teal. When four indices are multiplied together a product of one, or greater, indicates a worthwhile project. These indices are:

1. Index of Return on Research & Development = \( \frac{N}{2S} \)

2. Index of Return on Assets = \( \frac{N}{13.5A} \)

3. Index of Dollar Value = \( \frac{b}{B/25} \)
   (i.e., a project should make possible a k% increase in total billings)

4. Index of Market Capture = \( \frac{b}{M/2} \)
   (i.e., a new product should capture half of the total available market)

The symbols listed above are:

- \( N \) = Net profit during the life of the new product
- \( S \) = Research & Development costs
- \( A \) = Assets required
- \( b \) = Billings (sales) made possible by the product
- \( B \) = Total company billings (sales) during the life of the new product
- \( M \) = Total available market

Finally, Kiefer presents three different applications of the present value concept which are summarized below:

Sidney Sobelman's "Investment Worth" Model, as applied to new product development, emphasizes product life and development time.

\[
Z = P T + \bar{F}(1 - \frac{t}{T}) - c t + \bar{F}(1 - \frac{T}{T})
\]
\[ Z = \text{Product worth} \]
\[ P = \text{Estimated average net profit per year from the new product} \]
\[ T = \text{Estimated actual profit life or market life of the new product} \]
\[ \bar{T} = \text{Profit life or market life of an average new product} \]
\[ c = \text{Estimated average development cost per year for the new product} \]
\[ t = \text{Estimated time required to develop the new product} \]
\[ \bar{t} = \text{Time required to develop an average new product} \]

The Hoskold Transformation

\[ P = \frac{D}{r + \frac{r'}{(1+r')^{n}}} \]

\[ P = \text{Present worth of the income the project will yield} \]
\[ D = \text{Average annual incremental income yielded} \]
\[ r' = \text{Average net return on capital invested in the company} \]
\[ r = \text{Current rate of interest on investments} \]
\[ n = \text{Number of years in which research costs must be recovered} \]

Present Value of a Project

\[ P = \sum_{i=0}^{n} C_i (1 + r)^{-i} \]

\[ P = \text{Present value of the project} \]
\[ C_i = \text{Net cash inflow in each } i \text{th year (net cash outflow would make } C_i \text{ negative)} \]
\[ i = \text{Number of years hence the cash flow occurs} \]
\[ n = \text{Number of years hence the last significant cash flow occurs} \]
\[ r = \text{Discount rate (rate at which money could be invested to obtain cash flows of equal risk in the same year)} \]
Dr. Villers presents a summary of seven different computational methods, with examples, which may be used in the financial evaluation of proposed research and development projects. He also shows two graphic techniques. The first depicts the cumulative expenditures and forecast sales plotted against time. The second is the more classical breakeven analysis chart of total cost and sales.36 While the graphic methods are not considered to be a significant financial evaluation tool by the writer, they are useful in presenting a picture of the financial aspects of specific projects to higher organizational levels during the process of project selection.

The importance of the computation methods described above is that they reflect attention to detail and refinements only in the specific areas which are emphasized. However, this is not sufficient to satisfy the criteria developed. If, for example, product life or development time is a critical factor, the general model for project evaluation should be able to emphasize these factors to the level of detail necessary for reliable decisions. Similarly, if some competitive effect is significant, the model should provide for the integration of the several factors which could reflect this. The principle features to be taken from a review of these procedures then are flexibility and versatility.

In view of the above, it should be readily apparent that the foregoing computations are not necessarily limited to individual research and development project evaluation. Any student of finance will recognize that some features of the more general techniques of investment evaluation have been adapted and applied to the field of industrial research management. Acknowledgment should be made at this time to practices in this more general area of investment opportunity evaluation and its meaning to research and development management. Paralleling the work of Redman, Quinn, and others, and contributing significantly to their thinking, are an even larger number of references that appear in the literature concerning general investment analysis and modeling techniques of operations research.

Within the current literature the highly generalized method for determining discounted cash flow has been presented. 37 This imparted generalization easily includes the case of research and development expenditures and the subsequent resulting revenues. The external rate—that which could be earned by the capital in alternative uses—is recognized as cost of capital. Future fluctuation in this rate as well as in the cash flow rate are recognized. The general computational formula presented is considered suitable as a part of the over-all individual research and development project evaluation model. However, a final point dealing with the uncertainty of future

events should be recognized from the general literature concerning investment opportunity evaluation. Selection of probability distribution models and refinement of calculation methods are covered by this article as well as by many others. Because of the highly expectational nature of both cost and revenues in research and development programs, the determination of quantitative values relating to risk, other intangibles, and acceptable rates of return in the profitability model meeting the criteria proposed by this study could be used in part on the techniques described by Gaver. As another author has pointed out decision makers are often reluctant to assign values to probabilities concerning future outcomes. Three choices are open:

1. First, ignore the problem and compute the analysis as if certainties are involved;

2. Second, follow the principle of insufficient reason and assign equal probabilities to all states of the world; or

3. Third, apply the best information and method available to compute the most credible value.

The third alternative, of course, presents both an opportunity and a challenge to the exercise of management judgment.

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An expanded model. As stated previously, the approach proposed by Quinn requires only that it be expanded in a few areas to become a reasonably acceptable model for individual research and development project evaluation in accordance with the selection criteria developed. Starting with his basic formulation, but slightly modifying the symbols used, we have:

\[
PW = \sum_{t=0}^{n} \frac{(NOF)_i}{(1+R)^t} + \frac{L_n}{(1+R)^n}
\]

where:

\(PW\) = Present Worth or Present Value.

\(NOF\) = New Cash Flow in a given period (or the \(i\) th period).

\(t\) = The total time from the initiation of the research and development project to the end of the recovery period considered for evaluation.

\(n\) = The last period during which income from the project is expected.

\(i\) = The number of years between the present \((t = 0)\) and the \(i\) th year.

\(L\) = Liquidation value of nondepreciable expenditures at the end of expected recovery period \(n\).

\(R\) = Rate of return expected for the class of risk involved in the undertaking.

However,

\[(NOF)_i = (Y + D)_i - (I)_i\]

where:

\(Y\) = The net income after taxes and depreciation for the \(i\) th period.

\(D\) = The total project associated depreciation during the \(i\) th period.
The total investment (expenditures) in the project during the \( i \)th period.

The value of \((I)_{i}\) may be further broken down into its components as follows:

\[
(I)_{i} = (I_r)_{i} + (I_p)_{i} + (I_m)_{i}
\]

where the subscripts are used to designate the expenditures incurred during the various project phases as follows:

sub-\( r \) = research and development
sub-\( p \) = production
sub-\( m \) = marketing

The general formulation, therefore, can be expressed as follows:

\[
\sum_{t=0}^{n} \frac{(Y+D)_{i}}{(1+R)^{t}} - \frac{(I_r)_{i}}{(1+R)^{t}} - \frac{(I_p)_{i}}{(1+R)^{t}} - \frac{(I_m)_{i}}{(1+R)^{t}} + \frac{L_n}{(1+R)^{n}}
\]

The flexibility of the model in its expanded form is much more readily apparent. It can be utilized to determine the present worth of project results at the demanded rate of return for the risk class, or, by appropriately changing the "\( I+R \)" symbology, the rate of return that the project will yield through the end of the last period considered for recovery (\( n \)) can be computed. It lends itself well to a sensitivity analysis through repeat computations with varying inputs of the cost, return, and time factors. In addition, the actions of competitors which may influence the company's estimated position on the demand curve (or the total market demand) and the significance of the timing aspects of market entry can be appropriately reflected. Another advantage offered by this approach is that an automatic cutoff time for consideration given to the period of
recovery is somewhat inherent within the calculations. The discounting technique results in the declining incomes expected during the far distant periods becoming almost negligible, especially if a variable return rate is utilized and the R value is higher for these periods because of the futurity, risk of obsolescence, or other factors.

As indicated above, when computing the present worth it is possible to adjust the demanded rate of return from period to period in order to reflect the variable future risks which influence the probability of obtaining each period's projected cash flow. Adjustments can be made to reflect the risk of obtaining future incomes, the timing of such incomes, the amount of the interim investment variations in the future cost of capital (including alternate uses of funds), and management desires to obtain different rates of return on the major investment phases of the project - research and development, production, and marketing. For example, assuming the subscripts to carry the same connotations as above, the latter policy objective could be shown as follows:

\[
\frac{(I_r)_i}{(1 + R_r)^1} \rightarrow \frac{(I_p)_i}{(1 + R_p)^1}, \frac{(I_m)_i}{(1 + R_m)^1}
\]

Quantified intangibles (K) can also be accommodated by the model. When such an intangible is identified, assessed, and a monitory value assigned, it is merely added to the "sources of funds" statement of the model for those periods during which its benefits are expected to be realized. Any value thus given an expected future intangible is then appropriately discounted.
An alternate approach to the handling of the risk associated with the various model factors (perhaps most useful when computing over-all rate or return), and to performing a sensitivity analysis, is to formulate an estimate of the different probabilities (p) associated with obtaining the forecast incomes and not exceeding the estimated costs. These figures would then be directly applied to the factors of the model to reflect the risk involved and varied appropriately to determine sensitivity. These values would usually have an upper limit of one when applied to the return values and a lower limit of one when applied to estimated costs. Such an approach applied to the income portion of the model, including a consideration of quantified intangibles, would take the following form:

\[
\frac{(.48) (p_y Y' - p_d D) + (p_d) (D) + (p_k) (K)}{(1 + R)^i}
\]

where \( Y' \) equals the gross income expected for the \( i \)th period.

Having revised computations available at successive project reviews and decision points prior to the commitment to an additional investment phase enables the evaluation to be made in the light of the latest knowledge available and revised estimates of risk as a result of the effort completed as of that time.

As stated the model is inoperable because it is generalized in its broadest form. However, the steps to application are obvious. With respect to each term of the model, a specific company would establish a procedure for development of the values required. Such procedures would show the source of basic information, the source and
processing formats, organizational components involved in processing the information, process steps, output formats, and any other relevant information required in their planning process. The range of inputs would include work sheets for discounted cash flow projections, factors derived by application of formula, project budgets, and internal and external marketing projections. The algorithms or computational steps by which these data are compiled into the terms of the model would also be spelled out. At many points, guidelines and policies must be provided to direct and limit the assumptions made. The output of the model can be developed into a profitability index; however, each major term is detailed. Each can be treated as a critical factor and tested against a minimum or maximum allowable for that factor, and therefore any term of the model, as well as the over-all profitability, could be used as a controlling criterion. The model factors and output can be combined into a project proposal which can be analyzed in terms of a desirability function such as that being applied for various kinds of evaluation in industry today. Additionally, the terms and output of the model can be compiled in tabular form to show goals. Appropriate charts for review presentations can be easily made. However, if the use of the model is to be effective, the admonishment of two of the world's experts on modeling theory should be recognized:

Past experience with models—and related methods of analysis—may be an inadequate guide

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for managers considering a use of new tools now available. The latter viewed as multiple variable systems models may differ in their data requirements and decisions possibilities in comparison with predecessors that could handle only a few variables at a time. In approaching these new tools it is desirable to consider using the models as guides to data collections as well as decision. This refers not only to data variety but also to data quality as judged by reference to the model itself. It may then be possible to eliminate needless expenditures of time and money on collecting or refining data. It is also desirable to consider integrating the model in the decision making. Evaluation may then be secured which can guide alterations to the model and also open new decision possibilities which would otherwise not be apparent.\textsuperscript{42}

The role of executive judgment

The emphasis placed upon quantitative techniques in the previous discussions should not be taken as an attempt to degrade the importance of executive judgment. Such judgment is important not only at the final level of approval for proposed projects but at all levels where inputs are made regarding the project and especially in preparation of the project proposal. Any evaluation process is only as good as the basis upon which the decision is founded. Willers points out that decision is the culminating act of planning, and that to make the right decision the decision maker should consider all the facts, analyze them, consider alternatives, determine the effect on each plan, and then make the decision.\textsuperscript{43}

\textsuperscript{42} A. Charnes and W. W. Cooper, Data, Modeling and Decision (Northwestern Technological Inst., Evanston, Ill, June, 1965).

\textsuperscript{43} Willers, op. cit., p. 35.
From the time of the initial conception of a research and development project, human judgment plays the most significant role. Even where complex computer models are used as tools to assist in the identification of parametric trade-offs on alternative choices, judgment is the final factor in project selection. Anthony states the following:

There are few, if any, management decisions which can be made solely on the basis of numerical solution to a formula. There are many cases in which the intelligent use of quantitative information permits better decisions to be made than would otherwise be possible, but in the last analysis, the decision depends upon judgment. Until such time as all the factors which bear on a decision can be evaluated quantitatively and formulas for the interaction of these factors can be worked out, judgment will be a vital ingredient in decision making. Pending that millennium, the use of numerical information can narrow the margin of error inherent in any decision which involves good judgment, but that margin of error cannot be eliminated.44

Essentially, the numerical analysis and models which are used in the evaluation and selection process assist by making it possible to express certain factors in terms which can be manipulated in a much shorter period of time, thus reducing the number of factors which have to be evaluated and combined subjectively. It also ensures the identification of certain parameters which otherwise may have been considered unimportant. Composite executive judgment, such as that obtained as a result of committee review and discussion, brings the opinions and background of many different individuals to bear on the

44 Anthony, op. cit., p. 49.
evaluation of a proposed project and ensures that significant factors, that may be buried deeply in a computer model analysis, are given proper discussion and weight. Roberts points out the psychological aspects of this approach and identifies the fact that different executives have different knowledge and interest as a result of their background. He states the following:

In describing the way individuals or organizations predict the need for a product, we should further recognize that we are dealing with the entire psychological concept of perception as here applied to a particular area of product evaluation. What may look like a good product to one may not look like a good product to another. What we may perceive is not determined solely by the external facts of the real world environment. Rather, it is determined jointly by these external conditions and by the expectations, past experience, needs, goals, and capabilities of the decision makers and their organization.45

That there are differences of opinion based on individual background and experience among the members of the executive approval committee is acknowledged. However, it is an attribute rather than a detriment to the evaluation process. A heterogeneous group, provided it is not dominated by a single interest, will ensure that the over-all research and development program maintains proper balance rather than emphasizes one or a limited number of specific areas.

Project design and scheduling

Any discussion of research and development project selection, progress evaluation, and post appraisal must eventually address itself

to considerations of project design and scheduling. As a certain amount of preliminary planning is necessary for project selection, project design and scheduling is a prerequisite for adequate progress evaluation and post appraisal. The considerations primarily involved are the determination of the lines of attack to be followed in conducting the research and development effort within each major work phase of the project, as estimation of the time required to perform each individual task, and the formulation and coordination of a schedule for completing the entire project.

Scheduling, as it is considered in this study, involves determining when the work on each specific task should be started, when it should be completed, and what personnel and resources are required, arranging the separate tasks in proper order in relation to the major work phase into which they fall, and arranging all of the major work phases in proper order in relation to the overall project. In general, a schedule is considered as a plan for action as it appears when plotted against the coordinate of time.

Dr. Villers points out that until recently the idea of scheduling any kind of research work was generally rejected but that the successful use of scheduling methods has been proven in many actual applications. He states, however,

There is a difference of opinion as to what kind of research can be scheduled but when we speak of extremes, the answer is clear cut. Today no one would contend that the development of a new model car cannot be scheduled, neither would anyone contend that Albert Einstein could have scheduled his discovery of the theory of relativity. The question is where to draw the
line. Published reports of the successful scheduling of research and development operations in cases involving intricate exploratory research work as well as development operations show that schedules can be used for many diversified aspects of research work. The ultimate decision to use or not use schedules has to be made by technically qualified executives after a careful review of the system to be considered and of the conditions of operation.46

In by far the large majority of research and development projects it is not possible to predict exactly the time required for the completion of the over-all efforts or even for any given task of the project; therefore, both the individual project schedules and the over-all laboratory schedule for projects must be somewhat flexible. However, engineers and scientists are able to estimate, within varying limits, the time required to complete the task on which they work, and these in turn form the basis of a plan for coordinated action.

Quinn, however, notes the following:

One major difficulty in forecasting research performance is the lack of repetition in research operations. Even the most precise measurements of past experience may not allow accurate predictions of the time or cost required to solve future problems. Only in routine testing does the scientist's activity become repetitive enough for the use of standard time and motion work measurement techniques. Research progress schedules, therefore, are at best merely estimates based upon broad experience with similar problems.47

The field of basic research, as it has been defined, offers more resistance to the establishment of a schedule than any other area.

47 Quinn, op. cit., p. 11.
Because basic research seeks to uncover new knowledge and methods, it depends almost entirely on individuals or individual research groups working together as a team. However, as Anthony noted, this does not mean that there is no form of schedule that can be beneficially established to aid in basic research. 48 It is quite possible to plan broadly in terms of WHAT and HOW with respect to the immediate future, and to plan precisely in terms of WHO and WHERE. Planning in terms of the maximum funds to be allocated and the rate of expenditure can also be accomplished.

Projects that are considered to be in the area of structured applied research or development are more readily adaptable to formal scheduling than those classified as basic research. Roberts notes, for example, that although many aspects of a project contribute to its magnitude, there is a certain set of tasks inherent in the development of any new product whose magnitude is defined by the nature of the undertaking. The methods and procedures employed in accomplishing the required effort in such projects are for the most part based on established scientific principles and techniques. Generally, the scientists and engineers who will be performing the work have had considerable past experience in applying the same principles to similar projects in their specialized field. Project requirements and goals may be stated in definite terms; the reference points upon which

48 Anthony, op. cit., p. 65.
estimates of time requirements are based will consequently be more numerous and conclusive; and, therefore, progress over a given period of time may be predicted with a relatively high degree of accuracy.49

In discussing the degree to which an attempt should be made to schedule the research and development laboratory activity, Bush and Hattery state that formal planning and scheduling in the laboratory should be applied only to major work phases of the research projects and not to daily detail.50 The major work phases which they discuss generally correspond to the task level of effort utilized in this paper. Quinn also warns against over-planning and points out that, "research planners must take care to avoid stifling creativity and originality by over-planning. While top research executives should be expected to develop a sound over-all structure for the research program, overly detailed planning of the attack to be used by scientists can be extremely damaging." He touches upon one of the significant benefits to be realized from project design and scheduling when he recommends that planners not schedule work in any more detail than management expects to utilize for control purposes.51

Project progress reviews result in a management decision to continue the work as currently planned, redirect the effort or abandon

49 Quinn, op. cit., p. 11.
50 Bush and Hattery, op. cit., p. 55.
51 Quinn, op. cit., p. 175.
the undertaking entirely. Schedules provide the baseline against which this executive appraisal can be made and, in fact, schedules can materially assist in identifying the most pertinent milestone points at which such reviews can be most meaningfully accomplished.

Bush and Hattery point out that good project progress reports together with accurate cost and manhour records are invaluable tools for evaluating progress against an established schedule. They note, however, that in assessing whether the schedule can be maintained the research director is still, basically, dependent upon a considered appraisal of progress as well as the work remaining.\textsuperscript{52}

Villers points out that providing the cumulative expenditure figure to top management presents them with the over-all cost picture and at the same time protects the operating people responsible for variance. He notes that if some delay or unusual circumstances distort the picture from time to time, the cumulative figure will clarify the situation.\textsuperscript{53}

As previously discussed, the project profitability model in conjunction with an appropriate accounting system enables such information to be made readily available at successive progress reviews and permits a re-evaluation of the profit outlook in the light of any changes.

\textsuperscript{52} Bush and Hattery, \textit{op. cit.}, p. 57.

\textsuperscript{53} Villers, \textit{op. cit.}, p. 89.
Mees and Leermaker point out that when consideration is given to discontinuing a research and development project because of the additional funds that will be required to complete successfully the remaining work, the decisions involved become more complex. They note the following:

Some special considerations apply to discontinuing development programs. An investigation of considerable scope may reach a stage where it is evident that further large expenditures of money are required to arrive at a conclusion; the director must determine on the basis of commercial considerations whether the work should be continued or stopped.\(^54\)

Changes in the market demand and competitive situation are, of course, factors that must be continuously evaluated for all current projects, as well as for those that require additional expenditures to be successfully completed.

The survey findings relative to current practices regarding project progress reviews and "continue or abandon" decisions are discussed in Chapter VI.

Evaluating research results

Many studies have been conducted in an attempt to appraise the impact of research and development, and many techniques and models have been proposed as a tool for the measurement of its results. Generally, such studies can be placed in one of three categories as

dealing with interrelated, but distinct economic levels: (1) the broad macrolevel of the over-all economy or industry; (2) the level of the individual corporation; and (3) the level of the individual research and development project.

Investigations relating to specific companies usually attempt to appraise the relationship of the research and development activities to the company's growth and diversification or assess the over-all effectiveness of the research and development program. Some of these studies have proposed the use of various return indexes, while others suggest a purely qualitative type of evaluation.\(^5^5\) The Olin Industries Index of Return, previously reviewed, is perhaps one of the more widely publicised approaches falling into the former category. However, it is acknowledged not to be a measure of the actual sum realized and is regarded as a very conservative appraisal of the dollars earned.\(^5^6\) Another study investigates the utilization of the number and type of scientific papers published as a key to appraising an enterprise's productivity. While the assumptions necessary for the study are discussed and a warning is issued against making unwarranted conclusions, it is nevertheless concluded that the review and evaluation of such papers is a promising method for gaining insight into the research strength and strategy of industrial firms.\(^5^7\)

\(^5^5\) See Villers, op. cit., p. 112, for additional approaches.


Quinn defines research evaluation as the process of judging past performance for the purpose of guiding future action.\textsuperscript{58} It is in this light that post appraisal at the project level is considered to be so very significant.

Meaningful project post appraisal requires a baseline against which the actual results can be evaluated. This can be accomplished most conveniently by a profitability analysis which compares the actual returns attributed to the project with the total cost of undertaking the project. However, this is only a part of the post-appraisal process. In order to provide a basis for guiding future activity, it is necessary to compare the original estimates of project cost and returns with the actuals experienced. In addition, the reliability of the original estimates should be evaluated and related to the techniques used in formulating them, the assumptions upon which they were based, the methods of project design and scheduling, and the tendencies of the personnel who provided such estimates to either under- or over-state them. Such an approach involves, of course, not only the estimates generated for the research and development costs but also those provided for production cost, cost of capital, marketing cost, estimates of total demand, and estimates of the company's share of the market.

The desirability of accomplishing this when significant variances between estimates and actuals are experienced is readily

\textsuperscript{58} Quinn, \textit{op. cit.}, p. 8.
apparent. Dr. Villers notes that the follow-up and post-appraisal methods are essentially based on the recognition that variances should be adequately recorded and adequately analyzed. He states the following:

Adequately recorded means that actual results should be systematically compared to estimates and that the revised estimates, either after completion or when a revision is considered, should be compared to original estimates. Adequately analyzed means, first, that a reasonable range of variance should be anticipated. Within this variance, the performance should be considered as reaching the goal so that no analysis is needed. Second, whenever the expected range of variance is exceeded the one responsible should be given an opportunity to justify the variance.\footnote{Villers, \textit{op. cit.}, p. 97.}

The inference of the above that project post-appraisal is not necessary if performance is within established limits cannot be concurred with. It is entirely possible to have considerable variations from estimated cost and still remain within the upper limits as a result of compensating errors in the estimates. Similarly, the component estimates which make up the anticipated returns can vary significantly and still have the estimated return compare reasonably well with the actual. For example, if the total demand for a product was underestimated but the company's share of that demand was overstated, actual returns could be very close to those estimated as a result of balance between the two factors. The identification of this type of deviation forms an invaluable part of the baseline for guiding future action. In addition, again from the viewpoint of guiding future
effort, it could well be just as important to identify those practices which have led to the generation of valid estimates as it is to identify and eliminate those which have proven to be unreliable. The latter without the former, particularly if specific cause and effect relationships are not identified, could result in employing different approaches which are equally unreliable. The direction of future effort on the basis of past performance is best accomplished when both of these elements are present.

Post-appraisal in accordance with the above requires as a minimum, knowledge of the anticipated results of the project as well as the actual results and the research and development expenditures necessary to achieve these results. Depending on the nature of the stated project objectives, the post-appraisal analysis may require both quantitative and qualitative judgments, and these judgments, in turn, must be tempered by a knowledge of the extent to which the original objectives have been obtained, not just in regard to the effectiveness of the research and development program but also in regard to the effectiveness of the other components and operating divisions of the corporation which contribute to the results realized. For example, if a project was originated on the basis of a stated objective but the fallout information which became available through the research and

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development process led to the establishment and attainment of other objectives, the total benefits realized should not be allotted to the original project. Rather, as Quinn suggests, the point in time at which such surreptitious information became available and was recognized as significant in the attainment of another objective, should have resulted in it being specified as a separate project and evaluated on its own merits. Qualitative judgment and familiarity with the research and development activity is a prerequisite for such appraisal of project benefits.

While final project post-appraisal must wait until the end of the useful market life of a product, or the end of the application period for a manufacturing process, or as a minimum until the end of the time span considered for the initial project evaluation and selection, an appraisal can be made of the validity of the estimates of other components incorporated into the profitability analysis far before that point is reached. For example, if in the process of conducting the research and development portion of the project effort, it is found that the stated objectives cannot be accomplished in accordance with the most probable cost estimate, or the one best estimate even if this is solely the result of difficulties encountered in one task element, a revision in the best estimate cost (and possibly also time and manpower requirements) should be made. At such points in time it is possible to determine incrementally the causes for the required deviations. Similarly, variations between actual and estimated manufacturing costs can be determined and analyzed at, if not before,
the point of an actual production commitment. Also, certain indications regarding the validity of estimates relating to the marketing phase of the undertaking can be obtained prior to the end of the useful marketing life. As a minimum, preliminary appraisals of the estimates regarding the demand build-up, the total demand, the marketing cost, and to a lesser degree the company share of the market can certainly be obtained before the absolute end of the useful marketing life of the product.

A progressive appraisal procedure of the type discussed above enables the benefits of the experience gained to be incorporated into future activities at a much more rapid rate. Actually, even though a formal appraisal may not be conducted, the minimum benefits derived from such experience must be gained merely as a result of having to revise the estimates because original expectations were not met. An adequate system of project record keeping would ensure that such incremental appraisals are appropriately recorded for consideration in the final project post-appraisal analysis and reports.
CHAPTER III

THE ENVIRONMENT FOR PROJECT SELECTION

Introduction

Earlier discussions of Chapter I have outlined the purpose of this study, the major hypotheses that were investigated, and the methodology that was utilized. In the preceding chapter, selected portions of the contemporary literature and related research were reviewed in an attempt to familiarize the reader with areas of the process of industrial research management pertinent to this study and to develop a conceptual frame of reference.

The normal limitations placed upon a study of this type have precluded an exhaustive investigation of all aspects of industrial research and development management, many of which are appropriately emphasized in the existing literature. There are, however, certain areas which are of related significance and which indirectly tend to substantiate the study hypotheses. These have been identified as follows:

1. Organization for performance of the research and development functions.
2. Emphasis given the various objectives of the research and development program.
3. Methods of allocating resources for accomplishing research and development.
5. Over-all research and development program balance.
In a sense the above constitutes the environment within which the industrial research management functions of prime interest in this study must be performed. As a consequence, a limited amount of primary data relative to these areas were obtained during the research effort. These findings are presented in this chapter primarily to describe more thoroughly the related research and development practices of the companies participating in this study in areas where such information is not available from other sources.

Organization for accomplishment of the research and development function

Considerable diversity exists among the different industrial enterprises from the viewpoint of their organizational design for accomplishment of the research and development function. The evolution of these different organizational designs has, of course, been a function of the specific environment, requirements, and objectives of the sponsoring company. It is sufficient to note for the purpose of this study that the literature review and the case studies have shown that there are fundamentally four distinct organizational relationships prevalent within industry. These may be summarized as follows

1. Centralized Research and Development Organization - All research and development activity is undertaken at a central laboratory and no work of this type is done within the divisions or plants.

2. Decentralized Research and Development Organization - All research and development is accomplished at the division laboratories with no work at the corporate level, although there may be a vice president for research and development or a corporate technical director who functions as a consultant.
3. Functional Research and Development Organization - Where basic and applied research, together with some limited development, is performed at the corporate research and development center and the divisions perform their own development together with some limited applied research. The principal corporate research and development executive is responsible for and has control over all aspects of the corporate research and development program. Operation of a central research and development laboratory may or may not be found in a functional organization.

4. Parallel Research and Development Staff Organizations - Where the central laboratory is to provide the basic technological building blocks for the divisions, as well as performing some limited interdivisional development, and the divisions do their own development and limited applied research. Principal corporate executive officer is essentially a consultant to the divisions.

While the problem of industrial organization for accomplishment of the research and development function is interesting and somewhat controversial, it is not one of the prime areas of this study. It has been reviewed at this point because it is a principle environmental factor within which the project evaluation and selection functions, together with the progress follow-up and review, must be accomplished. However, these functions must be accomplished regardless of the organizational design. Organization per se only contributes to the effectiveness with which they are performed and to a degree dictates the level in the corporation at which they are performed.

The discussions of company practices presented in subsequent portions of this report are based primarily on information obtained from the eight companies visited and the three companies presenting case histories at the Purdue-Industrial Research Conference, together with practices as reflected in the current literature. For orientation
of the reader, the research and development organization of these eleven corporations is as follows:

<table>
<thead>
<tr>
<th>Centralized Organization</th>
<th>Functional Organization</th>
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<tbody>
<tr>
<td>Company A</td>
<td>Company D</td>
</tr>
<tr>
<td>Company B</td>
<td>Company E</td>
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<tr>
<td>Company C</td>
<td>Xerox</td>
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<td></td>
<td>Company F Goodrich</td>
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<tr>
<td></td>
<td>Company G Westinghouse</td>
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<tr>
<td></td>
<td>(no central laboratory)</td>
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</table>

Parallel Staff
Company H

It is perhaps significant to note that at no time during this study was there evidence of a totally decentralized research and development organization. In other words, it appears that in almost every instance an attempt is made by top corporate management to review and integrate the divisional level research and development activities. No attempt was made to obtain data relative to organization structure in the questionnaire.

Objectives of the program

The organizational design for accomplishment of the industrial research and development function has been discussed. However, the performance of industrial research must be purposeful and must support in some way the future of the particular company which sponsors it.

Perhaps the most fundamental aspect of the over-all research management function is that of establishing and clearly defining the objectives which are desired from the program. Without such a firm basis there is no relevancy criterion provided against which proposed projects can be evaluated and selected and against which the results of the research effort can be effectively measured.
Survey findings. Questionnaire recipients were asked to rank, within the framework of the established objectives for their research and development program, a list of the more commonly accepted functions that may be performed by research and development activities in accordance with the emphasis which they are given in their organization. The frequency of ranking and the weighted average is shown in Table 1. The following is a list of these functions in their rank order as shown by the survey results.

1. Develop new materials, processes, or products for existing markets.

2. Develop new materials, processes, or products to enter new markets.

3. Improve quality of current products.

4. Effect savings and cost of production or distribution.

5. Develop new uses for existing materials, processes, or devices.

6. Prevent or cure troubles of production or use.

7. Exploitation of high yield opportunities.

8. General applied research.

9. Increase sales appeal of a product.

10. Increase utility of a product.

11. Basic research.

12. Improve customer and public relations.

13. Abate nuisances or dangers.

## TABLE 1*

**FREQUENCY OF RANK GIVEN R&D PROGRAM OBJECTIVES**

| OBJECTIVE                                         | RANK 1 | RANK 2 | RANK 3 | RANK 4 | RANK 5 | RANK 6 | RANK 7 | RANK 8 | RANK 9 | RANK 10 | RANK 11 | RANK 12 | RANK 13 | RANK 14 | Average |
|---------------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|
| Improve quality of current products                | 20     | 18     | 11     | 15     | 5      | 7      | 4      | 2      | 2      | 2       | 2       | 2       | 2       | 2       | 2       | 3.31    |
| Develop new materials, processes, or products to enter new markets | 25     | 26     | 15     | 8      | 8      | 1      | 3      | 1      | 1      |          |         |         |         |         |         | 2.78    |
| Abate nuisances or dangers                         | 2      | 1      | 5      | 2      | 3      | 2      | 3      | 2      | 2      | 5       | 3       | 3       | 2       | 7.4     |         |
| Prevent or cure troubles of production or use      | 7      | 7      | 7      | 4      | 11     | 9      | 3      | 5      | 1      | 3       | 1       | 2       |          | 5.08    |         |
| Increase utility of a product                     | 6      | 8      | 2      | 4      | 3      | 5      | 3      | 8      | 5      | 3       | 2       | 2       | 2       |          | 6.05    |
| Increase sales appeal of a product                | 3      | 6      | 10     | 3      | 2      | 8      | 4      | 2      | 5      | 3       | 2       | 1       | 2       | 2       | 5.8     |
| Basic research                                    | 8      | 4      | 7      | 6      | 4      | 6      | 4      | 2      | 1      | 2       | 3       | 3       | 4       | 3       | 6.25    |
| Develop new materials, processes, or products for existing markets | 50     | 17     | 13     | 7      | 3      | 2      |        |        |        |          |         |         |         |         | 1.96    |
| Develop new uses for existing materials, processes, or devices | 7      | 13     | 12     | 11     | 6      | 5      | 4      | 4      | 1      | 1       |        |         |         | 1       | 4.0     |
### TABLE 1 - Continued

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<td>16</td>
<td>15</td>
<td>6</td>
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<td>4</td>
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<td>2</td>
<td></td>
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<td>8.08</td>
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<td>Improve customer and public relations</td>
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<td>3</td>
<td>5</td>
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<td>4</td>
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<td>4</td>
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<td>5.58</td>
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<td>Exploitation of high yield opportunities</td>
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<td>6</td>
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<td>6</td>
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<td></td>
<td></td>
<td></td>
<td>2.40</td>
</tr>
</tbody>
</table>

* As noted previously all tables presented are developed solely on the basis of the questionnaire findings.
A well balanced research and development program does not give prime emphasis to any one or two factors in the long run, although in the short term it may do this. Emphasis here should not be confused with proportion of effort. In other words, a company may do 10% basic research, 20% applied research, and 70% of product development. However, it would consider and emphasize the importance of the 10% basic research over the long run just as much as it would the 70% devoted towards product development. Many of the questionnaire respondents indicated this with their written comments and ranked several of the functions with equal emphasis. Others, however, ranked all fourteen factors in numerical order.

The first function was ranked first twice as frequently as was the second function, which received the next largest number of first place rankings. Exploitation of high yield opportunities, although ranked seventh over-all, received the fourth highest number of first place rankings. It lost ground in the over-all ranking, however, when combined with the total of first, second, and third placed positions.

The emergence of the function of developing new materials, processes, or products for existing markets as the number one objective of the research and development program should not have been totally unexpected. The protection of the current company share of the market against competitor's innovations is certainly an area which should receive a primary consideration. It does, however, indicate a departure from the suggestions of Furnas and Quinn who maintained that the dominant
consideration should be given to the protection of existing products and product lines. It may be representative of expanding markets which can absorb additional new products or may be an indication of rapid technological obsolescence. The improvement of the quality of current products was ranked third.

The clear identification of second place emphasis being given to research and development activities aimed at corporate growth, expansion, or diversification through the exploitation of new markets certainly indicates the nature of today's industrial research.

It is interesting to note that four out of the five first functions ranked are those having direct financial accountability, the results of which can often be measured directly and attributed appropriately to the research and development effort. Projects undertaken to improve the quality of current products is considered to be more nebulous and indirect as far as a direct measure of financial accountability is concerned. Often the best that can be done is to make an estimate of the share of the market or total sales that might have been lost had not such improvements been forthcoming.

Many statements of research and development program objectives are nebulous and vague. The approach employed in this study, of obtaining rankings for the various research and development functions, was adopted in the survey because it was felt that, in composite, it would give a better profile of the real corporate objectives both for individual companies and for the total of the universe.
Case studies. A brief summary of the major research and development program objectives of the companies interviewed and which presented case histories at the Purdue Conference and outlined their program objectives follows.

Company A concentrates effort at its laboratory primarily on applied research and development. The corporation sponsors (about 5% of the budget) basic research undertakings at cooperative industry research institutes. In addition, where investigations are desired that are considered as having proprietary value, the company will often go to universities to have the effort performed. The company ties in its research and development activities very closely with the requirements of operating management, which is usually of a short term nature, and frequently involves immediate production or quality control problems. As a consequence, the support engineering function represents about 25% of the total research and development effort. For the most part, the laboratory responds immediately to a request for such assistance without a prior evaluation. It was pointed out that this is necessary because when a product in production is having problems, either in the quantity being produced or in the quality control, money is being lost while a satisfactory product is not being turned out. It is considered necessary, therefore, to give this kind of situation a top priority.

Within Company A, competition is definitely responsible for much of the research effort, either in meeting the threats of potentially new products to be introduced by competitors or in attempting to get ahead of them and gain an even larger share of the existing market.
Emphasis is also given to the development of new products for introduction into new markets along similar and compatible lines. Company A's business necessitates a very high capital investment per unit of production, and emphasis within the industry is always on margins. While processing changes tend to be evolutionary and do not usually result in a high rate of technical obsolescence, consideration is always given in the research and development program to processing cost reduction projects.

Recently, Company A has undertaken an advanced program of projects for investigating the use of by-products. The company does not normally attempt to exploit the body of technology which it has accrued if its application would result in a product that does not match the corporate image or is outside existing marketing channels. In the past, however, where there was a sufficiently high potential payoff, it has undertaken such projects. These have been sold to other corporations for manufacturing under a license; in some few cases it has manufactured them themselves, within existing capabilities, and sold them through other channels. If such opportunities arise in the future, they will also be exploited.

Occasionally, Company A has been forced to undertake an unprofitable project in order to provide the service of a complete product line and maintain customer good will. This is a matter of qualitative judgment and generally results from inputs from the sales department, indicating that the corporation will lose customers to competition if it does not meet demands. Competitive position must be maintained.
Company B, on the other hand, has in the last five years fallen technologically behind the rest of the industry in the processing area, where the cost of manpower is a major portion of product manufacturing costs. Its labor costs are running about 43% of the manufacturing cost, whereas the company estimates its competitor's cost for labor to be about 30%. In order to maintain competitive prices, the company has been forced to operate on a reduced margin. The most urgent requirement established for the Company B research and development laboratory is the development of automatic processing equipment which will operate at a higher rate. Packaging, which represents about 20% of the cost, is the number two target for improvement through research and development. Two products manufactured by the company are in a very competitive market area, with high volume but low margin, and where customer acceptance depends more on quality and performance than on small reductions in price. In this area the development program is geared to keep pace with competitor's improvements. Less than 1% of Company B's effort is devoted, not to basic research, but attempting to keep pace with what is being developed within the industry and in the university programs in order to keep current with the knowledge being generated.

Company D devotes primary emphasis in its research and development activity to the development of new products which can be clearly differentiated from those already available. Some effort, however, is definitely devoted toward product improvement where it is felt to be warranted. Since the nature of the industry is such as to allow really
new products to be developed only as additional scientific knowledge and understanding become available, Company D devotes approximately 20% of its total effort to basic research.

Company E was founded over 40 years ago and still does 92% of its business in its original area of endeavor. The industry in general has tended to resist technological change and there has not been a significant innovation introduced for fifty years. The major emphasis in its research and development is that of attempting to adopt the techniques developed by a parallel industry with the objective of implementing these ideas before other companies in the industry can compete. The corporate management views this adoptive technology undertaking as a major key to future survival in the light of threats from new materials development and the rapid disappearance of the type of labor market to which the industry is oriented.

Company F is fundamentally oriented to a single product. As described, the product is basically a mechanical device, which will ultimately be totally electronic. In addition, by utilizing the module tie-in concept, its functional capability will be greatly increased through such integration and will permit company expansion into the total systems area. With this long range objective in mind, Company F's research and development program is rather diversified. However, its principal interest is the timely introduction of significant product improvement. Furthermore, it has a policy encouraging exploitation of the technology which it generates. In some cases it has licensed products
to other corporations. More recently, it has formed a special products division to handle those results of its research and development activity which do not match the corporate image or existing marketing channels.

Dr. F. K. Schoenfeld stated that the first concern of the B. F. Goodrich research and development program is to maintain cognizance of the advancement in technology necessary to protect the existing product lines and to improve corporate products through increased quality of products. This type of effort is balanced with active investigations leading to potential new areas of business. About ten years ago Goodrich lost competitive strength relative to the remainder of the industry in the areas of process improvement and cost reduction. Although their current technological position is felt to be good, this type of research and development activity is always of interest within the company.

Capital budgeting

Once the desired objectives of the corporate research and development program have been defined, the first criterion (not considering an obvious lack of technical feasibility) for a broad screening of proposed projects is available. However, the literature review and the case studies indicated that more project ideas are presented for consideration than can reasonably be undertaken. The limiting factor to the magnitude of the research and development activity then becomes the resources made available. It seemed important, therefore, to provide at least a cursory insight as to how this is accomplished before introducing the remaining discussions.
The establishment of the research and development budget is a very significant decision for companies in today's technologically oriented industrial complex. However, determination of the optimum sum to be allocated is a difficult problem.

Since the availability of funds is not unlimited, it would seem logical to expect a corporate research and development budget normally to be formulated not only on the basis of the ability to finance the proposed program for the next fiscal year but also with deliberate consideration being given to the future investment that may be required in order to exploit effectively the results of successful projects. This could fundamentally relate to the corporate long-range plans and the specified direction and rate of growth. Realistic long-range planning, supported by appropriate financial planning, can by itself form the basis for establishing each fiscal research and development budget when properly translated into an operating plan for the next period. Accepting, therefore, the number of people currently in the research and development organization as a lower limit budget goal, an upper budget limit would be based on a projection of the availability of funds for the next fiscal period, or a future outlook of the funding situation in terms of the ability of the company to support the required investment, whichever is the lower.

Survey findings. Questionnaire recipients were asked to check the factors which they consider in establishing their research and development program budget. A tabulation of the results is shown in Table 2.
<table>
<thead>
<tr>
<th>Factors</th>
<th>Percentage</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of Sales</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Number of People in Research &amp; Development Activity</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cash Flow Projection</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Percentage of Profit</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>As Necessary to Support Long-Range Plans</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Anticipated Return on Investment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

* The table should be interpreted by reading down the percentage column. "X" indicates the percentage of questionnaire respondents who rely upon the factor or combination of factors so marked in the column.
### TABLE 2 - Continued

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>P E R C E N T A G E</th>
<th>U S E D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Percentage of Sales</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Number of People in R&amp;D Activity</td>
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<td>X</td>
</tr>
<tr>
<td>Cash Flow Projection</td>
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<tr>
<td>Percentage of Profit</td>
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<td>X</td>
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<tr>
<td>Anticipated Return on Investment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Other</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

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The survey results indicated that 22% of the respondents established the amount available for the research and development program as necessary to support the corporate long-range plans. An additional 15% indicated the basis for funding to be in accordance with the long-range plans and anticipated return on the corporate investment. This carries the inference that 15% of the companies would, if the expected rate were high enough, undertake a research and development program outside the limits of the current long-range planning. A total of 70% of the respondents indicated support of long-range plans to be a basic determinant of the budget level but with certain limitations being imposed, such as cash flow projections, number of people in the research and development activity, percentage of sales, or percentage of profit. It should be recognized, however, that indicators such as percentage of sales and percentage of profit are of value only to the extent that they provide the funds which will be available for distribution throughout the company during the next fiscal period. Only 7% of the respondents indicated that the funding was based primarily either on a percentage of sales or a percentage of profits.

That 15% of the survey respondents are willing to undertake research and development projects outside the scope of current long-range plans, provided that an adequate return on the investment can be realized, should not be surprising. As pointed out, Company F on a regular basis undertakes research and development programs that result in products, processes, or techniques which do not fit the corporate image and marketing channels. If the body of technology
which has been generated indicates that there is value to such a project, it is actively pursued. An attempt is either made to license it for use by another corporation or, for those items not fitting the corporate image, the company has established an industrial products division which finds markets for and sells the results of the fall-out research and development. This is somewhat analogous to a company which produces several different products all of which require the same manufacturing technology, but one of which must be sold through a different outlet or marketing channel to a fundamentally different type of customer. The promotion and sale of all products but the one which requires other outlets may be handled by a company sales force, with the exception being distributed through wholesalers or selling agents.

As pointed out in Chapter I, each of the individual questionnaire replies was placed in either Group A or Group B. It will be recalled that these two groups were established on the basis of their management policy profiles. All respondents classified in Group A select research and development projects in accordance with a written plan, conduct a quantitative profitability analysis on at least a selected project basis, and perform project level post-appraisal. Respondents not meeting all three of these criteria were placed in Group B, although they may possess a combination of any two of the three characteristics.

For purposes of comparison, the distribution of considerations given for establishing the research and development budget between the management profile Groups A and B is shown in Table 3. A chi-square analysis indicated a 40% probability that the differences between
Groups A and B, as shown in Table 3, are due to random sampling errors and it may be concluded that no statistically significant difference between the two distributions exists.

**TABLE 3**

**BASIS OF RESEARCH AND DEVELOPMENT FUNDING — PERCENTAGE**

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>39.5%</td>
<td>45.9%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Group B</td>
<td>35.9%</td>
<td>35.9%</td>
<td>28.2%</td>
</tr>
</tbody>
</table>

*Note: X = Research and development funding being a function of long-range plans and/or anticipated return on investment.*

*Y = Research and development funding being a function of long-range plans and/or anticipated return on investment but with some limit.*

*Z = Research and development funding being a function of other factors, but excluding long-range plans and return on investment.*

**Case studies.** In all of the companies interviewed the research and development budget reflected the synthesis of management judgment. Even in Company F, where the Director of Research stated that budgets are usually fixed and that increases must be fought for, it was found that the program was integrated by a research and development committee with final approval being obtained for the proposed budget at the board of directors' level. In the research department of this company, the basis for establishing the budget was the previous year's funding plus an increase for salaries for technical personnel, together with whatever additional effort it is thought could be justified. In
opposition, the development portion of the research and development effort of Company F was established on the basis of a rather thorough analysis of the potential value of the results to the company.

The Vice President of Company B stated that projects are undertaken on the basis of market trends and indicated demands. However, he pointed out that the corporate objective was to maintain the research and development budget at a relatively constant level and that within this allocation specific jobs are undertaken. He noted that if you attempt to tie the research and development budget to the growth of the company, there is a tendency to allocate too much money and too many men, with Parkinson's Law taking over—namely that the job expands to fit the money and the men allotted to accomplish it, but not necessarily providing any increased benefits. While this is contrary to the philosophies expressed in other organizations, it serves to illustrate the point that research and development funding is a management judgment decision and is not tied to something like sales or profit; if anything, the decision is only limited by sales or profit because of the resulting funds availability.

The research and development budget in Company E has doubled each year since 1963. It may be recalled that this organization is engaged primarily in adoptive type work where the existing technology from another industry is being employed, and therefore, lends itself more readily to rapid expansion than is true in some of the other laboratories. However, budgets for the program must be approved at the corporate level as a result of a review of the projects proposed.
The Director of the Company E research and development laboratory noted that the procedure for project review was a result of his efforts and has been in effect for only a very short period of time. He pointed out that it is sometimes necessary to spend a great deal of time justifying and selling the program but that this must be accomplished in order to obtain the desired and necessary management backing. In the case of Company E, the long-range plan for corporate utilization of the results of the research and development program was drawn up and sold by the research director, rather than being provided to him by top management.

While reference to research spending in terms of percentage of sales, or percentage of profit, provides a convenient expression, this study has shown that such indices are used, at best, only as broad indicators to provide a guide for the initial formulations of research and development budget estimates. In such cases, experience through the years has probably shown that these figures represent a fairly constant relative proportion of the sales or profits that can be allotted for research and development purposes, but are ultimately determined by an analysis of other factors. The budgets allocated for sales, advertising, distribution, and manufacturing could be expressed in a similar fashion. Statements which indicate that management of the late 1960's allocates a blanket sum to research and development projects on the basis of a percentage of sales, simply because it is the fad or represents a status symbol, are pure mythology. For the most part, such funding is provided as a result of deliberate and objective top management
judgment, relating to the short- and long-range plans and objectives of the company and to the urgency of identified needs and requirements of the company and the market. The fact that the composite management judgment in the establishment of operating budgets for the various functional activities of the corporation, as reflected in financial plans or cash flow projections, is related to a percentage of sales for the research and development function is felt to be misleading. Limitations in the maximum funds made available result, of course, from considerations previously discussed.

Provision for the unusual

In the previous section the normal basis for establishing the funding level for the corporate research and development program was discussed. Such budget allocations generally cover the planned and foreseeable project efforts which have been selected for inclusion in the over-all program. However, the nature of research and development investigations is such that at any time it is entirely possible to conceive and definitize new ideas for potentially profitable projects not before envisioned. Additionally, unanticipated changes in market preferences or trends, or the introduction of new products or product improvements by competition, can suddenly create an urgent market or company requirement for a heretofore unanticipated endeavor.

Survey findings. Questionnaire recipients were asked to indicate what provisions they have for obtaining additional funds, or other resources, that may be needed to support a previously unidentified,
potentially profitable project. The results are presented in Table 4. Only an approximate 18% of the survey respondents indicated that they had no provisions for obtaining additional funds for their research and development program. Insight regarding the handling of such situations was obtained during the company visitations. An additional appreciation can be realized from the comments volunteered by survey respondents. Typical of these are the following:

1. If outside the budget, we would reallocate to project X from project Y, Z, etc. If outside of the total resource limitations we would probably not pursue project X unless it was determined beneficial to drop another effort. The issue has not yet come up.

2. A division can call upon the corporate research and development laboratory for assistance in any area.

3. Anything done is, by definition, within the budget. The budget is flexible and funds can be obtained from unmarked corporate funds.

4. Inapplicable to a company of this size.

5. Obtaining additional resources for a specific project not previously identified requires selling the project to the general manager who in turn must sell it to the Vice President of Finance.

6. Never had this trouble.

7. If the project is outside the limits of our available personnel and facilities we would attempt to use consulting laboratories. If it were outside the financial resources (including credit), we would either undertake a joint venture or attempt to sell the idea.

8. All projects are financed within the corporation, either by the division or with corporate opportunity funds.

Many other comments were received, but the substance of them is generally covered by the above.

Case studies. All of the companies interviewed had provisions for requesting additional funds by going back through the corporate
### TABLE 4

PROVISION FOR ADDITIONAL RESOURCES

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
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<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>E</td>
<td>B</td>
<td>N/P</td>
<td>I</td>
<td>E</td>
</tr>
<tr>
<td>Long Term Funds</td>
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<td></td>
<td></td>
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<tr>
<td></td>
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<td>3</td>
<td>9</td>
<td>17</td>
<td>18</td>
<td>4</td>
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<tr>
<td>Short Term Funds</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>1</td>
<td>7</td>
<td>10</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Intermediate Term Funds</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
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<td>8</td>
<td>11</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Technical R&amp;D Personnel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>9</td>
<td>18</td>
<td>10</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Specialized Facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>12</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

| No Provision for Additional Resources | 8 | | | 10 | | | | | 18 |

*I = Internal Sources  
E = External Sources  
B = Both Sources  
N/P = Not Provided for*
channels to the organizational level at which the budget approval was
granted, usually the board of directors or a committee of corporate
officers.

Every corporation visited has at one time or another experienced
the necessity of undertaking a "crash project" because of unexpected
market changes or the action of a competitor. The frequency of such
undertakings, of course, varies from company to company, as does the
primary origin of the requirement. The consensus from the industrial
research and development executives interviewed is that sudden changes
in market trends, which were not stimulated by a competitive new product
being introduced, are relatively infrequent. The interview portion of
this study indicated that the organizations visited maintain significant
detailed information on the markets with which they are concerned. It
may be generally stated, therefore, that for the companies which were
interviewed, the primary source of a requirement for a crash project
arises from the competitive environment as it affects the market.

Another aspect worthy of note is that the development of a
"me too" product does not by itself appear to offer sufficient motivation
for the expedited effort. In general, the interviews indicated that
the "all out" project activity will be pursued by a company for one of
three reasons, or combinations thereof: (1) when the competitor's
product is sufficiently superior in performance so as to jeopardize
seriously future sales; (2) when the introduction of a competitor's
product results in a shift of market preference away from the area of
prime interest to the company; and (3) when the company has already
invested a large amount of money in the development of a similar product and the timing of its introduction into the market is important from the share of the market viewpoint. A fourth possible reason pointed out by one vice president for initiating a crash effort, but to which response is more often handled in the normal development manner, is where a competitor's new product augments the existing line and there is the danger of a sales decline unless the same complete line can be offered.

Numerous examples of the above were discussed during the interviews conducted. To illustrate, a case is taken from the files of Company F. The nature of the business in which the company is engaged is such that it is extremely important for the company to have its product line, with appropriate technological improvements, ready to introduce at the time of, or before, a competitor's introduction. The situation arose where a competitor had introduced a piece of equipment not yet fully developed by Company F. Several millions of dollars had already been invested in the research and development effort necessary for the development of the unit; however, it was approximately one year behind in its planned market introduction. In addition to the possibility of losing a large share of existing market to competition, the lack of timeliness of the Company F development effort could have very possibly also resulted in the loss of the research and development investment that had already been made.

The potential impact of this situation on the company business was so great that it drew the personal attention of the Chairman of the
Board of Directors, who received weekly briefings on the development status and personally directed the counter strategy of the company in combating the situation. Concurrent action became the rule of the day, and all technical personnel who could assist in the expedited completion of the project were assigned to it. Production drawings were released and actual manufacturing commenced before the normal development testing was completed. The company decided to risk the occurrence of minor operating problems in initial units rather than to lose the market. Sales orders for the unit were accepted from customers even before production was started. The expedited effort resulted in introducing the product on the market slightly over six months sooner than the original planning had specified. In addition, a large portion of the market was saved as a result of promises made by salesmen to their customers that the unit would be available shortly. This type of situation is certainly far from what the interviews indicated to be normal in the industrial research and development laboratory. However, it well serves to illustrate the kind of activity that can be generated outside of the normal planning effort.

Company F appears to be one of the exceptions that proves the rule, having undertaken many such crash programs. This results primarily from its research and development management philosophy. Rather than trying to be a leader in the introduction of new products, the company follows the market trend and actions of competitors. The Vice President said that he does not feel that long-range planning in relation to research and development activities can really be accomplished.
He stated that as a consequence his company's plans are open ended and are adjusted in accordance with the needs identified, noting that project emphasis must be shifted to reflect the trends and demands of the market. He pointed out that in the past the company has been instrumental in introducing new products. However, he does not feel that this type of effort is really worth the payoff involved, since there is a relatively short development time required in the industry, thus allowing competition to enter the new product field rapidly. (The relatively short time referred to is a one- to two-year period.) Since Company F attempts to maintain a constant budget level for the research and development activity, frequent changes in project emphasis within the laboratory are experienced. The marketing people, however, do not agree with the Vice President's philosophy. They noted that by the time a market trend or preference has been established and the company has accomplished the necessary research and development effort to enable their version of the product to be introduced, they are very frequently on the downward side of the demand curve. In addition, it was pointed out that the only thing the company can really offer from a competitive viewpoint is lower price. Unfortunately, the company is generally not in a position to do this, since by the time it is ready with the product, the competitor's processing has been refined and its marketing established to a point where the margins are widely different.

The case studies brought out the fact that in most short-run situations the availability of additional funds is of little significance
and work on a new project cannot be effectively accomplished except at the expense of current projects within the laboratory. This is the obvious result of the limitation of the number of trained and experienced technical people available, and the inability, together with a usual lack of desirability, of a rapid expansion of the organization. As a consequence, the start of work on important new products which are outside the scope of the approved program is usually undertaken by diluting the over-all effort through an internal reprogramming or reassignment of people and funds from current projects. In some cases it was stated that current projects may be delayed or dropped altogether.

The Director of Development at one company pointed out that the manner in which such events are handled is entirely dependent upon the specific nature of the situation, the relative importance and timing implications of the new project compared to those currently being pursued, and the evaluation and judgment of the executives who must make the decisions. If, for example, the timing of the new project had no major impact on its ultimate value to the business, there would be no need to disturb the planned operations. It could be given a priority and added to the list of projects to be undertaken as current efforts are completed or phased out of the program. However, this is certainly not the case with the crash project; nor can it generally be said that the timing of the introduction of the results of the research and development have little influence upon their value.
From the previous discussions the reader may have identified three alternatives to the above which could potentially provide some relief.

1. Utilization of the time normally provided to laboratory personnel for independent investigations.

2. Pre-empting for application to the new project any allotted discretionary funds and associated manpower.

3. Employing outside technical consultants to work on the new project or to fill the gaps left by reprogramming.

While it must certainly be acknowledged that these alternatives could alleviate the ramifications of new project activity, many persons interviewed pointed out that each has rather definite limitations. Generally, the time granted for independent investigations is given to the scientists working primarily in the basic research area. Projects of the type under consideration usually involve highly structured applied research or development efforts. The experience of the "long haired" scientists may not be directly applicable. In addition, it is possible that such action could generate a morale problem. Discretionary funds, where they are provided, are usually intended to cover the inevitable laboratory contingencies such as the actual costs exceeding estimates, the overtime required to maintain schedules, and conducting exploratory and feasibility studies of potential new projects. Technical consultants are more expensive than full-time employees and their use makes the results more costly; they frequently do not have the highly specialized technical knowledge and intimate familiarity with other operating aspects of the company that may be required for over-all
consideration in the project results; and good technical consultants are busy and generally are not immediately available to work on an urgent requirement.

In situations involving new projects of a longer term duration, such as those frequently resulting from technological breakthroughs, the availability of additional funds can be of major significance. Two of the executives interviewed pointed out that in this type of situation the organization can be effectively expanded by reprogramming experienced people of the appropriate level from existing projects and by subsequently augmenting these projects with new people brought into the company. It is possible for this to be accomplished in such a manner as to minimize the over-all impact on the program, while at the same time absorbing at the desired level of activity the new project, or projects, that may have been identified.

The over-all research and development program balance

The substance of this study was addressed primarily to the specific management aspects relating to project level activity within industrial research and development organizations. However, the broader aspect of the over-all program—the summation of all approved projects and studies—cannot be ignored. Within established resource limitations, the balancing of effort within the over-all program can be a significant factor in the selection of individual projects for inclusion during any given period.
To assure that individual projects are selected and undertaken in accordance with stated management goals, or in support of long-range planning objectives, does not necessarily assure that an over-all program will evolve which adequately supports the corporate management desires and expectations from the research and development efforts in an optimum manner. Unbalance in the current program, in terms of long-range achievements and the relative emphasis desired between the various research and development functions, can easily occur unless specific management attention is devoted to this area. The over-all program should be such as to give consideration not only to the objectives of the next two or three years but also to those five or even ten years in the future. Tendencies to concentrate on projects relating to the existing business and products of the company may bring the immediate results desired but may leave a gap in business activities in the years ahead.

A cross section of all the projects current within the laboratory should be reasonably representative of the effort required to achieve stated objectives and should reflect a balanced approach in terms of the length of the project run or duration, the risk involved, the mix of technologies being investigated, the anticipated return on expenditures, and distribution of effort between the levels of research activity. The final phase of project selection should involve a screening of all proposed undertakings to see if the total program proposed reflects the balance desired and specified by previous planning effort.
Survey findings. Questionnaire recipients were asked to indicate what aspects of their over-all research and development program are reviewed, on at least an annual basis, in order to assure that a proper balance is maintained. The results are shown in Table 5.

**TABLE 5**

FREQUENCY OF FACTORS REVIEWED FOR OVER-ALL PROGRAM BALANCE

| Distribution of high and low risk projects | 67.5 | 29.7 |
| Emphasis on product innovation or improvement | 75.6 | 21.8 |
| "Mix of technologies" being investigated | 75.6 | 21.8 |
| Short run versus long run projects | 65.0 | 32.4 |
| Development of new products | 89.2 | 8.1 |
| Cost of research and development versus returns | 78.3 | 18.9 |
| None of the above | 2.7 |

Approximately 3% of the respondents indicated that they do not review the over-all program balance in relation to any of the factors listed. The largest percentage indicated a review to assure the proper balance in the development of new products. This is
consistent with the emphasis placed on this area in response to the question regarding the objectives of the research and development program, which was discussed previously. The second largest percentage of respondents showed over-all program balance consideration being given to the cost of research and development versus the returns that may be expected. The emphases being given to the improvement of current products and the "mix of technologies" being investigated are each reviewed by approximately 76% of the respondents. In contract to the emphasis given in some of the literature to the significance of over-all program balance in relation to a proper distribution of short- and long-term projects, fewer respondents indicated being concerned with this area than any other. It is reasonable to assume that those factors not reviewed on at least an annual basis are considered to be unimportant in terms of the over-all program balance.

To summarize the survey results, it may be generally stated that the managers of industrial research and development review the over-all program balance primarily from the viewpoint of an adequate level of anticipated profitability as a result of the periodic introduction of new products into the market and the improvement of existing products. Additionally, emphasis is given to the "mix of technologies" being investigated to assure a balanced effort across the scientific and technical areas of long-term interest to the corporation. To a somewhat lesser degree, emphasis is also given to the program balance in relation to the distribution of the project risks and the length of project run.
Case studies. Company visitations indicate that this type of program-level planning is accomplished as an integral part of the project review undertaken for the purpose of selecting projects and obtaining the budget appropriation for the next fiscal period. At that time any changes in corporate plans or objectives are reviewed and the relative emphasis given to the various laboratory efforts are reconsidered in the revised light. A common approach is to assume that the various areas of activity will receive about the same emphasis for the next period as they are currently receiving. Adjustments are then made as may be deemed necessary.

One approach for accomplishing this is to assume that approval for all current projects terminates at the end of the fiscal year. Under this ground rule, new project proposals compete with old ones for inclusion in the next year's program. Proposals are then prepared for all of the new projects that have been proposed for undertaking during the coming period, together with a status report and outlook on the current projects. Projects are then identified as candidates for inclusion in the program in accordance with established or anticipated resource limitations and any identified changes in the future outlook.

The manner in which this is accomplished was found to vary from company to company, but generally reflected committee action, either formal or informal, with the final approval being obtained at the organizational level where the program is reviewed for budget approval. Company B, as indicated previously, gives little consideration to this type of over-all program planning. The Company E program
reflects primarily the ideas and philosophies of the laboratory director; however, he must also sell his program to the board of directors. At Company F the program planning, and identification of candidate projects, is accomplished by a formal committee with representation from finance, production, and marketing as well as from the research and development laboratory. Their program is reviewed and approved by the board of directors. It must include for each project a qualitative estimate of the production, marketing, and technical risks associated with the undertaking. In addition, charts are included which show a breakdown of the proposed projects in terms of their percentage relationship to the following.

1. Levels of research and development (basic, applied, development)

2. Mix of technologies being investigated

3. Current and potential future product lines supported.

There is a general policy relating to the desired percentage distribution of the above and the proposed program is reviewed by the corporate directors from this viewpoint. It is not intended that each year's program adhere rigidly to the specified desired distribution. Rather, it is intended that deviations be implemented in an intentional and purposeful manner, with the knowledge and understanding of all concerned.

It was observed during the on-site studies that the frequency of review for overall program balance is sometimes found to be more than once a year—especially in those organizations holding semi-annual
or quarterly program status reviews. Additionally, it was pointed out that new information is always being gained relating to the technical aspects of successfully completing the project, the probability of economical production, and trend in the market, which could indicate the desirability of a reappraisal of the program balance. One executive noted that the change in status of a major project could perhaps automatically trigger a check of the over-all program balance. It would appear, however, that over-all planning on an annual basis, together with the approval of the projects which are to constitute the program for the next year and a check for balance at that time, would necessitate at the most a semi-annual review to assure that the desired balance is being maintained. More frequent reviews could result, of course, from a poorly planned or unstable program where objectives are constantly being revised.

While many resource allocation and optimization models have been proposed and could probably be readily adopted as a tool to assist management in arriving at the desired program balance, there was no evidence of the utilization of this type of analytical technique encountered anywhere during the study. Primarily such models utilize a priority approach, or an identification of the relative emphasis which it is desired to place on the various research and development functions. However, all companies interviewed relied solely on a subjective composite of management judgment for establishing the desired program balance.
CHAPTER IV

THE PROCESS OF PROJECT SELECTION

Planned project selection

This study has attempted to determine the extent to which the evaluation and selection of individual research and development projects within industry are formalized or preplanned. Information on this subject was sought both in the mail survey and during all of the interviews. It may be recalled as one of the criteria upon which respondents were classified into either Group A or Group B. The interviews offered, of course, the best opportunity to explore in depth the procedures employed for project evaluation and selection. However, the subject was also covered at the Purdue Conference, and the survey respondents were requested to enclose a copy of their written selection plan with the completed questionnaire. An analysis and synthesis of the data obtained are presented in a subsequent section of this chapter.

Survey findings. The questionnaire recipients were asked if their company has a definite plan for selecting proposed individual research and development projects. The results are shown in Table 6. Approximately 73% of the respondents have written plans for selection of their research and development projects. Roughly 20% of the
respondents indicated that they did not have a written plan but that
they had a definite plan which was verbally understood. Of these,
11.22% stated that their plan was written and variable according to
project, while 8.4% stated that their plan was verbally understood
and variable according to project. Approximately 4% of the respondents
indicated that they had no definite plan for project selection and an
additional 3.75% stated only that their procedure was variable according
to the project being considered.

TABLE 6
FREQUENCY OF RESEARCH AND DEVELOPMENT
PROJECT SELECTION BY AN ESTABLISHED PLAN

<table>
<thead>
<tr>
<th>Type of Plan</th>
<th>Frequency Reported</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written Plan</td>
<td>49</td>
<td>45.81</td>
</tr>
<tr>
<td>Verbally Understood</td>
<td>12</td>
<td>11.22</td>
</tr>
<tr>
<td>Variable According to Project</td>
<td>4</td>
<td>3.75</td>
</tr>
<tr>
<td>Written &amp; Variable According to Project</td>
<td>29</td>
<td>27.07</td>
</tr>
<tr>
<td>Verbal &amp; Variable According to Project</td>
<td>9</td>
<td>8.40</td>
</tr>
<tr>
<td>No Definite Plan</td>
<td>4</td>
<td>3.75</td>
</tr>
</tbody>
</table>

The question must naturally be asked as to how the organizations
with no definite plan, written or verbal, select projects for under-
taking. Perhaps some insight can be gained into this situation as a
result of the letters which accompanied some of the returned
questionnaires. In one instance, the respondent wrote that the company
does not have a written plan but does have a definite written procedure
which is to be followed. He enclosed a copy. Upon examination, it was
found to be a rather comprehensive and descriptive document, and the
survey results have included the respondent as having a written plan. However, it is not known whether the semantics affected the additional negative replies.

Another respondent wrote that he has a small research and development organization of less than 100 people, is in good communication with top management and other operating departments of the corporation, and knows what has to be done. The laboratory undertakes those projects which have the most urgent requirement or show the highest profit potential. Here, it is likely that project selection evolves as a result of both formal and informal discussions.

The respondents who indicated only that their plan for project selection is variable according to projects leave the impression that a specific plan, whether written or verbally formulated, is established for each project depending on its specific merits and the situational condition.

At any rate, it is not considered reasonable to assume that respondents from the selected universe operate unorganized and inefficient laboratories simply because they did not indicate having a definite plan for project selection. A more reasonable assumption is that their procedure is informal with project selection and overall program formulation evolving as a result of discussions over time and that the procedure is not identified as a verbally understood plan.

Case studies. All but one of the companies visited during the study had written plans which were generally followed in the evaluation and selection of research and development project proposals
except for "unusual" situations. The development effort of Company D largely depends on the background of knowledge uncovered during the basic and general applied research projects. Project selection, as well as the subsequent formulation of the over-all program, is evolved through a series of face-to-face meetings and discussions held with the various department heads in the laboratory. This is accomplished, not at a specific point in time, but on a periodic basis throughout the year. The Vice President for Research and Development pointed out that the enthusiasm and interest which the individual scientists show in given areas of research are frequently given prime emphasis in project selection. He noted that when a person is interested in an area and feels that he can solve the problem, he is most likely to be successful. He stated that market conditions and the timing of product introduction are also given high priority in the selection process. It was pointed out that the review meetings held are of such a nature that everyone who is knowledgeable in the area and who can provide an input participates in the discussions. The fact that the selection procedure of Company D is not planned, but rather verbally understood, should not be taken to indicate that appropriate analyses of significant factors relating to the project are not conducted when they are felt to be necessary and desirable.

The three companies presenting case histories at the Purdue Conference also acknowledged having written plans for project evaluation and selection. Mr. Damon, Xerox Corporation, described in depth a computer program which his company utilizes for such evaluations.
Elements of the plan

Throughout the course of this study, company plans for the selection of research and development projects were discussed with executives of the eight organizations visited and with industry representatives at the Purdue-Industrial Research Conference. In addition, twenty-three written plans provided with completed survey questionnaires have been reviewed and analyzed. As one would expect, the differences between these plans were great, varying in length from a single page with blank spaces for appropriate completion to a formidable twenty-nine page document. The latter contained definitions, flow charts showing the company organizations that are to participate, the sequence of steps to be taken and coordination to be obtained, sample tables to be filled out, detailed instructions for calculating the desired information together with examples of calculations, and typical charts which should be prepared and included. In some instances, the inputs from the different operating departments were to be prepared on color coded paper (i.e. Pink: research and development; Yellow: manufacturing; Green: marketing research; Blue: sales; Tan: finance; Orange: plans) in order to permit rapid and sure differentiation.

The amount of internal flexibility acknowledged and provided for in the various plans also differed significantly. Some, for example, made no apparent attempt to differentiate between the information to be provided on a basic research project and an applied research or development project. The author feels that in such situations there is the inference, or verbal understanding, that the requested data are to be
furnished to the fullest extent possible—perhaps with some sections being marked "not applicable" or "unknown" as may be most appropriate. Other documents, however, specified different types of presentations for the different levels of research activity. In certain situations, provision is made for project approval, within the total budget allocation, at different organizational levels depending on the nature of the research activity, the total estimated costs and the predicted impact of successful project conclusion on other operating departments. In a contrary fashion, some plans, judging by the coordination and approval blocks, require review and signature at the same level regardless of the specific nature of the project under consideration.

Perhaps the most significant difference evidenced among the various plans was the degree of sophistication and back-up study desired in compiling the information and the depth of analysis or treatment given after it had been obtained. Some of the more important variations in these company practices will be discussed in subsequent sections of this report. In spite of the many differences between the various plans reviewed, there was one factor in common with all of them: each required the preparation of a written project proposal to be submitted and reviewed for approval. As noted in Chapter II, the desirability of this approach has long been recognized.

While it would be impossible, and not necessarily desirable, to synthesize all of the plans reviewed into an optimum plan that could be used in all situations, the approaches are sufficiently similar throughout so that a general discussion can be developed. It is felt that in
order to accomplish this most effectively, however, the discussion
should be divided into the preparation of a project proposal for (1)
basic research undertakings and (2) applied research and development
undertakings. One survey respondent wrote the following:

Our plans for selecting development projects
are quite different from those for selecting research
projects. In the area of fundamental research we
must have faith in our scientists, and projects are
selected by the research man in accordance with the
general interest of the company. On the other hand,
a new product development project will be selected
on the basis of estimated market size and potential
profitability.

Basic research proposals. As stated previously, basic
research project selection of Company D largely depends on the
interest and enthusiasm shown by the scientist working in the area.
Here, however, close attention is paid to the time and money which
go into the project, with effort being accelerated or decelerated
according to the results that appear to be forthcoming.

In the large majority of the situations reviewed, preparation
of a written project proposal for formal approval (as opposed to
projects worked on during the free time provided) was required for
basic research projects. Where such proposals are prepared, they
usually require the following information.

1. A statement of the research objectives
2. Identification of the related company interest or area
(product lines) supported
3. The planned technical approach (including time requirements)
4. Resource requirements
5. Potential or anticipated results

Executives at Company D and Company H pointed out that even in
basic research, which by its very nature is carried out in a "scientific"
manner, the undertaking is not pursued in a haphazard manner. There are definite objectives or purposes for conducting the study. A summarization of these is required in the project proposal, even if it is so nebulous as to state, "to investigate the basic relationship involving....."

If a corporation is to support basic research investigations, it must be made aware of how its interest is supported by or influenced by the consideration of the project being proposed. This may relate to the general field of interest of the company, to specific products or product lines, or to the general processing techniques which are employed. At any rate, it is usually necessary to identify the manner in which the proposed basic research project supports the corporate objectives.

The planned approach for pursuit of the proposed project is usually presented in terms of the fundamental methods of research investigation to be employed, together with an identification of the major phases of efforts necessary. In some situations, it is possible to identify the completion of major phases of effort as milestone events, the completion of which will enable a determination to be made as to whether the undertaking is yielding favorable results and should be continued, or whether it is unfavorable and should be dropped for the present time. Where such is the case, it was found to be considered desirable for this information to be included. This section of the proposal would generally also include an explanation of the probability of achieving successful project conclusion and why the program is felt to be warranted.
Several research directors pointed out two primary reasons for including a plan of the technical approach in a proposal for a basic research project: (1) to ensure that the project is well founded, well thought out, and pursued in a systematic manner and (2) to enable a realistic estimate to be made of the time requirements and associated man-hours and equipment cost for the total resource planning. It was almost uniformly found that basic research projects, where they are undertaken at all, are based on a certain percentage of the total effort or total allotted dollars. With this as the situation, it is the review and evaluation of the project proposal which enables management to decide the allocation of resources among the various basic research projects proposed.

In subscribing to the theory that it is possible to define objectives and lay out major phases of activity for basic research projects, it is maintained both at Company D and Company H that it is possible to develop hypotheses regarding the anticipated results that may be forthcoming. These, of course, may vary from a total lack of success in producing useful information to the desired results that the scientist had in mind when he proposed the project. In the latter case, an extrapolation of these benefits to direct application for company exploitation is sometimes described. Many research and development executives acknowledged, however, that serendipity plays a major role in achieving usable results from basic research projects.

The director of research, Company D, stated that his laboratory conducts continuous basic research investigations in the fields and
general areas which support the company long-term interest. He pointed out that through time various projects provide the knowledge which enables applied research and later development projects to be initiated. This concept is illustrated in Figure 4.

Figure 4 - Evolution of Product Development from Basic Research

It is not unusual to find that no usable results are obtained as a result of basic research investigations. It is even more likely to find that results, when they are obtained, require some additional
time before they are put to practical use. It was noted by Company D executives that this sometimes involves additional applied research or development projects. Frequently, the results of basic research projects lead to what Westinghouse's Dr. Shoup has termed "a solution looking for a problem." He points out that this is a fundamental benefit derived from basic research undertakings, and that in the long run, it may be just as important as finding a solution to a current and identified problem, noting that atomic energy was in this category for a long time and that perhaps lasers are in this category today.¹

Applied research and development project proposals. Hertz points out that Industrial Research is a matter of risk and that the risk involved may be immeasurably reduced by the collection of as much pertinent information as possible concerning a proposed project and a review of this information in the light of the over-all situation.² It is the author's observation from the plans reviewed and the discussions held that the applied research and development project proposals prepared within the industrial laboratory are prepared in an attempt to identify and provide management with this pertinent information. It is not felt, however, that management intends or desires by this approach to eliminate risk but rather hopes to balance the risk with the potential benefits that can be realized if the project

¹ First Annual National Conference on Industrial Research, Purdue University, January 10 and 11, 1966.

undertaken is totally successful. Although the types of projects under consideration are definitely oriented towards application, varying degrees of detailed information are necessitated for project approval, depending upon the level of activity (barely applied research versus late stages of development and pilot plant operation), the level of investment required by the company, and the probabilities of successful conclusion.

Most plans require that the written project proposals for applied research and development undertakings contain some type of presentation on the following.

1. **Statement of Objectives**—presents a clearly defined statement of the ultimate objectives of the proposed project and identifies the final application of the results in terms of a product or process and its usefulness to the company. A discussion of the pertinency of the anticipated results to the company interest may also be included.

2. **Impact of Successful Results**—contains an analysis and identification of the scope or impact of a successful project conclusion upon the company operation or upon other operating departments. This section of the project proposal may discuss such things as requirements for augmenting present production facilities, compatibility with existing marketing channels, replacement of current products or manufacturing processes, product line augmentation, identified areas of potential company expansion, and relationship with general fields of technical interest.

3. **Research and Development Technical Analysis**—provides a description of the research and development effort required to complete the undertaking, an identification of the major problem areas, a plan (sometimes including a schedule) for accomplishing the work involved, an assessment of the probabilities of obtaining successful project conclusions, and a summary of the resource requirements at least in terms of any unusual equipment and technical manpower requirements.

4. **Manufacturing Analysis**—includes an analysis of the production aspects of a research and development project whose objective is the development of a new product. This section covers such things as the adequacy of existing production facilities, a materials and parts list together with a plan for production or procurement, the production rate that can be reasonably expected, estimates of
unit production costs, and estimates of the probability of holding such costs, together with any variances which may be considered appropriate.

5. Market or Application Analysis—presents an estimate of the total product demand, the company's anticipated share of the identified market, the competitive situation and expected reaction, the recommended marketing channels for sales and distribution, the advertising or promotional campaign required, the anticipated marketing cost, and an estimate of the price range in which the product can be competitively sold. Such an analysis usually projects over the anticipated product life, or covers a span of time which experience has shown to be reasonable for purposes of analysis. An application analysis is substituted for the market analysis when the project proposed has as its objective the development of a new or improved process. Such an analysis will include an identification of cost savings, increased production rates, reduced waste, improved quality, and the expected useful life of the process.

6. Resource Requirements—contains the investment requirements for pursuit of the proposed research and development project, together with that required for exploitation of successful results. This section of the project proposal is essentially a plan which presents the integrated resource requirements covering all aspects of the total program, including the company's ability to finance the effort necessary in order to realize the desired or anticipated benefits. In a few instances, it was found that the resource requirements were included as a part of the profitability analysis. However, where this was done, it was separately identified.

7. Profitability Analysis—this analysis will be the subject of a detailed discussion in the next chapter. Every plan reviewed required the preparation of some type of profitability estimate for evaluation of the proposed research and development project.

Basis of project proposal information

The information discussed for inclusion in a research and development project proposal represents a near optimum collection of factors required for management decision. It must be recognized, however, that for different projects the quality of the information provided may vary significantly, even within the same company.
The press of time resulting from the urgency with which a decision must be made, or the cost involved in obtaining accurate data such as that which could be obtained by conducting a consumer market survey, could easily prohibit a high degree of accuracy. The definition of an end product of an applied research project, for example, could be so nebulous at the time it is originally proposed as to preclude the formulation of accurate estimates. The question may reasonably be asked as to whether estimates based on vague considerations resulting from such as the above are even worth making.

One Vice President interviewed offered an explanation. He pointed out that the accuracy of the data upon which a decision is based depends on two things: (1) the ability to obtain more accurate information and (2) the impact or significance of the decision being made. To illustrate his point, he drew a typical cost curve for a project undertaking (illustrated in Figure 5), noting that in the early stages of an applied research project the costs are rather low and the build-up is slow, especially in comparison to the later stages of development and initiation of production. As an example, he indicated that in a project where the results could not be clearly defined but the general composite opinion was favorable, the company would probably allocate some level of funding for limited effort on the project. By incremental approval of this type, the effort could be pursued until it was clear that the desired objective could not be obtained or until such time as the results became apparent and the basis for more detailed estimates could be provided. He pointed out
that the objective composite judgment of executives who were knowledgeable and experienced in the field was significantly different than a "hunch."

The Director of Development at Company F offered a slightly different explanation. He pointed out that for the initiation of an applied research project, where the end product has not been built in a laboratory working model and exists solely in the minds of the laboratory scientists, only the roughest approximations of manufacturing costs can be provided. He stated, however, that research and development project proposals of this type are not generated in a vacuum and that it is necessary for the people preparing different sections of the proposal to talk to one another. He noted that in a case such as has been mentioned, the personnel preparing the production estimates can
discuss the end product, to the degree that it may be reasonably described, with the laboratory people who will be conducting the development effort. He pointed out that past experience with similar products in the company line, perhaps having similar performance functions and of the same approximate size, can frequently be used for the basis of an estimate. At the development end of the spectrum where a laboratory working model has been constructed and tested, the product can be described in more detail and estimates of production cost are more reliable.

In some instances, it was found that production cost estimates will work back from the marketing considerations. Here a marketing survey could perhaps indicate that the products would be competitive when introduced in the market if they sold for a certain price. Working from the selling price backwards, it can be determined what production costs must be. In such a situation, the manufacturing analysis would indicate the probability of being able to produce the product for this cost.

To illustrate the above, an example is cited from the experience of Company D. The company had pursued a project to a rather advanced state of development effort. Technical feasibility of successful conclusion was no longer in doubt; however, the marketing analysis indicated that the product must sell for a certain price or below. On the basis of available information, analysis showed that the product could not be produced for the price specified by marketing. Although an obvious approach would have been to drop
the development effort immediately, this alternative was not pursued in the particular case. Rather, an additional research and development effort was initiated, the results of which enabled the processing costs to be significantly reduced to the point where the company could manufacture the product and sell it at a rather attractive margin.

Several of the selection plans reviewed acknowledged differences of the type discussed by requiring, in some manner, an explanation of the basis on which the estimates were made be provided. However, the written plan of two companies visited did not clearly request this information. In one case, the writer was told that the subject is always discussed in relation to the risk specified for the various project phases; in the other, it was pointed out that the basis for the estimates provided is discussed in the summary and recommendation section of the project proposal.

Many of the persons interviewed indicated that in some areas they will tend to keep working on things up to the point where a fair idea is established of what can be done. It is then time to put the project on the shelf for a while or to pursue the effort more actively and induce others to use the knowledge or results. All warn, however, that there is a tendency, if you leave a project on the shelf too long, for it to become obsolete and for you to lose what you have already put into it.

At the Purdue-Industrial Research Conference, Mr. Hart stated that Goodrich would never undertake a produce development project of
"any size" without first having conducted a market survey. This position was generally reflected by all those interviewed, although a few people indicated that if there were high confidence in the project's success, it might be carried through development without such positive information. All stated that before a production commitment would be made, positive market and sales volume information would have to be available.

The factors of project selection

In studying the relative emphasis given the various factors considered in the process of selecting research and development projects for incorporation into the company's program, the questionnaire survey results offer the soundest basis for discussion. Questionnaire respondents were asked to rank any of eighteen different factors which they consider and evaluate when reviewing a proposed research and development project in accordance with the level of importance (one = most important; two = secondary consideration; three = general consideration only) they attach to the factors. Table 7 shows the weighted average of the ranks given these factors in the order of importance established by the total respondent sample. The importance level assigned by both Group A and Group B is also shown for purposes of comparison. It will be noted on the Table that factors 1 and 2, and 4 and 5, have the same ranking in the total sample. In order to establish the relative position, the calculations were carried out to a fourth significant number.
<table>
<thead>
<tr>
<th>FACTOR</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential project profitability</td>
<td>1.21</td>
<td>1.64</td>
<td>1.44</td>
</tr>
<tr>
<td>Long-range plan objectives</td>
<td>1.36</td>
<td>1.52</td>
<td>1.44</td>
</tr>
<tr>
<td>Company's ability to exploit a successful result effectively</td>
<td>1.63</td>
<td>1.44</td>
<td>1.53</td>
</tr>
<tr>
<td>Compatibility with marketing channels</td>
<td>1.73</td>
<td>1.74</td>
<td>1.74</td>
</tr>
<tr>
<td>Urgency of company or market requirement</td>
<td>1.56</td>
<td>1.90</td>
<td>1.74</td>
</tr>
<tr>
<td>Company policy</td>
<td>1.64</td>
<td>1.85</td>
<td>1.75</td>
</tr>
<tr>
<td>Compatibility with product lines</td>
<td>1.76</td>
<td>1.95</td>
<td>1.86</td>
</tr>
<tr>
<td>Technical risk of the undertaking</td>
<td>1.90</td>
<td>2.00</td>
<td>1.95</td>
</tr>
<tr>
<td>Compatibility with R&amp;D skills</td>
<td>1.78</td>
<td>2.13</td>
<td>1.96</td>
</tr>
<tr>
<td>Estimated project cost</td>
<td>2.05</td>
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<td>2.04</td>
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<tr>
<td>Compatibility with production facilities</td>
<td>2.03</td>
<td>2.18</td>
<td>2.11</td>
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<tr>
<td>Concentration or resources required for timely completion</td>
<td>1.97</td>
<td>2.27</td>
<td>2.13</td>
</tr>
<tr>
<td>Interaction with other projects currently in work</td>
<td>2.08</td>
<td>2.36</td>
<td>2.23</td>
</tr>
<tr>
<td>Patent situation</td>
<td>2.16</td>
<td>2.44</td>
<td>2.31</td>
</tr>
<tr>
<td>Length of project run (time)</td>
<td>2.44</td>
<td>2.42</td>
<td>2.43</td>
</tr>
<tr>
<td>Projected plant loading</td>
<td>2.69</td>
<td>2.45</td>
<td>2.56</td>
</tr>
<tr>
<td>Response by competitors</td>
<td>2.73</td>
<td>2.50</td>
<td>2.61</td>
</tr>
<tr>
<td>Extent of standard parts used in new products, processes, etc.</td>
<td>2.89</td>
<td>2.95</td>
<td>2.92</td>
</tr>
</tbody>
</table>
It is felt that the factors lend themselves to a natural classification of **intrinsic** and **situational** considerations. The intrinsic factors are those related to the basic characteristics of the project itself and would remain relatively constant regardless of the corporation which was evaluating it. The situational factors are related to the specific position, policies, capabilities, and interests of the particular company performing the evaluation. It cannot be said that either group is more significant than the other, rather it must be realized that each is important (although some to a lesser degree) and both classifications must be reviewed and evaluated in the light of the other. By this classification, the factor alignments are as follows

**Intrinsic factors—**
1. Potential project profitability
2. Technical risk of the undertaking
3. Estimated project cost
4. Concentration of resources required for timely completion
5. Patent situation
6. Length of project or run (time)
7. Response by competitors

**Situational factors—**
1. Long-range plan objectives
2. Company's ability to exploit a successful result effectively
3. Compatibility with marketing channels
4. Urgency of company or market requirement
5. Company policy

6. Compatibility with product lines

7. Compatibility with research and development skills

8. Compatibility with production facilities

9. Interaction with other projects currently in work

10. Projected plant loading

11. Extent of standard parts used in new products, processes, etc.

Discussion of some of the more apparent inferences that can be drawn from Table 7 is considered appropriate at this point. The fact that factors 1 and 2, and 4 and 5, have the same ranking at three significant numbers is considered to be unimportant. Recognition of the lack of a clear predominance of one factor over the other in the usual evaluation situation precluded requesting a forced ranking of all factors by the questionnaire recipients. Classification of the factors into a general level of importance was felt to be more meaningful. Allowing for gray area cross-overs due to specific conditions, the first six factors may generally be considered to be of primary importance; factors seven to twelve of secondary importance; and the last six factors as being significant only from the viewpoint of receiving general consideration.

The prominence of the corporate long-range plan objectives in both the research and development program funding and project selection indicates that projects are for the most part selected in such a manner as to support these objectives. However, the case studies and numerous comments received with completed questionnaires
indicates that it is not uncommon for company policy to allow the pursuit of a research and development program which does not fit the corporate long-range plan objectives or company image, provided that the potential profit probability warrants such an undertaking. A reasonable long-range plan might be to diversify into any new area that would fit in generally to the company's field and would have a good promise of profits. This is a built-in "deviation" from any present product line or plan to develop a known area. One respondent wrote as follows:

For the most part projects are selected in such a manner as to align the over-all research and development program with the specified corporate long-range plans. This does not mean that we would pass over a project simply because it does not match current plans. If the return is promising and we have the capabilities of doing the job, company policy encourages the research and development project. Such projects must pull their own weight and are frequently much more thoroughly scrutinized. In the past, the corporation has derived many beneficial results from this flexibility.

It is considered reasonable to state, therefore, that the general framework for project evaluation and selection is established by the corporate long-range plan objectives and/or appropriate company policy. Within this framework, the primary intrinsic factor of selection is that of potential project profitability. However, the intrinsic value of a project is of little significance to the company profit posture unless the company is in a position to capitalize effectively on its results. The emergence of the company's ability to exploit a successful research and development project.
result effectively as a prime factor of selection, number three in the over-all ranking, gives confirmation of the over-all importance of ultimately achieving profitable application of research and development results.

An additional inference which can be drawn from Table 7 is that a company's ability to utilize effectively the end products of research and development is dependent, in order of importance, upon the following.

1. Compatibility with existing corporate marketing channels
2. Compatibility with existing product lines
3. Compatibility with production facilities

The above listing assumes, of course, that the required capital investment is available or can be acquired.

The level of importance in the selection process attached to intrinsic factors such as the technical risk associated with the research and development project undertaking, the estimated project cost, and the length of project run could perhaps be misleading. It must be remembered that these factors are incorporated into a potential project profitability analysis and should not be expected to receive first level importance as independent factors. A similar explanation is considered logical for a discussion regarding the level of importance given to the factors of response by competitors and the patent situation, although the significance of being able to obtain patents varies from industry to industry and may account to a large degree for its rating. It is hypothesized that the higher level rating given the technical
risk of a project is partially due to the different manner in which this factor is handled by various companies in the evaluation. In some situations, it is incorporated directly into the profitability analysis. In other cases, however, the profitability analysis is predicated on the basis of no risk, with this factor being overlaid, either subjectively or quantitatively at a later time. The various procedures for accounting for risk will be discussed in more detail in the next chapter.

The secondary level of importance given to the compatibility of the proposed project with existing research and development skills was somewhat surprising to the writer. It indicates that a ready willingness, for the right projects, to augment the existing capability either by hiring additional employees, employing outside consultants, or by going to a contract research type of effort such as that which is available at the Universities and many not-for-profit organizations. The relatively low level of importance attached to the concentration of resources required for timely project completion, and the interaction of this effort with other projects currently in work, should not be surprising for two reasons: (1) the indication just discussed of corporate willingness to augment existing capabilities and (2) the fact that new projects often compete with old ones for their share of the research and development effort, with the choice being a selection among alternatives.

In view of the above, the first major hypothesis of this study, that within the framework of objectives established by the corporate
long-range plan (or company policy, whichever is appropriate) potential project profitability is the major single factor in project selection, is considered to have been satisfied and demonstrated as valid.

Table 8 presents a comparison of the percentages and frequencies with which respondents from Group A and B stated that primary consideration was given to the first six factors as shown in Table 7. A chi-square analysis of the differences between the two groups indicated that in only twenty-five times out of a hundred could sampling differences of the magnitude observed be due to sampling errors. It cannot be conclusively stated that there is a significant difference between the emphasis given those factors of selection in Group A and Group B. However, the variations in the management policy profile between the two groups would indicate that one could expect the difference as shown above.

### TABLE 8

**PERCENTAGE OF RESPONDENTS ASSIGNING FIRST LEVEL IMPORTANCE TO THE FIRST SIX FACTORS OF SELECTION**

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
</tr>
<tr>
<td>Profitability</td>
<td>82.3</td>
<td>42</td>
<td>60.7</td>
</tr>
<tr>
<td>Long-Range Plan</td>
<td>74.4</td>
<td>38</td>
<td>66.0</td>
</tr>
<tr>
<td>Ability to Exploit</td>
<td>58.8</td>
<td>30</td>
<td>58.8</td>
</tr>
<tr>
<td>Market Channels</td>
<td>51.0</td>
<td>26</td>
<td>42.9</td>
</tr>
<tr>
<td>Urgency</td>
<td>56.8</td>
<td>29</td>
<td>32.2</td>
</tr>
<tr>
<td>Company Policy</td>
<td>60.7</td>
<td>31</td>
<td>51.8</td>
</tr>
</tbody>
</table>
Procedure for project selection

The details of the procedures employed for the evaluation and selection of research and development projects vary from company to company. As a consequence, it is impossible to develop a procedure which will exactly fit every situation. However, it is reasonable to attempt to synthesize a procedure which is representative of the steps taken by the various companies. Figure 6 is considered to reflect reasonably well the general procedures employed, varying, of course, in exact detail. It has been developed in order to present a better understanding and framework of reference as to how some of the things which have been discussed actually come about.

Top corporate management furnishes objectives (short, intermediate and long term) and appropriate policies to the research and development laboratory. These are examined by the research and development executives and translated into a meaningful form that will provide a framework of guidance for the direction of the program which should be formulated and the type of individual project which should be established.

In addition, the identification of requirements and suggestions for numerous projects is received from organizations outside the laboratory itself. (Furnas presents the results of a study which attempted to identify the percentage of projects selected from different origins.³ However, it is not really pertinent to the

Figure 6 - Procedure for Originating Project Proposals and Evaluating and Selecting Projects for Undertaking.
purpose of this paper whether a project idea is initiated within the laboratory or by an outside source. Research and development personnel do not have a monopoly on good ideas.

The consequence of such inputs, together with many other factors internal to the laboratory, results in numerous suggestions for project undertakings. A preliminary screening of such proposals must be accomplished by the appropriate management level within the laboratory in order to decide which warrant the time and effort required for additional analysis and investigation. This is accomplished in the light of stated objectives and requirements, a knowledge of the technical capability of the laboratory, and with a view of the state of the art in the various technologies which are relevant. Of particular significance is an appraisal of those proposed projects which are pertinent to the corporation's interest. Many proposals may represent undertakings that are technically feasible and perhaps quite interesting; however, it must be realized that any projects totally outside of the designated company interest tend to dilute the over-all effectiveness of the research and development program. Again, this is not an indication that such projects should not be evaluated and undertaken when warranted. It is only brought up to point out the concern expressed by many executives that this area should not over-shadow projects directly supporting the company's primary interest. As pointed out previously, such undertakings must show real promise and should be thoroughly evaluated. The evaluation starts at this point.
The preliminary screening was generally found to be accomplished within the laboratory through a series of both formal and informal meetings. At such a time the "pros and cons" of the proposed project are discussed, and the opinions of people who are knowledgeable and concerned are carefully weighed. In this manner, a decision is eventually made, sometimes through an iterative process, either to eliminate the project suggestion from further consideration or to conduct the additional analysis necessary for the preparation of a project proposal. The importance of the knowledge, background, and experience of the research and development executive personnel responsible for the preliminary screening process must be emphasized. It is to be remembered that in addition to not eliminating undesirable projects, a lack of objectivity or sound judgment could result in the elimination of many potentially desirable projects.

For those projects which survive the preliminary screening process, additional analysis and study must be performed and, if warranted by the results, a project proposal prepared. The responsibility for accomplishing this and the methods used vary significantly in different organizations.

Anthony points out that a strong minority of research directors do not believe in formal committees, stating that the laboratory program should evolve from face-to-face conversations and from informal meetings, and that formal committee meetings cost more in terms of wasted time than the value of the benefits derived from them. He also notes that all of the research directors with whom he talked pointed
out that committees do not originate plans; rather they appraise ideas made by others in an attempt to fit them into a program. For all practical purposes, the conclusions of this study are in concurrence with Anthony's observation. Basically, the essence of the program is formulated as a result of the preliminary screening. However, the effective use of working committees in the preparation of project proposals and in a review of the proposed program seems to be an effective and sound approach currently employed within industry.

In the small laboratory of Company E, the director of research and development assumed technical responsibility for the entire operation, including the selection of the projects to be undertaken and the preparation of any formal documentation required. Even here, however, the approval of the research and development projects involved a presentation to higher corporate officers before the appropriate funding could be obtained.

In larger organizations, it was found that the responsibility for the preparation of project proposals was given to one or more formal committees. Depending on the size of the company, the members of the committee may or may not have other functions in addition to those connected with this aspect of the work. In any case, the composition of the committee was such as to enable reasonable estimates.

4 Robert N. Anthony, Management Controls in Industrial Research Organizations (Harvard University Graduate School of Business Administration, 1952), p. 111.
to be provided of the manufacturing cost and the market potentials, together with estimates of project feasibility and other basic technical data and miscellaneous information required for the evaluation. While such committees are basically a working group established to prepare project proposals, their procedures are sometimes such that the required information can be obtained from other persons within the company if it is felt that the committee itself cannot generate such data with sufficient reliability.

Of the companies visited, four have product planning departments within the research and development laboratory. These departments have responsibility for the adequate preparation of project proposals as an assigned function. In one company, this responsibility came under the cognizance of the Vice President for Long-Range Planning. In another, it is undertaken by the staff under the corporate Vice President for Technical Operations. As stated previously, this function was performed by the Director of Research and Development in Company E; Company D did not prepare formal project proposals.

In the process of preparing the research and development project proposal, many additional suggestions are eliminated as candidates because of a lack of technical feasibility, inadequate market potential, and similar weaknesses. The number remaining and meeting the specified minimum criteria, however; usually exceeds in total the scope of effort the company is expected to undertake; the selection then becomes a choice among alternatives.
Although it was found that several companies had developed computer models for conducting a profitability analysis, Company H was the only organization visited which had developed an over-all evaluation model. The model was designed to provide "desirability profiles" on different proposed projects, with scale ranges being assigned from zero to one hundred. The scheme basically is used by Company H for selecting commercial research and development projects within the corporation. It handles up to twenty-five different factors and includes a matching of the market need, or requirement, with the technical capability of the organization, the difficulty and magnitude of the research and development effort, projected production and facility requirements, market life and volume, all risk and uncertainties associated with the undertaking, and discounted cash flow projections of the financial situation. Company H executives pointed out, however, that the model is only a quantitative tool used to assist management in establishing relative relationships and parametric trade-offs in a rapid manner and that it is not a substitute for judgment. They noted that in those areas where three or more projects may be about the same level of desirability and the corporate resources would not allow undertaking them all, the decision automatically becomes a matter of judgment. It was stated that such a decision would be made on the basis of the project having the highest chance of success, best matching the corporate long-range objectives, and indicating the most desirable over-all profitability outlook.
Xerox and Westinghouse use a similar computer program to develop preference ratings for various proposed projects. Mr. Main pointed out that the Westinghouse program had the ability to tie-in proposed projects with the "strategic aspects" of the corporate objectives. He also emphasized the necessity for a team effort from marketing, finance, engineering, production, and research in providing sound inputs for the program. He noted, however, that the method in which projects are evaluated by corporate executives after they come from the computer is also an important aspect. Mr. Main stated that in the long run, the success realized from research and development depends on wise management and the decision factors employed.

Essentially, Figure 6 is intended to describe such a formalized procedure; the project proposal, together with the supporting data, provides the criteria upon which judgments and decisions are to be based.

Whatever the system of priority or preference rating used, the proposed projects meeting minimum acceptance criteria are arranged into a program for the following period. In the majority of situations, it was found that alternatives to the program are also included, as is information on the projects which meet acceptance criteria but have not been recommended for undertaking.

The proposed program is then reviewed by an executive committee which either endorses it or has incorporated those changes which are felt to be desirable. The final phase in the over-all research and development program formulation is the presentation of the proposed effort for the next period to top corporate management for review and approval.
The level at which final approval is obtained varies from company to company. In several of the corporations visited, the board of directors constitutes the final approving authority. In many situations, the approval authority is composed of a committee consisting of the president, the corporate vice president, and other appropriate corporate officers. For this purpose, the B. F. Goodrich Company utilizes what it terms the "Research and Development Council." This is a group composed of the treasurer, the controller, vice president for research, two group vice presidents, and the executive vice president. The proposed research and development projects are presented to the council by the operating heads of the various divisions and the director of the central laboratory.

The process which has been described may seem long and tedious and overly formalized. However, it is the one generally followed in the majority of corporations visited, at least in terms of the steps taken. It emphasizes the need for complete data in arriving at decisions, and, for the most part, it assures that the inputs of all departments of the company are obtained in order to bring pertinent information to bear in the process of evaluation and selection. Hertz states the following

....The research program of a particular enterprise is not a thing apart, to be developed from technical considerations alone, but an integral entity dependent upon all those functions which affect the remainder of the company.5

5 Hertz, op. cit., p. 132.
The top level management review of the final proposed program allows this echelon to participate in the planning of this most important corporate function. Additionally, it assures that the program is supporting the corporate image, objectives, and strategy. Top management is given, in this manner, the opportunity to re-emphasize the program and to shape it to what is considered to be to the best over-all interest of the corporation. It is reasonably well assured that executive guidance at the top level is not misinterpreted. Executive control is provided by the necessity for receiving a funds allocation for the proposed research and development program. Quinn points out that program budget reviews from this aspect provide a sound planning device, since they allow managers to summarize detailed operating plans and to see their aggregate inputs. He notes also that the budget assists in balancing the research and development program because budget data are summarizable, and it is easier for managers to see in relative terms (1) the amount of research which supports each product line and (2) a balance between expenditures on each phase of research.6

The final step in the selection process is approval (or rejection) of the project proposal and, if required, preparation of a project authorization form. The manner in which this is handled also varies from company to company. The various plans reviewed during the course of this study indicated that a place is provided

on the project proposal for signature and approval. In other situations, a separate project authorization form is prepared. Where the latter is used, it contains much of the information which was presented in the project proposal in terms of an outline plan, the method of attack, the funding requirements, the estimated completion date, and other comparable information. It was pointed out by three of the executives interviewed that such a document accomplishes two basic functions; first, it serves to inform all the persons concerned with the project proposal that it has been evaluated and approved for the company to undertake; and, second, it will inform the individuals who are to work on the project of the exact result expected and provide them with a proposed plan of attack. Such a document also contains information regarding any changes that the approving body might want incorporated. Such changes may involve the timing of the project undertaking, the emphasis to be placed on it, and the funds allocations that have been made. If there is a back-log of projects within the laboratory, the authorization form also includes a statement regarding the priority of the particular project and sometimes indicates when it is to be started. An official number is usually assigned at this time for purposes of control and funds allocation. When this authority is received by the research and development laboratory, formal effort can officially be undertaken.

Relative importance of executive judgment

In an attempt to determine how universally executive judgment is relied upon, the questionnaire recipients were asked whether they
form a subjective, or qualitative, executive profitability judgment in the process of evaluating and selecting research and development projects. The results of the questionnaire survey are shown in Table 9.

**TABLE 9**

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
</tr>
<tr>
<td>Form Project</td>
<td>49</td>
<td>96.08</td>
<td>49</td>
</tr>
<tr>
<td>Profitability</td>
<td></td>
<td></td>
<td>98</td>
</tr>
<tr>
<td>Judgment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do Not Form</td>
<td>2</td>
<td>3.92</td>
<td>7</td>
</tr>
<tr>
<td>Profitability</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Judgment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It will be noted that almost 92% of the respondents indicated that such a judgment is formulated. Ninety-six per cent of Group A form an executive profitability judgment, while approximately 88% of Group B indicate conducting a judgment appraisal of potential profitability. Analysis has shown that there is only about an eleven per cent probability that the difference observed between the two groups is due to random sampling errors. Significant differences between the groups are attributed to the differences in the completeness of their respective management policy profiles. In this particular situation it could perhaps be hypothesized that the project
post-appraisal, conducted by all respondents in Group A, is the major factor contributing to the higher percentage of executive profitability judgments. An inference could then be made that although this type of past experience may be integrated into the analysis at different places, it would appear to be reflected strongly at the approval level. However, the author does not feel that this type of rationalization is realistic.

The question presented in the survey dealt with the formulation of an executive judgment regarding potential profitability, rather than any of the other numerous aspects of the project proposal, for a very specific reason. The profitability analysis incorporates practically all aspects of the analysis and investigation which has been made. An affirmative answer to the question indicates that the executive judgment is made not only in relation to specific factors but also relative to the over-all conclusion. There is a relatively high feeling of confidence that an executive judgment of some type is made one hundred per cent of the time. Reviews and discussions which result in evolving a judgment regarding any phase of the project (research and development, production, and market demand) in effect must relate to the potential profitability of the venture. When conclusions regarding the individual factors are reached separately, they must subsequently be developed into an over-all project outlook. If nothing else, such a judgment must be formed as to the proper balance regarding the over-all long-term profitability aspects of the many projects which constitute the total program. Additionally, risk is
a subject which is frequently treated independently by both the
review committee and the approval group.

All of the corporate executives interviewed stated that
such an over-all executive profitability judgment is made during
the project selection process. Two examples are cited from the
Purdue-Industrial Research Conference.

The representatives from the Xerox Corporation were asked
whether the computer model which they described as currently being
used for evaluation of research and development projects would have
indicated that they should proceed with their investment in xerography.
Dr. Damon replied by stating that there were certainly high technical
risks associated with the xerography investment. However, he pointed
out that the potential pay-off was also very high. The evaluation
model utilized by Xerox recognizes that when you take high risks, you
must require a higher return. He stated that to his knowledge the
xerography project had not been programmed through the model and that
he did not really know what it would show. Mr. Damon maintained that
the company had faith in the process and that there is certainly never
a substitute for executive judgment. He pointed out that James Hillier,
RCA, said that color television development would have defied all
model analysis. It was a matter of conviction.

Dr. Guy Suits noted that when the electric tooth brush
project was first undertaken at General Electric, the analysis
indicated it did not look too favorable because of a lack of complete
information regarding the market. In addition, there was much
skepticism on the part of higher management which stated that of all the electric labor-saving devices which could be used by the American people, an electric tooth brush seemed to be the least needed. Throughout the entire project there were many skeptics who did not think it would really sell. Whole-hearted and enthusiastic support was not received until after the dental association endorsed it. This project represented a new type of proposal which had not previously been on the company or consumer need list. However, it was one which research and development management felt would be a success.

In view of the above, the third hypothesis of this study, that even in the cases where models are used for identification of desirability or profitability, executive composite judgment is always made and plays a significant part in the final selection, is considered to have been demonstrated as valid.
CHAPTER V

THE PROJECT PROFITABILITY ANALYSIS

Introduction

If the ultimate objective of industrial research and development is to increase the profits of the enterprise through the introduction of new products and by product and process improvement and cost reduction, it seems important for as much care as possible to be taken during the evaluation and selection process to provide a clear picture of the project's profitability potential. The decision to invest in a research and development project is really a profit decision and in many cases is a choice between alternatives. If all projects are analyzed in a similar manner, profitability profiles can be developed and used as a basis for comparison. While such forecasts are based on estimates of conditions that by their very nature are subject to change, they can provide a useful tool in the identification of the areas of greatest payoff, for the least amount of investment, in the shortest period of time.

Basically there are only two ways in which an estimate of the potential project profitability can be generated: (1) by a quantitative analysis and (2) by a subjective or qualitative judgment. Some would argue that the only basic method is that of the subjective
evaluation, since this fundamentally is the approach that must be
used in generating the estimates for use in a quantitative analysis.
This is acknowledged. However, such estimates are based on a
careful study of the considerations involved and often are determined
as a result of preliminary planning and laboratory exploration; they
lend themselves well to a valid mathematical analysis and form a
more sound defensive position than pure "intuition."

If an analysis has been made in the preparation of the
research and development project proposal in general accordance with
the procedure discussed in the last chapter, the results to be
anticipated if the undertaking is successful should be clearly
outlined. On the basis of this information an analysis of the
financial value of successful project results can be made and the
results subsequently presented to the review committee and approval
authority to assist in the decision process.

The second hypothesis of this study states that current
practices for assessing the potential profitability of research
and development projects are completely diversified within industry,
varying from the use of quantitative and highly sophisticated models
which allow the treatment of many pertinent factors, to the subjective
or qualitative evaluation of a few selected factors with reliance
primarily on composite management judgment. Articles can be readily
found in the existing literature which describe in detail the
evaluation techniques utilized by a certain corporation, a corporate
division, a specific research and development laboratory, and even
for individual projects. However, broad coverage data indicating
the frequency with which quantitative project profitability analyses
are performed and the computational methods relied upon, are not
available. Data relative to corporate policies regarding the minimum
return which it is desired to realize from research and development
ventures is almost nonexistent. Primary research data pertaining
to the above subjects are presented in this chapter.

Data are also presented on three of the factors identified
as essential for incorporation into a meaningful project profitability
analysis by the criteria for the selection of a computational model
developed in Chapter II. The assumptions made and the rationale
employed in developing the classifications presented are discussed.
Also included in this chapter is a synthesis of the different
techniques utilized in handling the various model factors. This
discussion is based on the interviews conducted and the project
selection plans which were reviewed and analyzed.

The use of quantitative techniques

The mail survey portion of the study attempted to identify
the frequency with which some type of quantitative technique was used
in formulating an estimate of the potential project profitability. The
results are shown in Table 10. Approximately 91% of the respondents
indicated that they do use some method of analysis, 23% performing it
on all projects undertaken and 68% performing a quantitative analysis
on a selected project basis only. Approximately 8% of the respondents
indicated that they do not conduct any quantitative analysis of project
profitability.
TABLE 10

USE OF QUANTITATIVE ANALYSIS
IN ESTIMATING POTENTIAL PROJECT PROFITABILITY

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PERCENTAGE</td>
<td>PERCENTAGE</td>
<td>PERCENTAGE</td>
</tr>
<tr>
<td>Performed on all projects</td>
<td>23.5</td>
<td>23.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Performed on a selected basis</td>
<td>76.5</td>
<td>60.7</td>
<td>68.2</td>
</tr>
<tr>
<td>No quantitative estimate is made</td>
<td>0</td>
<td>16.1</td>
<td>8.4</td>
</tr>
</tbody>
</table>

The fact that 23% of the questionnaire respondents indicated that a profitability analysis is conducted for all projects undertaken carries the inference that their programs are constituted primarily of highly structured applied research and/or development projects, with perhaps a high percentage of engineering type activity. (A review of other appropriate portions of their questionnaire substantiated this hypothesis.) Some of the respondents who indicated that such an analysis was conducted on the basis of selected projects offered comments and explanations for their approach. Typical examples are as follows:

1. Quantitative profitability analysis is conducted on all development projects but only on major applied research projects.

2. Such an analysis is conducted when the information is available as to make an evaluation of this type meaningful. Most of the time it can't be determined what the research and development effort is really going to be until it has been worked on for awhile.

3. Performed in the later phases of development.
4. Conducted for applied research and development only—not for basic research.

5. Except for basic research, some type of profitability estimate is always made, but the method and depth of analysis varies with the stage of the project.

That it is not always feasible to attempt to estimate profitability on basic research projects and some applied research undertakings has been previously acknowledged. Advocates of this approach, however, usually recommend that it be accomplished as soon as possible. Villers, for example, suggests that the quantitative evaluation should be used as soon as possible and whenever the size of the investment involved justifies the amount of time and effort needed to do so. He maintains that quantitative evaluation is essentially concerned with collecting the information needed to compare the various expenses to the expected benefits, using one or another method of calculating return on investment. He points out that the figures used are merely estimates on a long-range plan basis and are subject to both change and error.¹

One vice president interviewed stated that in trying to decide whether to undertake a project on which no quantitative profitability data are available, you must be able to satisfy yourself subjectively on the following points:

1. That the objective of the project basically supports the technological interest and long-range planning goals of the corporation.

2. The project appears to possess sufficient merit to undertake it at all.

3. It should be undertaken at the present time.

4. The effort should be pursued in the manner proposed.

5. It should be undertaken in view of possible alternatives—both in the way of doing this project and in the light of other projects which could be undertaken instead.

Two explanations are offered as possible reasons why approximately 8% of the respondents indicate that they conduct no quantitative profitability analysis. First, they may be engaged in a large amount of trouble shooting type of work which requires immediate action and precludes any type of profitability analysis; and, second, their philosophy may be that no amount of quantitative analysis can replace a composite management judgment as to whether a project will be successful. The attitude of this latter group is perhaps typified in a conversation which the writer had with Mr. J. Gibson Pleasants, Vice President for Research and Development at Procter and Gamble. He stated that they do not attempt to classify project undertakings on the basis of mathematical models or developed indices, but rather that subjective judgments are made by qualified people who are in the best position to know whether such projects, and the resulting products, will be successful. Mr. Pleasants noted that projects for product development must meet the criteria of (1) matching the corporate image, (2) compatibility with existing marketing channels, (3) rapid turnover, (4) low price, and (5) high volume.

He emphasized the fact that it must be related to the company field,
stating that they do not work on miscellaneous research and
development projects. Another factor which he stated bears
heavily on selection is that proposed projects must match the
corporate capabilities, both in the research and development
technical area and the marketing area.

Methods used in estimating profitability

The questionnaire recipients who indicated that they conducted
a project profitability analysis, at least on a selected basis, were
asked to identify the techniques which they employed in formulating
such an estimate. The results are shown in Table II. It is readily
apparent that only a few of the survey respondents indicated the use
of a single technique, the majority reporting that two or more methods
are being utilized. There are two very obvious reasons why so many
combinations of answers should have been received. First, several of
the techniques listed for selection are really "what" is calculated,
rather than "how," and, second, depending on the degree of advancement
of the particular project under consideration, as indicated by the
discussion of the previous section, different methods of calculating
profitability will be utilized in accordance with the significance
of accuracy and the validity of the information that is employed in
the calculation.

The first four techniques listed as alternative selections
in the questionnaire (computation of gross profit, net operating
profit before taxes, net profit before taxes, and net profit after
taxes) are clearly a statement of what is calculated by the respondent.
### TABLE 11*

**COMBINATIONS OF QUANTITATIVE METHODS USED IN PROJECT PROFITABILITY ANALYSIS**

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>P E R C E N T A G E</th>
<th>U S E D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 9 9 7 7 6 5 4 3</td>
<td>3 3 3 2 2 2 2 2 2</td>
</tr>
<tr>
<td>Computation of gross profit</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Net operating profit (before taxes)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Net profit before taxes</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Net profit after taxes</td>
<td>X</td>
<td>X X I X</td>
</tr>
<tr>
<td>Contribution to profit analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakeven analysis</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Term of recovery or payback</td>
<td>X</td>
<td>X X X X</td>
</tr>
<tr>
<td>Average rate of return to average investment</td>
<td>X</td>
<td>X X X X X</td>
</tr>
<tr>
<td>Discounted cash flow with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal rate of return</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>present worth at cost of capital</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>No analysis</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

*The table should be interpreted by reading down the percentage column. "X" indicates the percentage of questionnaire respondents who rely upon the factor or combination of factors so marked in the column.*
<table>
<thead>
<tr>
<th>FACTORS</th>
<th>PERCENTAGE</th>
<th>USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computation of gross profit</td>
<td>X X X</td>
<td></td>
</tr>
<tr>
<td>Net operating profit</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>Net profit before taxes</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Net profit after taxes</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Contribution to profit analysis</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>Breakeven analysis</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>Term of recovery or payback</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>Average rate of return to average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>investment</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>Discounted cash flow with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal rate of return</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>present worth at cost of capital</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No analysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To a lesser extent, the next three alternatives (contribution to profit analysis, breakeven analysis, and term of recovery or pay back) are also an indication of "what" is calculated as well as "how" the analysis is conducted. The basic techniques by which such computations are made have traditionally been limited to a current dollar analysis and have not given any consideration to discounting.

The fact that different types of analysis may be conducted for different projects at different ends of the research and development spectrum was indicated in the previous section. Such analyses are time consuming and should be conducted only to the degree that they have a realistic meaning. An obvious exception to this, of course, is where computer time is available and a computer program has been established which appropriately handles the more nebulous data. In this regard, however, it should be pointed out that presenting the results of a profitability analysis which utilized input estimates that were accurate to ±25% in a computer program which provides a net profit after taxes figured to second decimal point accuracy, can be misleading to higher corporate management and to a very large degree somewhat foolish. One respondent wrote, "The situation determines the computational method used to estimate profitability."

In a given company the techniques employed may vary from project to project depending upon the specific circumstances, such as the type of research activity, the accuracy of the information available for the analyses, and the importance which accuracy bears on the decision. For example, one company considers the rough computation of gross
profits as adequate for initiating an applied research project. Before continuing the same project into the development phase a check is made of the average rate of return to average investment figures. The selection between two or more development projects that appear to have the same relative merits could require a detailed discounted cash flow analysis. In the later stages of development, before committing a production effort, discounted cash flow computations are always prepared, if for no other reason than to provide a basis for financial planning.

The logic expressed in the above approach was reflected by comments received with many completed questionnaires as well as by several of the research and development executives interviewed throughout the study. Even those formulating only a subjective executive judgment of profitability consider the knowledge of potential project profitability to be of paramount significance in a decision to pursue it. In summary, it was found that the depth to which a profitability analysis is conducted depends on the three following factors:

1. The level or stage of research activity.

2. The accuracy of the estimates which are available for the analysis.

3. The significance or the impact of accuracy of the analysis on the decision to be made.
Comparison of groups by methods

It was desired to obtain some type of comparison of the degree of sophistication of the methods of analysis used by Group A versus those employed by Group B. To accomplish this two assumptions were made: (1) that the alternative choices listed in the questionnaire were, for the most part, in order of increasing sophistication, and (2) that when a sophisticated analysis is warranted for the decision process, computations are prepared to the highest level indicated. Therefore, a tabulation was compiled showing the frequency of reporting for the various methods of profitability analysis for both study groups. The results are shown in Table 12.

A chi-square analysis indicated only a 1% probability of obtaining differences of the magnitude of those indicated due to random sampling variations. Since nine respondents from Group B indicated that they perform no qualitative analysis, probably as a result of management policy, the chi-square analysis was repeated ignoring the nine, effectively resulting in a smaller number for Group B and reducing the degrees of freedom in the analysis. In this situation it was shown that there is approximately a 7% probability of obtaining differences of the magnitude observed due to random sampling variations. Some differences in the degree of sophistication of analysis between Group A and Group B would be expected as a result of the variance in the completeness of the management policy profiles between the two groups. One could hypothesize that the Group A respondents, if for no other reason than the experience gained through their more consistent formulation
TABLE 12

COMPARISONS OF METHODS OF PROFITABILITY ANALYSIS

<table>
<thead>
<tr>
<th>Method</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No analysis</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Computation of gross profit</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Net operating profit (before taxes)</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Net profit before taxes</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Net profit after taxes</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Contribution to profit analysis</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Breakeven analysis</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Term of recovery or payback</td>
<td>6</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Average rate of return to average investment</td>
<td>18</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Discounted cash flow</td>
<td>17</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

of quantitative estimates and use of the project level post-appraisal technique, would be more concerned with the various facets of profitability and therefore use a more sophisticated and accurate method of analysis.
Time considerations in project analysis

Consideration of the time periods associated with the various aspects of the proposed projects must be acknowledged as warranting equal consideration with other facets of the evaluation. It must be treated as an integral part of any profitability analysis since it directly influences total cost, rates of investment, returns, depreciation allowances, and tax considerations, as well as the strategic advantage which a company may enjoy from the timely introduction of a product into the market, or adaptation of a new manufacturing process. One writer, using survey results, points out that for industries as a whole perhaps five years of research plus two years to develop a market is the estimated time required for a new product to start paying off. He estimates that it takes at least seven years before research programs begin to affect product sales or capital investment for new plant facilities.  

The questionnaire respondents were asked to rank the various time factors in accordance with how they were considered pertinent to their management approach in project evaluation and selection. The results of the survey are shown in Table 13.

Approximately 53% of the respondents from Group B and 51% from Group A ranked the duration of the marketing period during which returns are expected as the most significant time factor. About 23% of Group B and 16% of Group A indicated the length of time during which research and development expenditures are expected to occur as

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TABLE 13

WEIGHTED AVERAGE OF RANK GIVEN TIME FACTORS

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of period (time) during which R&amp;D expenditures are expected to occur.</td>
<td>2.60</td>
<td>2.88</td>
<td>2.74</td>
</tr>
<tr>
<td>Time lag between the end of R&amp;D effort and the start of production (or use).</td>
<td>3.11</td>
<td>2.70</td>
<td>2.89</td>
</tr>
<tr>
<td>Time lapse between the start of R&amp;D expenditures and the start of returns.</td>
<td>2.32</td>
<td>2.16</td>
<td>2.23</td>
</tr>
<tr>
<td>Total time span of production (or use).</td>
<td>3.32</td>
<td>2.94</td>
<td>3.12</td>
</tr>
<tr>
<td>Duration of the marketing period during which returns (income) are expected</td>
<td>1.91</td>
<td>1.89</td>
<td>1.90</td>
</tr>
</tbody>
</table>

the prime factor. Approximately 25% of the Group B respondents and 16% of Group A respondents ranked the time lapse between the start of research and development expenditures and the start of the receipt of returns from the venture to be the most significant time factor. Many of the respondents gave primary consideration (rank of one) to more than one of the factors listed. Analysis has shown that there is more than a 99% probability that the differences in ratings between the two groups is due to random sampling errors. It is readily obvious that Group A and Group B does not differ in the level of significance which they attach to these time factors. The last place position given to the total time span of production or use is attributed to the fact that the majority of the respondents have geared their
research and development programs toward new products and product improvements, with process and manufacturing improvements being given tertiary considerations. In a project where improvement of manufacturing techniques is the objective, it is felt that it would replace the marketing period duration as number one consideration.

It was brought out in several of the interview discussions that the time at which the results of successful project conclusion are available can have a direct influence on the returns anticipated by the enterprise and that the evaluation process must consider all operating aspects of the organization (production, sales, and finance, as well as research and development) and reach a conclusion as to how long the company can afford to wait for the anticipated objectives to be achieved.

If the expected results are of such a nature that their value to the organization will not diminish over a long period of time, the optimum concentration of resources on the project, in accordance with the over-all laboratory workload, may determine the time at which it is desirable to complete the work. On the other hand, if the value of the anticipated results rapidly decreases, some definite time limit must be established for a successful project conclusion to be reached. This may be particularly important with respect to new products and various competitive factors. One of the vice presidents interviewed during the study was very strong in his emphasis that being first with a new product means more than just prestige. He pointed out that appropriate timing in the introduction of a new product frequently
enables a company to capture a large share of the market before competition is in a position to market their substitute. Additionally, he noted that equally as often a company is able to better competitive prices because of experience and increased efficiency in production which has resulted from the time differential.

Projects oriented towards manufacturing and process improvements are, of course, in a similar situation. Extensive effort devoted towards improved manufacturing techniques for a product whose market life cycle is all but exhausted could be fruitless. In a like manner, technological improvements in manufacturing and processing equipment could all but negate the advantages gained from such an undertaking. Any evaluation of projects aligned to this area should give consideration to such future developments, either through appropriate market projections or technological forecasts.

Naturally, there will always be other projects the anticipated results of which are designed to meet long-range contingencies at a time when economic conditions are at an optimum to realize maximum profitability. Work on these undertakings may be accomplished at times when the laboratory is not too busy with more urgent work. In the majority of situations discussed during the interviews, however, it was found that priorities assigned to the various projects current within the laboratory are based on the economic factors affecting their completion date.

The fact that the results of a research and development project will be of value for a limited period of time after they are made
available means that the return to the organization during that period must be sufficient to enable all of the expenditures incurred in achieving and utilizing the projects results to be written off in accordance with the minimum acceptable profitability criteria. The period of time over which this write off may occur will largely depend on the nature of the results obtained and the desires of management. One of the companies visited during the study, for example, will not undertake any research and development project unless it can entirely write it off its books within three years after successful project conclusion. The three-year period is somewhat of an arbitrary figure, and many of the developments maintain a market value for a much longer period of time, which enables the company to realize a significantly greater return than that upon which the original decision is based. The rationalization offered for this approach is based on an inability to predict the market that far in advance, particularly considering the time lag between original project initiation and the estimated market life of the successful project results. It was pointed out that technological improvements, not even considered at the time a production commitment is made, could easily pre-empt the market position of such a product.

Essentially what the company has done by requiring that the project be written off in this period of time, when the actual period could perhaps have been longer, was to incorporate a risk factor which allows for possible error in determining the present worth of the projects objectives from the viewpoint of marketing duration. Perhaps,
in some industries, the nature of the market is such as to allow a
determination of this type to be effectively utilized; but it is felt
that any risk due to possible error in determining a project's total
value is better estimated separately for each undertaking. The various
methods employed for handling such risks during project evaluation will
be discussed in a later section.

Any additional discussion regarding the significance of the
impact of timely conclusion of research and development projects on
the benefits to be derived as a result of improvements in manufacturing
processes, or new product introduction into the market place, are
considered to be outside the scope of this paper. They are better
left to studies which address themselves primarily to these subject
areas. In view of the relationship of the timing aspect to the over­
all subject of this study, it could not, however, be totally ignored.

About the only conclusion that can be drawn as to the relative
significance of the various project time phases results from a synthesis
of discussions during the many interviews conducted and numerous comments
received with completed questionnaires. All of the time phases of a
project undertaking are significant and important. They must be
considered together in an evaluation rather than separately. However,
if any one factor had to be singled out as the most significant, it
would probably be the duration of the marketing period during which
returns were anticipated. The forced prominence of this aspect of
time duration is the obvious result of (1) the fact that it is the
main determinant of when it is mandatory for project conclusion to
have been successfully reached and (2) it is the principal indicator of the total benefits which the company can expect to achieve through successful exploitation of project results.

The handling of intangibles

The benefits derived from successful research and development projects may be rich and rewarding and may generally be found to lie in the areas previously discussed. The methods employed to estimate the value of such benefits varies widely from company to company. However, a discussion of these methods is outside of the scope of this paper, since the study was oriented towards the research and development aspects and not the market and production activities. It is sufficient to say that all potential benefits considered in a profitability analysis must be assigned a monetary value in order for them to be compared with the expected cost of the undertaking.

In industrial research the benefits that will be derived if a project is undertaken and successfully completed can often be stated in terms of the profit that will be realized as a result of the sale of a new product or the cost savings that can be made through a manufacturing or process improvement. In addition, successful research and development projects frequently have associated with them one or more intangible benefits. Typical of these are increased customer good will, the service of providing a complete product line, improved corporate image, and strengthened competitive position.

Because the existence of such factors is real, and because they frequently have significant impact on the over-all operations of the
company, often in terms of dollar sales volume, it was felt desirable to attempt to identify during the study how such factors are handled in the process of project evaluation and selection. Once the existence of such intangible factors has been identified and acknowledged, there are basically three ways in which they may be handled:

1. Intangible benefits associated with research and development projects may be evaluated, their value to the company assessed, and a monetary value assigned which is then considered as an actual dollar return from projected results and incorporated into a quantitative profitability analysis.

2. The evaluation and selection process may ignore any specific value which might be assigned to these factors, requiring that the proposed research and development projects meet given profit criteria before intangibles are considered.

3. Without attempting to assign a dollar value to intangible factors, a qualitative evaluation can be made and considered in assessing the over-all research and development project desirability.

Depending on the logic employed, and the specific circumstances relating to a given project, application of any of the above three approaches could be reasonable. For example, a project which had intangible benefits associated with it such as strengthened competitive position or increased customer service through providing a complete line, could well utilize the first alternative. Providing the service of a complete product line could result in not losing existing customers and perhaps in obtaining new ones. Where such a situation exists, the formulation of reasonably valid estimates of the dollar value of this benefit to the company could probably be made without excessive difficulty. On the other hand, projects which resulted in improved customer good will or a bettered corporate image could have such factors totally ignored in the evaluation since they are rather nebulous
### TABLE 14

**CONSIDERATION GIVEN INTANGIBLE BENEFITS DURING PROJECT SELECTION**

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
</tr>
<tr>
<td>Assign dollar value to intangibles and include in profitability estimate</td>
<td>1</td>
<td>1.96</td>
<td>2</td>
</tr>
<tr>
<td>Ignore the value of such factors</td>
<td>13</td>
<td>25.48</td>
<td>19</td>
</tr>
<tr>
<td>Consider qualitatively in assessing over-all project desirability.</td>
<td>37</td>
<td>72.56</td>
<td>34</td>
</tr>
<tr>
<td>Given other consideration</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

and certainly difficult to value in terms of dollars. The third alternative, which ignores any attempt to assign a specific value for consideration in a profitability analysis, is applicable regardless of the type of intangible benefit which may be forthcoming.

The question of handling intangibles was discussed during the interviews and was presented to questionnaire recipients. The results of the latter are shown in Table 14, which presents the soundest basis for conclusions regarding the general handling of such intangible factors in the project evaluation process.

Only a very small percentage of the respondents, in either Group A or Group B, indicated that they attempt to assign a dollar value to intangible factors for subsequent consideration in a profitability analysis. A much larger number, 25% of Group A and
of Group B, indicated that they completely ignored the benefits to be derived from project results in terms of intangible factors in their evaluation. Several of the respondents who indicated they followed this approach also stated that, if the situation were such as to be a choice between alternative projects, all of which seemed to have relatively the same degree of desirability, one of the deciding factors could be an executive consideration of the relative merits of the intangible benefits associated with the various projects. Two respondents stated, however, that this was an exceptional situation and that for the most part intangibles were ignored. By far the largest number of respondents, 73% of Group A and 61% of Group B, indicated that intangibles were identified and a qualitative evaluation made of their value for consideration in assessing the over-all project desirability. The prominence of this approach as a standard procedure is not illogical when one considers the dangers of totally ignoring these factors and the difficulties that may be encountered in attempting to derive a quantitative dollar value for such intangibles. However, the survey results do not substantiate the requirement for selecting a profitability model which is capable of handling quantified intangibles.

A chi-square analysis shows a 50% probability that the observed differences between the two groups as shown on Table 14 is due to random sampling errors. It is concluded, therefore, that in their handling of intangibles Group A and Group B are essentially the same. However, the writer cannot help but observe the larger percentage of
Group B which tends to ignore totally the intrinsic value of such intangible factors. The completeness of the management policy profile of Group A, considered in conjunction with the interactions of the various management functions, would lead one to suspect that respondents of this group would be less likely to ignore potential benefits than those of Group B.

**Project risk factors**

Industrial research and development project ventures, like any other business undertaking, involve risk. For the purposes of this study such risks have been conveniently divided into two basic categories: (1) the type or area of risk and (2) the amount of risk. Each category is further sub-divided into basic elements.

The **types** of risk involved in a research and development project may generally be considered as including the following:

1. The technical risk associated with the research and development activity itself, involving an inability to obtain successful project results in accordance with stated objectives, or being able to achieve them only with the expenditure of larger amounts of resources than had been originally anticipated.

2. The risk associated with an inability to economically produce the developed product (or adapt a new process to the manufacturing line), or the inability to hold production costs at the level necessary to achieve the anticipated sales volume.

3. The risk of potential changes in total demand or market preferences between the time of research and development project initiation and the projected marketing period.

4. The risk of changes in profit margins during the projected marketing period, depending on the relative saturation and the entry of competitors.
No attempt has been made in this study to establish a procedure for determining the risk involved in successfully completing any given research and development effort. The variables associated with setting this figure are dependent on such factors as the nature and extent of the work involved, the capabilities of the technical personnel and the technical staff, the correctness of the assumptions that have been made, the proper selection of the lines of attack to be used in pursuing the research and development effort, the choice and accuracy of equipment, the ability of management to clear obstacles to an orderly work procedure, as well as other factors. The risk associated with any undertaking must be investigated individually for each situation that might arise and considered separately in accordance with the various areas involved before any attempt is made to establish an over-all project risk.

The manner in which the assessment of risk is derived varied in the different companies studied, but in all cases the technical risk of the research and development project phase was formulated within the research and development laboratory. In four instances this judgment was provided by the engineers and scientists who were actually to perform the work. In these situations, however, their opinions were subject to supervisory review, at least at the departmental level, prior to being incorporated into the project proposal. In one case the technical risk of undertaking the project was assessed exclusively by the laboratory director. In three of the companies the estimate of technical risk was derived as a result of
the composite judgment of the laboratory director and his department heads. Estimates of production and marketing risks, except for the one situation previously discussed, appear to be obtained from the manufacturing and marketing personnel to the maximum degree possible.

With a full recognition that the amount of risk assumed in any given area, will vary significantly from project to project, questionnaire recipients were asked to indicate the relative importance of any of the risk factors which they consider in their evaluation of research and development projects. The results are shown in Table 15. Approximately 63% of Group A, and 52% of Group B ranked the technical risk of the research and development undertaking as being the most important risk factor considered. About 31% of Group A and

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>Total Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 Average</td>
<td>1 2 3 4 Average</td>
<td>Average</td>
</tr>
<tr>
<td>R&amp;D Risk</td>
<td>32 9 8 0 1.51</td>
<td>29 11 6 0 1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Production Risk</td>
<td>8 13 7 10 2.50</td>
<td>4 14 5 7 2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Total Demand Risk</td>
<td>16 20 9 2 1.94</td>
<td>15 15 9 2 1.95</td>
<td>1.94</td>
</tr>
<tr>
<td>Profit Margin Risk</td>
<td>12 17 13 3 2.16</td>
<td>9 12 15 2 2.26</td>
<td>2.21</td>
</tr>
</tbody>
</table>

27% of Group B indicated that the risk of potential changes in total demand was considered to be of first order significance. The last place relative emphasis given the risk associated with production and
manufacturing is perhaps an indication of the capability of the respondents in this area. A review of the table readily reveals that many of the respondents indicated giving a first level of importance in their evaluation to more than one of the area risk factors.

The first level of importance associated with the research and development technological risk was expected, in view of the unanswered questions which prevail at this stage of the project evaluation and selection process and with the realization that it represents the first phase of the over-all project undertaking. The second level consideration given the demand risk should also offer no surprise.

There is one additional inference which the writer considers appropriate to be drawn from Table 15. The fact that the risk in different areas of a project undertaking can be broken out and assessed separately, coupled with the fact that the level of risk in each area will vary, might indicate a need for a method of analyzing potential project profitability which allows different rates of return to be associated with varying degrees of risk and the amounts required for investment. This is a sophistication beyond the assignment of an over-all project risk, but the step would allow a more accurate identification of the returns that should be realized from the different phases of project effort as discussed in Chapter II. It could also be used, in composite, as a check against the over-all rate of return desired for the project at its calculated risk level and to identify those phases which are contributing more or less of their required share. Several people with whom discussions were held throughout the
study indicated that they did in fact strive to achieve different rates of return for different phases of the over-all project effort. Analysis of Table 15 indicates that Group A and Group B attach the same importance to the various risk factors during the evaluation of proposed research and development projects. A chi-square analysis has shown an 81% probability that the group differences shown in Table 15 are due to random sampling variations. The amount of risk assumed in any phase of a research and development project is to a very large degree dependent on the information available and the validity of that information. As used here the term information encompasses not only the current situation but also knowledge regarding the future situation, such as the ability to predict future changes in market preferences. The reliability of such information decreases with futurity; and consequently the risk associated with acting on the basis of such information increases. In a similar manner, the confidence with which the cost necessary to carry out a research and development project and the returns that can be expected from successful project conclusion can be estimated is also dependent upon the information which is available. Therefore, it can be reasonably assumed that the risk associated with any given research and development project is to a large extent reflected by the confidence with which the cost and returns to the company can be predicted.

For purposes of this study the above assumption formed the basis for establishing a classification of risk in terms of the amount assumed.
The subdivision is as follows

1. Low risk projects— Research and development projects where both cost and returns can be estimated with a high level of confidence.

2. Intermediate risk projects— Projects where returns, but not cost, can be estimated with a high degree of confidence; or, where cost (but not returns) can be estimated with a high degree of confidence.

3. High risk projects— Project undertakings where neither cost nor returns can be predicted with confidence.

Numerous examples could be given of various projects falling into the above categories, but it is not felt that this would serve a useful purpose at this time. However, there are two aspects that should be pointed out: (1) that a balance of risk between the projects current within the laboratory should be maintained, and (2) that a decision with regard to risk is also a decision regarding the alternative uses of available resources. To illustrate the latter point, suppose that a company has a project proposed where both cost and returns can be estimated with a high degree of confidence. Under such circumstances the evaluation process is not necessarily concerned with the risk associated with the research and development cost, nor the demand for the final result of the undertaking. However, it will be necessary to determine, perhaps through a profitability analysis, whether the returns warrant undertaking the project. In addition, the concentration of technical personnel and other resources required to complete the project in a timely manner and the impact of this on the over-all operations of the research and development laboratory must be taken into consideration. This type of iterative evaluation should be made in all cases where the choices involve the selection of certain projects over others which have been proposed.
Questionnaire recipients were asked to provide a percentage breakdown of their total research and development effort in accordance with the above classifications relating to the amount of risk assumed. The results are shown in Table 16.

**TABLE 16**

<table>
<thead>
<tr>
<th>DISTRIBUTION OF RISK IN R&amp;D PROJECTS BY PERCENTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP A</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost and returns estimated with confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Returns estimated with confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs estimated with confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neither costs nor returns are estimated with confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

An interesting observation is that, although changes in demand or market preference received a second rank consideration in the level of importance attached to the factors of risk associated with the different phases of the project (reference Table 15), accurate predictions of expected returns can apparently not be estimated with the same level of confidence as can cost. On the average, returns are
estimated with a high level of confidence for only about 37% of the projects, while costs are estimated with a high level of confidence for about 60% of the projects. About 27% of the time neither cost nor returns can be estimated with a high level of confidence. It is very possible that a large percentage of the time, where it is indicated that returns can be accurately predicted, the project effort relates to results which will be used "in house," such as process or manufacturing improvements. The explanation again offered for the ranking of the risk factors associated with the marketing phase after those related to the technological feasibility of the research and development effort, is because of the natural order of business in evaluating and selecting projects for undertaking, particularly in view of the high cost sometimes incurred in obtaining valid estimates of market demand.

A chi-square analysis indicates an 81% probability that the differences in the risk assumed by Groups A and B are due to random sampling errors. There is, however, an additional consideration which must be acknowledged when attempting to determine if a significant difference exists between the two groups. The completeness of the management policy profiles of all companies in Group A, as compared with those in Group B, considered in the light of the interaction within the research and development management process, should enable Group A to predict both cost and returns more accurately. Therefore, the estimates which they provided in response to the survey questionnaire could be inherently more reliable.
Different estimation techniques

The techniques used in analyzing the factors which must be considered in any meaningful profitability analysis were found to vary considerably from company to company. This became readily apparent as a result of an analysis of company selection plans and procedures during on-site interviews. Additional clarification was evidenced through a study of the research and development selection plans submitted with completed questionnaires. The following discussion attempts to synthesize and classify the numerous approaches encountered during the study.

The various approaches used in handling the risk relative to the time, cost and return factors associated with a proposed project undertaking can broadly be placed in one of three categories.

1. Those who perform a profitability analysis on the basis of one best estimate and consider variance and risk subjectively at the executive level.

2. Those who use a "minimum/most probable/maximum" approach and analyze potential profitability on the basis of all three conditions, often combining them for the most adverse combination.

3. Those who formulate quantitative estimates of cost and returns and adjust such estimates for time variances and risk factors in the profitability analysis.

Perhaps typical of the approach used by those in the first category is the procedure followed by Company A, as explained to the author by the vice president for research and development. The profitability analysis is performed on the basis of everyone's best estimate as to what conditions really reflect. Potential risk and variances in time, cost, and returns are acknowledged and discussed
in the project proposal. Additionally, these areas and their ramifications are discussed when the project is presented to top management for approval. It was pointed out that the Company A management understands such situations and is capable of formulating its own judgment. In fact, it was emphasized that this approach was preferred to a quantitative analysis of these factors since subjective evaluations are better made by a composite management judgment.

Three examples, all extracted from actual project proposal plans, will be used to illustrate the various approaches. Example A typifies the approach of those who employ the first technique. The reader should be aware, of course, that the remarks column may be expanded to take the room needed.

**EXAMPLE A:**

<table>
<thead>
<tr>
<th>Area</th>
<th>Unknown</th>
<th>Fair</th>
<th>Good</th>
<th>Certain</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Success</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Success</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial Acceptance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Acceptance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patentability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example B is representative of the approach taken by those companies who utilize the second technique. The writer was told at one company where the approach is employed that if a poor profit picture is
shown by the most adverse combination of factors, it will not necessarily mean the project is rejected; however, if such a combination of adverse factors still shows an acceptable profit position, it is almost a 100% guarantee that the project will be undertaken.

**EXAMPLE B:**

Projected total cost and time to completion of this project:

<table>
<thead>
<tr>
<th>Least/Earliest</th>
<th>Most Likely</th>
<th>Greatest/Latest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ /Date</td>
<td>$ /Date</td>
<td>$ /Date</td>
</tr>
</tbody>
</table>

Projected production costs per 1000 units:

<table>
<thead>
<tr>
<th>Least</th>
<th>Most Likely</th>
<th>Greatest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

Projected date for shipping first production order:

<table>
<thead>
<tr>
<th>Earliest Date</th>
<th>Most Likely Date</th>
<th>Latest Date</th>
</tr>
</thead>
</table>

Projected selling price per 1000 units:

<table>
<thead>
<tr>
<th>Least</th>
<th>Most Likely</th>
<th>Greatest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

Projected annual sales volume ($000) or cost savings:

<table>
<thead>
<tr>
<th>Least</th>
<th>Most Likely</th>
<th>Greatest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

Projected product market life or production use:

<table>
<thead>
<tr>
<th>Least Years</th>
<th>Most Likely Years</th>
<th>Greatest Years</th>
</tr>
</thead>
</table>

Example C is representative of one of the many techniques available to those who utilize the quantitative approach. The company
from whose plan this example was taken calculates profitability on the basis of annual return on the total investment over the estimated life of the market for the product, after taxes. The probability of success figure, calculated as shown in the example, is applied to the projected gross sales. In situations where quantitative estimates of risk are developed, detailed written instructions have been made available for guidance of the personnel formulating them.

EXAMPLE C:

Probability of Success

A four-part factor (0-100%), produced as follows:

\[
\frac{A}{\text{Technological}} \times \frac{B}{\text{Manufacturing}} \times \frac{C}{\text{Economic}} = \frac{D}{\text{Probability}}
\]

A - is the probability of actually being able to complete the research and development effort.

B - is the probability of being able to produce the item in the factory at the estimated cost.

C - is the probability that the actual sales volume can be maintained at the level predicted.

D - is the product of the three probabilities.

An example is:

\[
\text{PROBABILITY OF SUCCESS} = 80 \times 90 \times 70 = 50.4\%
\]

The above observation conforms with that made by Dr. Villers. Regarding the use of such a technique, he states that the obvious advantage of the index is that it provides a standard of measurement for each of the projects considered. Villers warns, however, that it
is meant only to be a guide in making the decision, and from this regard can be useful, but it should be clearly understood that the use of an index is no substitute for the responsibility of decision-making. The writer also observed that, where this approach was utilized, an explanation (both written and verbal) was required to substantiate the judgment at the management review level.

In some situations it was found that an upper limit on the investment which management is willing to make in the research and development phase is established for control purposes. The allowable total expenditures thus obtained, together with the time permitted for the entire project to be successfully completed, can then be proportioned to the various major phases of effort involved. Past experience with similar projects is an invaluable aid in determining the proportionate amount that should be allotted to each stage. Unfortunately, there is no definite percentage for the breakdown that can be given here, since such values will depend entirely upon the nature of the work involved. The problem appears to be best resolved by joint discussions between laboratory and management personnel.

There are three variable factors that are involved in establishing the desired limits for each project stage. These are: the percentage of the total project cost that management is willing to invest in the research effort, the portion of the total time allowed for completing the research and development phase of the project, and

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3 Villers, op. cit., pp. 43-44.
the concentration of resources brought to bear on the project. Theoretically, when any two of these factors are established, the other will be more or less automatically determined. For example, if the investment that is to be made in an applied research stage is determined and the time at which it is desired to have this effort completed is established, the concentration of resources upon the problems involved will also be set. However, problems lying in the area of research and development are not always susceptible to efficient and economical solution by more than a limited number of personnel and resources. If the optimum technical approach to the solution of the problem is less than this, it may be necessary to permit the time required for completing the phase under consideration to be determined by the funds to be allotted and the technical approach that must be followed, perhaps assuming that additional time required for this stage can be compensated for during the development phase, perhaps by increasing the number of personnel assigned at that time.

At one company it was noted as being possible to increase the progress of a project as work progresses and more information becomes available. Under such conditions, work on a project could begin with a relatively few scientists and engineers assigned, but the concentration of personnel could be steadily increased in accordance with the timing and funding requirements. The problems involved in achieving a proper balance between the three variable factors require that each proposal be given individual consideration before adequate decisions can be reached.
In all situations encountered where upper limits were set, authority to continue work on the projects terminated when the project work stage had been successfully completed, when the allocated funds had been deleted, or when the time deadline had been reached, whichever occurred first. At this point, the project is again evaluated to determine whether the present outlook warrants continuing the effort. If continuation of the project is approved, the remaining effort may or may not be subject to the same limitations, depending on the specific conditions as shown in the light of the new evaluation.

The data presented in Table 11 and the discussion of this section are considered to have substantiated the second hypothesis of this study that current practices for assessing the potential profitability of research and development projects are completely diversified within industry, varying from the use of quantitative and highly sophisticated models which allow the treatment of many pertinent factors, to the subjective or qualitative evaluation of a few selected factors with reliance primarily on composite management judgment.

Minimum return sought

An attempt to establish the minimum return that research and development projects should yield is considered outside the scope of this study. When considered independently of risk, it is a function of the desires of management and of the prevailing economic and competitive conditions. However, the returns which a company receives as a result of a research and development project should be commensurate with the risk involved, and appropriate emphasis must be given to this
factor, either in a quantitative analysis or through qualitative considerations. Without the opportunity of realizing returns which are correspondingly higher for higher risk projects, the industrial research and development programs would be of a much less speculative nature and would only be concerned with the pursuit of those projects where success was known to be relatively intimate. It is also pointed out that the returns realized from successful research and development projects must be sufficient to support those that fail and still show a reasonable over-all profit.

Questionnaire recipients were asked what general minimum return their company strives to achieve from successful research and development projects. It was recognized that a "fill in" type question such as this would probably result in a myriad of replies that could not be synthesized in such a manner as to present a meaningful average. However, it was hoped to obtain an indication of the percentage of the respondents who would provide a quantitative statement of the minimum return objectives. The response to this question was the poorest of any in the survey questionnaire. However, it did serve its basic purpose.

Replies were classified into one of four basic categories: (1) good replies, where a quantitative statement of the minimum return objectives was provided, (2) where no specific answer was given, but a statement was provided to the effect that company policy precludes releasing such data, (3) statements which gave recognition to the fact that the minimum returns sought will vary from project to project in
accordance with risk and other factors, sometimes accompanied with a quantitative statement of the extremes, and (4) statement indicating a lack of understanding of the question or simply providing no response. The results are shown in Table 17.

It is interesting to note that the Group B respondents were either able to provide a quantitative statement of the minimum returns objective or gave no response. In no instance did any of them use the "company policy" excuse or cite the variations resulting from different risk levels. Approximately 68% of the Group A respondents provided acceptable quantitative statements, as compared to 50% of Group B. Only 12% of Group A provided inadequate or no response answers as again compared to 50% of Group B. Typical of what was classified as an inadequate reply are the following:

1. No set figure.
2. Research division only three years old--no return yet.
3. Return on what?
5. Profitable production business.
6. Not calculated this way.
7. No single figure.
8. What is meant by "return?"
9. Do not use rate of return.
10. Difficult to answer.
11. Not really germane.
TABLE 17

ANALYSIS OF COMPANY REPLIES ON MINIMUM RETURN SOUGHT FROM R&D PROJECTS

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
</tr>
<tr>
<td>Good replies</td>
<td>35</td>
<td>68.63</td>
<td>28</td>
</tr>
<tr>
<td>Company policy precludes release</td>
<td>6</td>
<td>11.75</td>
<td>0</td>
</tr>
<tr>
<td>Varies with projects depending on risks, etc.</td>
<td>4</td>
<td>7.86</td>
<td>0</td>
</tr>
<tr>
<td>Inadequate or no response</td>
<td>6</td>
<td>11.75</td>
<td>28</td>
</tr>
</tbody>
</table>

12. Cannot be answered in a sensible manner—successful projects must carry failures.

13. A large number of projects have no measurable return.

A chi-square analysis performed on the data as shown in Table 17 indicated less than a 1% probability that differences of the magnitude observed would be encountered due to random sampling errors. It is concluded, therefore, that a significant difference does exist between the Group A and Group B respondents. It is reasonable to assume that research and development executives are more familiar with the corporate expectations regarding minimum project return objectives if they are affiliated with a laboratory where potential project profitability is emphasized. They should, therefore, be more capable of stating such objectives, of acknowledging their existence but being unable to release them because of policy, or of indicating that such objectives are varied in accordance with the
specific situation. In view of the above, the Group A response leads to the conclusion that their research and development executives are more familiar with the corporate desires regarding project returns and are more cognizant of their significance in their research and development program. This was of course anticipated in view of the fact that formulating a quantitative project profitability estimate and conducting project level post appraisals were mandatory prerequisites for entrance into Group A.

It is appropriate to note that seventeen of the questionnaire respondents who provided a statement of the minimum return objectives, clearly pointed out that they are the minimum potential returns that must be indicated by analysis before a project will be undertaken. They further stated that the majority of the projects undertaken indicate a much higher potential return than the minimum required. These comments served to point out that, other criteria having been met, the selection between alternatives is based on potential profitability. This is consistent with the statements made by the company representatives presenting case histories at the Purdue Industrial Research Conference.

Table 18 was compiled primarily for purposes of information. It shows a breakdown of the frequency with which a positive statement of the minimum return objectives was provided, classified in accordance with the method of profitability analysis employed by the firm responding. It also shows the percentage that a positive reply was received on the basis of the number of companies employing the indicated method of analysis (as reflected in Table 12).
In order to provide as complete a picture of the survey results as is possible, some synthesis of the statements regarding minimum return objectives was undertaken. However, no attempt was made to differentiate between the two study groups.

For those companies that estimate project profitability on the basis of the average rate of return to the average investment, the average minimum return sought from successful research and development projects is 16.5%, after taxes. Unless stated otherwise in the completed
questionnaire, responses were assumed to be compounded annually. The high value specified was 30% after taxes and the low was 10%. Two respondents gave a before-tax figure: one at 25% and the other at 30%.

For those companies that estimate potential project profitability on the basis of a discounted cash flow, the average minimum rate of return sought from successful research and development projects is 15.8% after taxes. The highest rate of return specified as being generally sought was 30% and the lowest was 10%. The companies employing the term of recovery or payback method of analysis indicated a maximum recovery period varying from one year to eight years, with an average of 3.2 years.

One additional observation should be made before leaving this subject. Since the question asked addressed itself to the general minimum return that the company strives to achieve from successful projects, it is assumed that the values specified are those associated with the low risk projects. Presumably appropriate adjustments would be made to reflect the higher risk associated with other ventures.
CHAPTER VI

PROJECT PROGRESS EVALUATION

Introduction

After a proposed research and development project has been approved for the laboratory to undertake and the research effort has begun, it is essential to have some means of evaluating the progress being made. A proper evaluation of the original proposal and a basic plan and schedule for accomplishing the work involved are invaluable aids in assuring that the research effort is started in the right direction. However, this is not sufficient to guarantee that the final outcome of the program will be in compliance with the original objectives upon which it was instigated. A continuous job of research management must be that of checking and evaluating the work being performed, encouraging efforts in the right direction, tapering off and discontinuing work in directions where the outlook has become less promising, and reevaluating the financial value of the project to the organization in the light of changing scientific, economic, and market conditions.

Periodic project evaluations which are conducted throughout the research and development effort serve to bridge the gap between the selection process and post-appraisal and contain elements of each.
Management must look forward in the light of current information and reassess the desirability of individual undertakings in terms of the pertinent factors of selection. The considerations involved are much the same as those significant to the original evaluation.

Knowledge of market trends, for example, is an essential in evaluating the profitability of the project as it advances and it may have a very definite influence on the direction and control that management exercises on the work that is being performed. In certain undertakings successful attainment of the project's objective may be considered to be of a specific financial value to the organization for only a limited period of time, perhaps on the basis of indications obtained from a previously conducted market survey. However, the outside factors that influence the returns that may be realized from successful project conclusion are constantly changing, and they could, therefore, have a marked effect on the desired project completion date and the allowable project expenditures.

In addition, management must look back at the effort which has been accomplished and evaluate this in terms of the initial (or officially revised) project design and work schedule. Periodic appraisals of the current and future relative value of the project results to the organization must be conducted. If it is found that conditions have changed appreciably, the basic plan for completing the project, as originally conceived, must be modified accordingly, and the research effort directed in the manner considered most beneficial. Periodic
reviews could readily result in such actions as discontinuing work on the project, increasing the concentration of resources on the project, changing the desired project completion date or modifying the ultimate project objectives.

It will be recalled that one of the criterion developed in Chapter II for the selection of a profitability model was that it be capable of providing pertinent information at successive project reviews. It is necessary, therefore, to provide information regarding the current industrial research and development project review practices, to identify the factors considered in decisions to continue or abandon a project, and to determine how cumulative expenditures are treated. Data collected relative to the above subjects are contained in this chapter.

Frequency of project progress reviews

Questionnaire recipients were asked how frequently individual project progress was formally reviewed. The results are shown in Table 19. Many questionnaire respondents did not answer this question in terms of time, rather they provided such comments as: rarely on a formal basis—informal meetings determine the fate of projects, formal evaluations of progress are held on the basis of pre-selected milestone events, not calendar time, and vary with the significance of individual projects to such an extent that generalizations cannot be made. The following quote from a letter received with a completed questionnaire perhaps typifies the variance which one may encounter in this area.
A brief semi-monthly report is written for each project. For development projects, this results in semi-monthly review by laboratory management and by staff members. For research projects, the semi-monthly review process stops at various levels in the laboratory management. Some section supervisors hold a formal monthly oral review.

In addition to the above process there are two general annual reviews. One of these involves a summary report for the year for all projects and an oral presentation at a meeting of results which are thought to be important to the company. The other involves a visit from the General Manager of the Research Technical Department to each laboratory and his review of oral presentations by project leaders concerning current status of projects.

TABLE 19

<table>
<thead>
<tr>
<th>FREQUENCY OF PROJECT PROGRESS EVALUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP A</td>
</tr>
<tr>
<td>Freq.</td>
</tr>
<tr>
<td>Weekly</td>
</tr>
<tr>
<td>Semi-Monthly</td>
</tr>
<tr>
<td>Monthly</td>
</tr>
<tr>
<td>Quarterly</td>
</tr>
<tr>
<td>Semi-Annually</td>
</tr>
<tr>
<td>Annually</td>
</tr>
</tbody>
</table>

An analysis of the results shown in Table 19 indicates a 93% probability of the differences observed being due to random sampling errors. It is concluded, therefore, that no significant difference exists between Group A and Group B practices.
Little consistency was found among the companies interviewed in relation to the frequency with which formal project progress was reviewed. Three organizations indicated that this was accomplished on a monthly basis. Two laboratories stated that they attempt to hold formal progress reviews on a quarterly basis, but that in many instances the pressure of work necessitates semi-annual reviews; in another organization a semi-annual review represented the maximum time between progress evaluations, but on selected projects reviews are held as frequently as monthly. In still another laboratory it was found that formal progress reviews are held annually unless such a review is warranted as a result of having "flagged" an unusual situation, such as major deviations to the schedule or estimated expenditures, or of indications that market conditions have changed significantly. The one point universally agreed upon by the executives interviewed was that, in general, the significance and importance of the individual projects will to a large degree determine the frequency with which progress is evaluated. The other factor found to be significant in determining when progress will be evaluated on specific projects relates to the nature of the activity on that project and whether significant progress can realistically be expected during a certain time span.

**Indicators of project progress**

In a research and development undertaking progress may be defined as the obtaining of partial, complete, or negative answers to the various problems that must be solved before the final project
objectives can be realized. Also, the creation and recognition of any new and unforeseen problems should be considered as falling within this category, as should the obtaining of data or methods which enable the work to proceed further. Each of the major work phases into which the project is divided represents a group of tasks all of which may involve numerous task elements and their sub-elements; it is the successful attainment of the solutions to these task elements that constitutes tangible progress.

When progress has been defined so that its presence or absence may be recognized, it would be desirable to have a standard upon which it can be effectively evaluated. Unfortunately, no such standards for evaluating the progress of research and development are available because of their characteristic lack of repetition. Rather, intelligent consideration must be given to each individual project and decisions made in accordance with prevailing conditions.

Questionnaire recipients were asked to rank in order of importance any of a list of attributes which they studied to measure or infer progress on research and development projects. The results are shown in Table 20. It will be noted, however, that three of the items listed -- activity reports, project review meetings, and other meetings such as general staff meetings -- are not attributes by which progress can be measured but rather are the methods used to obtain the information for the evaluation of project progress. Surprisingly enough, no comments regarding this point were received with the completed questionnaires.
<table>
<thead>
<tr>
<th>Completion of a previously established list of sub-tasks</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion of tasks not necessarily previously identified</td>
<td>1.53</td>
<td>2.32</td>
<td>1.94</td>
</tr>
<tr>
<td>Activity reports</td>
<td>3.71</td>
<td>4.71</td>
<td>4.23</td>
</tr>
<tr>
<td>Project Review Meetings</td>
<td>3.68</td>
<td>2.98</td>
<td>3.31</td>
</tr>
<tr>
<td>Number of manhours input</td>
<td>4.25</td>
<td>3.90</td>
<td>4.06</td>
</tr>
<tr>
<td>Other meetings, such as general staff meetings</td>
<td>3.93</td>
<td>5.05</td>
<td>4.52</td>
</tr>
<tr>
<td>Expenditures to date</td>
<td>2.94</td>
<td>3.42</td>
<td>3.20</td>
</tr>
<tr>
<td>Estimates by project personnel of percentage completion of tasks</td>
<td>3.10</td>
<td>4.18</td>
<td>3.67</td>
</tr>
<tr>
<td>Remaining funds versus planned workload remaining</td>
<td>3.62</td>
<td>4.55</td>
<td>4.11</td>
</tr>
<tr>
<td>Estimates by project personnel as to whether project is &quot;on time&quot;</td>
<td>3.96</td>
<td>3.54</td>
<td>3.76</td>
</tr>
<tr>
<td>PERT or other CPM system</td>
<td>4.79</td>
<td>5.35</td>
<td>5.30</td>
</tr>
<tr>
<td>Remaining time versus planned workload</td>
<td>5.19</td>
<td>4.64</td>
<td>4.91</td>
</tr>
</tbody>
</table>
Some of the respondents, although they provided the ranking requested, indicated that all of the factors were significant and had to be used together in order to appraise adequately the progress which had been made. Others stated that the significance attached to the various indicators will vary depending on the level of research activity (basic, applied, development) and the number of people working on the project, together with the various disciplines involved.

Analysis has shown that there is only a 1% probability of obtaining differences of the magnitude observed that are not due to random sampling errors. It is concluded, therefore, that no significant difference exists between Group A and Group B in regards to the relative emphasis which they give the attributes by which progress can be studied and the methods employed in obtaining this information.

It is interesting to note, however, that a weighted average of the rankings from Group B places a method of obtaining information --project review meetings--in the number one position. Group A, on the other hand, ranked the completion of a previously established list of sub-tasks as the number one item of consideration. It may be observed that the number one Group A ranking corresponds to the number two Group B ranking and vice versa. Separating the methods of obtaining information from the indicators of project progress, it may be rather strongly concluded that the completion of a previously established list of sub-tasks is the most significant indicator of
project progress and that project progress review meetings are the most significant method used in obtaining the information necessary to evaluate progress. An additional inference may be drawn from the above, namely that there is a large amount of project planning by both groups which is probably accompanied with appropriate scheduling at least at the task level.

In order to more clearly show the difference in rankings between the methods utilized in obtaining information and between the attributes studied to measure progress, Table 21 has been prepared. It contains the same data as Table 20, but presents it in a slightly different manner.

The Group A third place ranking was given to considerations of expenditures to date. This carries the inference that project expenditures reports are of a secondary level of consideration to Group A in obtaining the information necessary for appraising progress. The Group B respondents on the average ranked this item in number four position. However, they ranked activity reports number three, again a method rather than an attribute. Separating the methods from the indicators once more it can be seen that both Group A and Group B consider expenditures to date as having a second position of importance to be studied in measuring research and development project progress.

The Group A respondents provided an average rating of eighth place position to the number of manhours input, while Group B ranked this attribute next to last as a measure of progress. Appreciation of the low level of significance attached to this factor is perhaps best
<table>
<thead>
<tr>
<th>Attributes of Progress</th>
<th>Group A</th>
<th>Group B</th>
<th>TOTAL SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion of a previously established list of sub-tasks</td>
<td>1.53</td>
<td>2.32</td>
<td>1.94</td>
</tr>
<tr>
<td>Expenditures to date</td>
<td>2.94</td>
<td>3.42</td>
<td>3.20</td>
</tr>
<tr>
<td>Estimates by project personnel of percentage completion of tasks</td>
<td>3.10</td>
<td>4.18</td>
<td>3.67</td>
</tr>
<tr>
<td>Estimates by project personnel as to whether project is &quot;on time&quot;</td>
<td>3.96</td>
<td>3.54</td>
<td>3.76</td>
</tr>
<tr>
<td>Remaining funds versus planned workload remaining</td>
<td>3.62</td>
<td>4.55</td>
<td>4.11</td>
</tr>
<tr>
<td>Completion of tasks not necessarily previously identified</td>
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<td>4.71</td>
<td>4.23</td>
</tr>
<tr>
<td>Number of manhours input</td>
<td>3.93</td>
<td>5.05</td>
<td>4.52</td>
</tr>
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<td>Remaining time versus planned workload</td>
<td>5.19</td>
<td>4.64</td>
<td>4.91</td>
</tr>
<tr>
<td>PERT or other CPM system</td>
<td>4.79</td>
<td>5.35</td>
<td>5.30</td>
</tr>
<tr>
<td>Methods of Communication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project review meetings</td>
<td>2.13</td>
<td>1.79</td>
<td>1.95</td>
</tr>
<tr>
<td>Activity reports</td>
<td>3.68</td>
<td>2.98</td>
<td>3.31</td>
</tr>
<tr>
<td>Other meetings, such as general staff meetings</td>
<td>4.25</td>
<td>3.90</td>
<td>4.06</td>
</tr>
</tbody>
</table>
obtained by the realization that the technical manhours input to date is appropriately reflected in the project expenditures to date, to which both groups attached a high level of importance.

It is interesting to note that PERT or other CPM systems were ranked next to last by the Group A respondents and last by the Group B respondents. While the elements required for this type of networking are to a large extent represented by the other items in the list, it may be inferred that research and development managers do not generally consider the additional effort and cost associated with formalized computer networks to be warranted for purposes of progress evaluation.

The interviews which were conducted during this study provide additional insight relative to the methods by which information is transmitted. It was pointed out that one of the most effective ways of communicating timely information regarding the progress and status of research and developments projects is through the informal conversations and discussions which take place within the laboratory. Often, problems arise in research and development undertakings that require immediate action. When such situations are encountered, it would be impractical to waste valuable time and manpower by waiting until the next Project Progress Report is issued or the next formally scheduled meeting is held before the matter is brought to the attention of the appropriate management level. Obviously then, information regarding the existence of such circumstances must be conveyed to management by informal conversation and/or by more formal oral reports.
The organization and operation of the research and development laboratory is usually such that the research worker can communicate directly with his section supervisor and the project leader to inform them of any problem areas that may have developed. If warranted, management is immediately alerted, and it then becomes management's responsibility to see that an analysis is carried out which would make available all of the information required to facilitate proper direction.

Further, daily conversations with the project leader and laboratory personnel working on a project are a constant source from which management obtains general and supplemental information about the trends and progress resulting from the research effort. It was also found that much of the actual process of controlling and directing the research and development effort is accomplished by such informal conversations, rather than by the issuance of formal management directives or instructions. In every organization visited the importance of informal daily conversations in effective operations was emphasized.

Verbal communications were not covered in the questionnaire. As a result of the interview discussions, the writer feels that had informal conversation been included it would have been highly ranked, perhaps ahead of Project Review Meetings.

The attributes used to measure or infer progress by the persons interviewed conforms generally to the survey findings. The three factors found to be considered most significant are summarized.

1. Successful completion of work in accordance with previously established schedules.
2. Attainment of solutions to the problems involved in accordance with the resources allotted.

3. Opinions of project and supervisory personnel regarding the status of project tasks.

The persons interviewed, however, did not attach as much importance to project review meetings (although they were held) as the survey respondents did. They placed greater emphasis on periodic reports which contain manhour and expenditure data by projects. In practical month to month operations, it was found that attempts are made to establish a control of the expenditures on individual projects so that they will be in accordance with the funds that have been allotted. This permits an evaluation of the research progress in view of the actual cost versus the planned expenditures.

Mr. G. G. Main, Vice President for Finance at Westinghouse, pointed out that the research and development cost planning and control system at Westinghouse extends to the lowest level of supervision. He noted that in order to develop an effective system it was necessary to revise the entire research and development cost accounting procedure, but expressed the feeling that it has resulted in better expense control and higher output of the research and development laboratories. Four of the eight companies visited during the study also indicated that they found it necessary to revise their accounting system in order to provide a more accurate picture of the actual research and development project cost being incurred for purposes of comparison with those planned. Two of these companies had their systems set up by outside consulting organizations specifically for the purpose of enabling an evaluation of project progress to be made in terms of expenditures.
Only a few months before the writer visited Company B it had instituted a new system for project selection, project reporting, and progress evaluation. A copy of the letter to all laboratory personnel which outlined briefly the new system and had attached detailed instructions for conforming with the new approach was obtained. It is offered as an example. Space limitations preclude showing this in its entirety. However, appropriate abstracts are shown for purposes of illustration as follows.

In recognition of the above deficiencies, we are overhauling the entire project system in order to provide better service, more properly established priorities, more accurately account for and predict project cost, and provide a systematic periodic review of each project. The new system will be put into operation September 1, 1965. While it will impose certain additional administrative burdens, these should be offset by improvement in performance on projects.

II. PROJECT REPORTING

Form No. 480-005-0865 (copy attached) will be used within the __________________ laboratory as a monthly reporting means. This method will recognize problem areas, provide emphasis on future plans rather than past accomplishments, and provide information necessary for the director and his project review committee to periodically reappraise the priorities, benefits, feasibility, and cost of active projects.

III. PROJECT ACCOUNTING

Effective September 1, 1965 every employee of the __________ laboratory will fill out a daily time card reporting his activities in order that this information can be coded to the proper project. This information will be forwarded to the data processing center and a monthly report will be issued for use at the __________ laboratory.
Your cooperation in this new project system is obviously needed and urgently requested. It is requested that you understand that the only reason for this expensive overhaul of the project system is to provide better service to the operating divisions, improve the efficiency of the ________ laboratory, and by this means, improve the profitability of the corporation.

A copy of the detailed instructions for compliance with the new system procedures, together with appropriate forms, are attached.

Signed

Abandoning a project

The decisions that are to be made before work on a research and development project is discontinued can be just as critical as those involved in undertaking the effort originally. It would certainly be foolish to continue the investment of funds in a fruitless undertaking; but, on the other hand, it could prove just as foolish to abandon a sound project, on which much effort has already been expended, without proper cause or justification. Obviously, a research and development project should be abandoned when it becomes apparent that it is not scientifically nor technologically possible to achieve a successful conclusion at the present state of the art, when it is realized that the ultimate project objectives will be superseded by another advancement that will effectively render the results of the current undertaking valueless, or when it is definitely indicated that the anticipated market for the project objectives no longer exists.
Questionnaire recipients were asked to indicate the relative level of importance (1 = most important, 2 = secondary importance, 3 = general consideration) of any of a list of factors which they considered in decisions to continue or abandon current research and development projects. The results are shown in Table 22. A chi-square analysis has indicated that there is less than a 1% probability of obtaining differences of the magnitude observed that are not a result of random sampling variations.

The significant observation to be made from Table 22 is the high ranking prominence which both Groups A and B gave to the ability of the company to exploit project results successfully and to the consideration of a reappraised technical risk of successful project completion. These factors were rated one and two, respectively, by both groups. In fact, it can be seen that the top five rated factors in either group, four were in the top five of the other group. In the order of the total weighted average ranking these are as follows.

1. Ability to use successful results effectively
2. Technical risk of successful completion
3. Current state of the art
4. Estimated cost to completion

The ability of the company to use successful project results effectively is considered to cover both the factors of rapid technological obsolescence and a disappearing market. Obviously, the revised estimate of technical risk of successful completion deals with the same factor previously discussed in Chapter IV.
<table>
<thead>
<tr>
<th>Factor</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatibility with existing internal technical capabilities</td>
<td>1.92</td>
<td>2.42</td>
<td>2.18</td>
</tr>
<tr>
<td>Estimated cost to completion</td>
<td>2.18</td>
<td>2.10</td>
<td>2.14</td>
</tr>
<tr>
<td>Cost to date versus prior estimates</td>
<td>2.78</td>
<td>2.50</td>
<td>2.63</td>
</tr>
<tr>
<td>Estimated time to completion</td>
<td>2.68</td>
<td>2.25</td>
<td>2.46</td>
</tr>
<tr>
<td>Technical risk of successful completion</td>
<td>1.44</td>
<td>1.67</td>
<td>1.56</td>
</tr>
<tr>
<td>Time spent to date versus initial estimated length of project run</td>
<td>2.86</td>
<td>2.59</td>
<td>2.72</td>
</tr>
<tr>
<td>Current state of the art</td>
<td>1.97</td>
<td>2.23</td>
<td>2.10</td>
</tr>
<tr>
<td>Interaction with other projects in work and proposed</td>
<td>2.33</td>
<td>2.12</td>
<td>2.22</td>
</tr>
<tr>
<td>Ability to use successful results effectively</td>
<td>1.41</td>
<td>1.45</td>
<td>1.43</td>
</tr>
<tr>
<td>Extent of use of standard parts in result</td>
<td>3.45</td>
<td>2.82</td>
<td>3.12</td>
</tr>
<tr>
<td>Other</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
All of the persons interviewed, together with the executives presenting case histories at the Purdue-Industrial Research Conference, universally indorsed the above conditions as being the three most significant factors which would indicate immediate termination of a research and development project. Mr. Main (Westinghouse) stated that the success realized from research and development projects depends on wise management and the decision factors employed. He noted that projects must be carefully selected on the basis of their potential profitability and that schedules and plans must be carefully laid out. He emphasized the fact that periodic check-ups must be made on the progress being made on the undertaking to see whether the initial and anticipated results can still be realized. Mr. Main pointed out that there must be an unwillingness to compromise by delays and a very strong willingness to abandon a given project when it becomes obvious that it will not give the technical or market results initially anticipated. He stated, "A dollar sign has to appear over the research and development door."

One corporate executive interviewed cited an example of a major project undertaken by his laboratory which involved an annual expenditure of several hundred thousand dollars over a three-to-four year time span. Semi-annual progress reviews, together with progress evaluations at critical milestone points throughout the scheduled effort of the project, were held. Although they were still making satisfactory technical progress, it was discovered that the complexities of production would be such as to make it impractical to introduce the product at
a competitive price. This was identified after total project expenditures had accumulated to about two and one-half million dollars. Even though the market was still there, project re-evaluation indicated that it had to be dropped.

When consideration is given to discontinuing a research and development project because of the additional funds required to complete the remaining work, the decisions involved become more complex.

Research and development projects must be re-evaluated in order to confirm their relative value to the organization whenever the delays or problems encountered in the research process are of a magnitude sufficient to require the total project cost to exceed the limit that has been established on the expenditures. Actually, before any decisions can be adequately made, it must be realized that if the project is abandoned, all of the time and funds already invested will be completely lost, except for any experience that may have been gained or fallout information pertinent to other efforts. Also, it should be readily obvious that the total cost of the project, from the time it was originally started until it is successfully concluded, is not going to yield the return previously anticipated, since expenditures are currently expected to exceed the upper limit set. There are exceptions to this, of course, such as where the market has increased in size. In the light of the two above conditions, it is the writer's opinion that the determination of whether a project should be abandoned is best based on a comparison of the estimated remaining costs required to
obtain the desired results to the returns that are presently anticipated, excluding considerations of more attractive alternative applications for the resources being considered. The methods of profitability analysis utilized in the original selection of the project may be effectively employed in accomplishing this (utilizing a revised risk estimate where it is appropriate).

If continuation of the project in accordance with the revised schedule does not adversely affect the over-all program or specific projects current within the laboratory, it may be reasonably stated that the project should not be discontinued if the expenditures required to complete the remaining work are such that the minimum profitability criteria that management desires to realize on a research and development undertaking of the nature involved in completing the effort are satisfactorily met. However, the final criterion that should be adopted in making "continue-or-abandon" decisions is whether it is possible efficiently to substitute the work on a more promising project, or a combination of projects, in place of the one to be abandoned.

The manner in which survey respondents indicated that they handled cumulative project costs at the time of a continue-or-abandon decision is shown in Table 23. The results are somewhat surprising—approximately 67% of Group A and 61% of Group B indicated they consider such costs in the re-evaluation. Only 33% of Group A and 34% of Group B treat such expenditures as sunk costs.
### TABLE 23

**TREATMENT OF CUMULATIVE PROJECT EXPENSES IN CONTINUE OR ABANDON DECISIONS**

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
<th></th>
<th>TOTAL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
</tr>
<tr>
<td>Consider costs in the</td>
<td>34</td>
<td>66.6</td>
<td>34</td>
<td>60.7</td>
<td>68</td>
<td>63.6</td>
</tr>
<tr>
<td>re-evaluation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treat such expenditures</td>
<td>17</td>
<td>33.3</td>
<td>19</td>
<td>34.0</td>
<td>36</td>
<td>33.6</td>
</tr>
<tr>
<td>as sunk costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Given other consideration</td>
<td>0</td>
<td>—</td>
<td>3</td>
<td>5.3</td>
<td>3</td>
<td>2.8</td>
</tr>
</tbody>
</table>

In no other area was such a large discrepancy found between the practices indicated by the persons interviewed and those of the mail-survey respondents. Six of the companies visited considered cumulative project expenditures at the time of the re-evaluation for the purposes of making a continue-or-abandon decision as sunk cost. The other two companies visited did consider total project cost to date in such a re-evaluation. The explanations offered for this were: (1) as a matter of policy effort must show the desired profit on the basis of total expenditures and (2) if you considered just cost-to-completion you might wind up carrying a project on for years, especially if you did not have a good handle on what was really coming in the future work.

At the Purdue Conference, Mr. W. E. Shoup pointed out that as a matter of criteria projects must meet the check points established
in order to meet the schedule laid down. He noted that if this is not accomplished, estimated costs are generally not adhered to and that if this becomes the case, the project is usually headed for the graveyard because of excessive cost.

The three Group B respondents who indicated that they give "other" considerations to such costs provided comments as follows.

1. General consideration of such costs is given by executive judgment.

2. May do it either or both ways, depending on how critical the decision is.

3. Considered in the light of expected results.

There is the possibility that the question could have been misinterpreted by the respondents. For example, they might have taken it in the light of whether expenditures to date were given consideration together with the technical problems experienced in projecting the estimates of cost to completion. This, of course, was not the intent of the question. At any rate, the author would hesitate to draw a firm conclusion from Table 23, in spite of the rather dominant 2-1 majority shown, without additional research.
CHAPTER VII

PROJECT POST-APPRaisal

Introduction

Previous chapters have discussed the research and development project evaluation and selection process, the various methods employed to estimate potential project profitability and industrial practices relative to periodic project progress reviews. This chapter contains the study research data which pertain to the project post-appraisal function. Also included are primary research data on the sensitivity of project profitability estimates to variations in the factors considered in formulating the estimates.

In addition to the above, a discussion and analysis of the difference between Group A and Group B in their predictability of research and development project costs and returns is presented. For the convenience of the reader, the basis for the establishment of Group A and Group B is repeated. The mandatory requirements for the entrance of respondents into Group A were as follows.

1. Selection of proposed individual research and development projects in accordance with a written plan.

2. Utilization of some type of quantitative method in estimating potential project profitability, at least on a selected project basis.

3. Comparison of estimated costs and returns with actuals through project level post-appraisal for at least a limited number of selected projects.
Group B includes all respondents not meeting the criteria for classification into Group A.

**Frequency and type of post-appraisal**

The survey portion of the study attempted to identify the frequency of the practice of conducting financial analysis for post-appraisal purposes of research and development projects in order to compare estimates of cost and profits with actuals. Additionally, the same question was worded in such a manner as to enable identification of the type of effort undertaken for all successful projects, for a limited number of projects, for the over-all program, or not felt to be of significant value. The results are shown in Table 24.

**TABLE 24**

**POST-APPRaisal, TYPE AND FREQUENCY ENCOUNTERED**

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
<th></th>
<th>TOTAL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
</tr>
<tr>
<td>All Successful Projects</td>
<td>4</td>
<td>7.84</td>
<td>1</td>
<td>1.79</td>
<td>5</td>
<td>4.67</td>
</tr>
<tr>
<td>Selected Projects</td>
<td>47</td>
<td>92.16</td>
<td>9</td>
<td>16.12</td>
<td>56</td>
<td>52.37</td>
</tr>
<tr>
<td>Over-all Program to Determine Effectiveness of Total Research and Development Expenditures</td>
<td>19</td>
<td>37.3</td>
<td>22</td>
<td>39.33</td>
<td>41</td>
<td>38.28</td>
</tr>
<tr>
<td>No Post-Appraisal</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>42.76</td>
<td>24</td>
<td>22.41</td>
</tr>
</tbody>
</table>

The readily apparent difference between the frequency of post-appraisal at the project level in Group A and Group B should not be surprising. (A chi-square analysis has indicated a probability of less than 1% that this distribution could be obtained as a result of
random sampling errors.) Post-appraisal at the project level was a mandatory prerequisite for entrance into Group A. Because of the interactions always present within the management process, it was felt that the management policy profiles studied should include not only project selection in accordance with a plan and a quantitative profitability analysis but for purposes of completion should also include post-appraisal at the project level in order to close the loop. Approximately 92% of Group A performed project level post-appraisals on a limited number of projects as contrasted to about 16% practicing this procedure in Group B. About 43% of Group B do not perform any post-appraisal at all, stating that it is not felt to be of significant value. About 37% of Group A not only conduct post-appraisal at the project level but also utilize this practice for the over-all program in order to assess the effectiveness of the total research and development expenditures. This compares with approximately 39% of the Group B respondents who indicated that they perform post-appraisal at the program level in order to assess total effectiveness.

The interview portion of the study (including both company visitations and discussions at the Purdue Conference) resulted in essentially four reasons being stated why post-appraisal was not undertaken. These may be summarized as follows:

1. Project post-appraisal tends to emphasize selected successful projects and presents a misleading representation of the over-all laboratory endeavors, since it tends to ignore the many efforts which do not prove to be fruitful.

2. The accounting system which we utilize just does not make it possible to properly appraise either what a project has actually cost or what the returns realized actually are.
3. The scientists and engineers working in the laboratories are professional people, and as such they would resent being checked upon like the hourly wage people in the factory. Additionally, if they were frequently called in to justify why a certain effort took more time or cost more money than they had predicted, they would probably start padding their estimates to such a degree that reasonable research projects would appear to be out of reach because of cost.

4. It is not felt that the time and effort required to conduct meaningful post-appraisal would be warranted by the value yielded.

In regards to the first point, the writer must concur with Quinn's position that no management purpose is served by estimating research returns that are not associated with a specific opportunity for exploitation and the actual profits yielded as a result of a particular project being successfully undertaken.\(^1\) Arbitrary credits given to the research and development laboratory, such as that associated with the Olin Industries Index of Return previously discussed, or qualitative assessments of these results, such as that resulting from the company's market position and past growth relative to its competitors, do not provide adequate justification for the large research and development expenditures found in most companies. If the type of information required for financial post-appraisal at the project level is maintained, it should be available for the unsuccessful projects as well as for the successful ones, since it is certainly not known at the offset with 100% assurance which ones will not succeed. There is no rule which states that the practice need be applied only to successful

undertakings. Additionally, approaching over-all program appraisal in this manner will allow an identification to be made of the portion of the effort that was successful versus that which was not. A review of Table 2.1 would indicate that about 45% of the respondents in Group A do in fact tend to utilize such an approach.

The inadequacies of an existing accounting system are viewed as an excuse rather than a reason for not conducting post-appraisal. It will be recalled that the planning premises outlined in Chapter II for selecting a project profitability model stated that a uniform method should be prescribed for data acquisition and computation in the development of model inputs, inferring compatibility with the accounting system. In the preceding chapter, it was pointed out that some of the companies studied revised their accounting systems to assure providing the appropriate records. It would appear that with the electronic data processing equipment which most of the universe studied certainly has the recording and analysis of the necessary data would be a relatively small task. Personnel from two organizations which conduct project level post-appraisal indicated that some revisions were required in their accounting system to integrate all of the data but stated that they were really of a minor nature. One executive stated that before recently revamping the over-all laboratory operation, they had no accounting system and that it was established in such a manner as to automatically provide the information required for project level post-appraisal.

The author observed the existence of the "laboratory prima donna" in two instances during the interview phase. In fact, one
vice president pointed to this situation and acknowledged the management responsibility for allowing the situation to develop. He stated, however, that it was now traditional and there was probably nothing that could be done about it. It would seem that the professional scientist, above all other people, would certainly understand and appreciate the necessity for applying the very scientific method which he employs to the business situation, if he were properly approached and the necessity was adequately explained. In those situations where the research personnel continuously provide such poor estimates that they fear they would frequently have to substantiate their position, it may well be far past time for management to establish an adequate follow-up system in order to assess properly such estimates in view of their past experience with specific individuals.

It is really felt that all of the above reasons essentially amount to a feeling that post-appraisal is not felt to be of significant value in view of the work involved. This view was, to a degree, substantiated by the survey questionnaires by the fourth choice given the respondents. Although comments were freely written on the completed questionnaire, only one respondent scratched out the reason given for not doing post-appraisals. He noted that they are not currently doing it but plan to start in the very near future. The value of post-appraisal as a part of the complete management policy profile will be discussed in a subsequent section of this chapter.

The fact that only 22% of the respondents do not engage in any type of post-appraisal of the research and development effort
indicates that increased attention is certainly being given to the evaluation of the laboratory efforts in the over-all corporate profit posture. However, the inference might well be drawn that those companies that only conduct an appraisal of the over-all effectiveness of the research and development expenditures, while at the same time arguing that project level appraisal tends to overlook the unsuccessful efforts, might themselves be tending to hide the failures by showing the over-all effectiveness and allowing successful projects to carry the unsuccessful ones without a proper identification. Unfortunately, the survey results do not permit an identification of the methods and depth with which post-appraisal is conducted, identifying only the levels at which it is conducted. It would be an unwarranted assumption to indicate that it was all performed in the manner discussed previously.

**Sensitivity of profitability estimates to cost factor variations**

The controller of one corporation where project level post-appraisal is practiced pointed out that the purpose of his organization is to assist management in obtaining the maximum return on investment and that in attempting to accomplish this function, he feels it necessary to provide the following information in relation to the corporate research and development activity. (1) where the company is going with its research and development expenditures, (2) where they presently are, and (3) where they have been.

It was noted that post-appraisal is accomplished on a periodic basis prior to the market introduction of a new product or the
manufacturing application of a process. Individual project expenditure reports are prepared monthly. These present a comparison of the actual project expenditures with the planned expenditures, together with the original cost estimates if the latter have been revised. In addition, the total accrued expenditures are compared with the estimated total program cost.

He pointed out that in attempting to provide management with a measure of effectiveness of the research and development program, he conducts financial post-appraisals of projects after the results have been on the market for a one-or-two year period. This is usually his final report on the project and it compares the actual return on investment with the estimated return on investment and identifies all areas where deviations from original estimates were experienced, together with an explanation of such variance. (This particular company uses the average rate of return to average investment method of analyses for project evaluation and selection as well as project post-appraisal).

Company G's experience on the basis of the above post-appraisal procedure has been summarized as follows for the purpose of this discussion.

1. Achievement of the marketing volume originally estimated is the most significant point in obtaining the desired profitability. There should be a relatively high degree of confidence that the market demands will be what was originally estimated.

2. Variations in production costs from estimates can be significant if they slip in the order of 20%-30%. If this occurs, the company must take either a lower margin or increase the price over
that originally planned. Higher price, of course, influences the volume, and experience has shown that over-all profitability is maximized by accepting a slightly lower margin.

3. It is a rare situation for increases in research and development expenditures themselves to contribute significantly to a lack of success on the part of the product under development. Research and development costs are usually not what would be called a sensitive element. It is possible for these costs to double without significantly affecting the profitability estimates, particularly on a high volume item.

It was pointed out, however, that in spite of the above, the research and development cost estimates are significant in the selection phase, since the principle of scarcity applies and the decision is a choice between alternatives. In addition, it was stated that cost control is maintained on research and development projects and that over-runs must be justified. It was noted that if the knowledge of the effect of research and development cost savings, and cost reductions, on profitability became generally known, it would make it much more difficult to enforce control procedures.

Questionnaire recipients were asked to rank, using a scale from one to ten, the determinant factors of cost and return in accordance with how sensitive the over-all profitability estimates are to variations in these factors. Additionally, they were asked to indicate with an X any factor not considered during the evaluation and selection process. The results are shown in Tables 25 and 26 respectively.
TABLE 25

WEIGHTED AVERAGE RANKING OF PROFITABILITY
SENSITIVITY TO FACTOR VARIATION

<table>
<thead>
<tr>
<th>Factor</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research and Development Costs</td>
<td>3.98</td>
<td>4.72</td>
<td>4.37</td>
</tr>
<tr>
<td>Production Costs</td>
<td>2.28</td>
<td>2.69</td>
<td>2.49</td>
</tr>
<tr>
<td>Capital Costs</td>
<td>5.05</td>
<td>5.79</td>
<td>5.44</td>
</tr>
<tr>
<td>Marketing Costs</td>
<td>4.40</td>
<td>4.67</td>
<td>4.54</td>
</tr>
<tr>
<td>Total Demand</td>
<td>1.98</td>
<td>2.73</td>
<td>2.37</td>
</tr>
<tr>
<td>Share of Market</td>
<td>3.15</td>
<td>2.78</td>
<td>2.96</td>
</tr>
</tbody>
</table>

The sensitivity of the over-all profitability estimate to variations in the different factors would, of course, be expected to fluctuate from situation to situation. It is dependent entirely on the nature of the project undertaking and the specific situation of the company in terms of such things as basic industries, degree of competition, firmness of established market position, effectiveness and flexibility of established marketing channels, sales force, and promotional activities. As indicated by previous discussions, however, there are two prerequisites for profit realization—a certain minimum market demand must be present (or created) and the capability must exist for production at a cost which enables market entry at a realistic price level. With these two elements present, an individual firm must be able to attain a sufficient share of the total market demand to enable economic production and distribution.
The survey results clearly substantiate the universality of the above as significant factors in achieving the expected profitability levels. Group A ranked variations in total demand as being the most significant factor influencing profitability estimates, with production cost variations being second. Group B respondents ranked variations in total production cost as being most influential in over-all profitability, but changes in total demand estimates were such a close second that the two should be considered as receiving equivalent ranking. Both groups ranked variations in estimates of the company's share of the market as having third-level significance on the project's profitability. Ranking was reversed between the two groups on the positions given research and development cost and marketing cost. Group A respondents assigned a fourth place position to variations in research and development costs, with changes in marketing cost estimates receiving a fifth-place ranking. Group B respondents ranked these two factors in just the opposite manner. Analysis has shown that there is no significant difference in the ratings assigned by the two groups for the various component costs and return factors of the project profitability analysis.

While the ranking obtained from the survey does not allow conclusions to be drawn as to the relative significance of one factor versus another in its influence on profitability expectations, the interval scale used for purposes of ranking does provide some indication of the intensity of the feeling of the Group A respondents and Group B
respondents in regards to factor variations. Figure 7 shows the weighted average ranking of each group plotted against an appropriate scale. Some interesting inferences can be drawn from this Figure.

A general inference that the Group A respondents are more alert to the over-all significance of variations in estimates of the factors shown and have a better appreciation for the relative relationship of the impact of such variations on estimated profitability are felt to be supported by Figure 7 in two ways. First, all of the factors rated are higher on the scale than the comparable factor position given by the Group B respondents, indicating a more intense attitude towards such factors. Second, the Group A spread in rating indicates a better understanding of the relative impact which the various factors have on their company's area of business than does the cluster type of approach shown by the Group B respondents. The almost identical rating positions assigned to variations in production costs, total demand and share of the market estimates by the Group B respondents indicates a general appreciation for their significance over other factors, but an inability to identify clearly which is the more significant. The same is true, of course, for the marketing cost and research and development cost variations as assigned by the Group B respondents. Group B also obviously recognizes that the variations in the cost of capital (it cannot be assumed that this includes opportunity

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Figure 7 - Weighted Average Ranking of Factor Variation Influence on the Over-all Project Profitability Estimate.
cost) is of an order or magnitude less significant than variations in marketing costs and research and development costs, as these latter are to the higher rated cluster of factors.

An additional inference which can be drawn is that the Group A respondents, given a reliable estimate of the total demand, are less concerned with their share of the market. This would indicate a relatively firm competitive position. Group B respondents indicate that total demand is only slightly more significant than variations in estimates of their company's share of that demand. An alternate way of looking at this would be to infer that the Group A respondents have not realized an expected level of project profitability because of variations in total demand and production costs more frequently than have Group B respondents, and they are, therefore, more keenly aware of their significance. It could perhaps also be reasonably inferred that the Group A respondents are engaged in a more innovative type of research and development activity which does not enable them to predict total demand and production costs as accurately as those who pursue a more conventional type of program.

Many additional inferences can be drawn from Figure 7. However, it is felt that pursuit of such speculation would not serve any additional purpose. It was acknowledged previously that the significance of variations in the component factor estimates on the over-all estimate of profitability depends on the nature of the project and the situation of the company. However, the writer does not feel that a random sample of the type obtained would result in differences of the type shown in
Figure 7. It is concluded, therefore, that the first difference discussed is reasonably valid.

TABLE 26

PER CENT NOT CONSIDERED IN EVALUATION

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
<th></th>
<th>TOTAL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
<td>%</td>
</tr>
<tr>
<td>Research, Development</td>
<td>0</td>
<td>--</td>
<td>1</td>
<td>1.79</td>
<td>1</td>
<td>0.94</td>
</tr>
<tr>
<td>and Engineering Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Costs</td>
<td>1</td>
<td>1.96</td>
<td>0</td>
<td>--</td>
<td>1</td>
<td>0.94</td>
</tr>
<tr>
<td>Cost of Capital</td>
<td>2</td>
<td>3.98</td>
<td>1</td>
<td>1.79</td>
<td>3</td>
<td>2.80</td>
</tr>
<tr>
<td>Marketing Costs</td>
<td>1</td>
<td>1.96</td>
<td>2</td>
<td>3.58</td>
<td>3</td>
<td>2.80</td>
</tr>
<tr>
<td>Estimate of Total Demand</td>
<td>0</td>
<td>--</td>
<td>1</td>
<td>1.79</td>
<td>1</td>
<td>0.94</td>
</tr>
<tr>
<td>Estimate of Company's</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of the Market</td>
<td>1</td>
<td>1.96</td>
<td>1</td>
<td>1.79</td>
<td>2</td>
<td>1.88</td>
</tr>
</tbody>
</table>

The almost universal consideration of all of these factors, either quantitatively or subjectively in the evaluation of research and development project profitability, is readily apparent from Table 26. It can be seen, however, that each factor is not considered by at least one of the respondents. Although there are logical reasons why any given factor would not receive consideration in specific instances involving project selection, the author is really at a loss to explain why each factor would always be omitted from consideration by at least one respondent when formulating a project profitability analysis. The survey results are simply presented.
Difference in predictability

The management practices of the Group A respondents obviously involve more time and effort than those generally practiced by the majority of the Group B respondents. Their management process must consequently be more costly. However, this is a narrow-view, short-run consideration. The Group A companies are apparently willing to provide any additional funds required in anticipation of the long-range benefits expected to be derived. One of the benefits which can be realized is increased predictability of both project cost and returns. The fifth major hypothesis of this study states that those companies who select research and development projects in accordance with a written plan, conduct a quantitative profitability analysis, and perform post-appraisal at the project level are more able to predict results accurately than those who do not. This section will explore that hypothesis.

It should be noted that a lack of predictability does not necessarily mean a lack of profitability. It is, of course, a matter of degree. It is entirely possible for the actual cost and returns experienced on a project to vary significantly from the estimates and still be highly profitable. Accidental discoveries, often encountered in research and development and which frequently result in a high payoff, cannot be completely disregarded. Finally, it must be acknowledged that rigorous planning and analysis cannot be substituted for corporate capability as expressed by such things as sound executive judgment, production know how and marketing experience and skill.
The universe selected for this study was the Fortune 500 Top Industrialists. Obviously, all of these companies have been relatively successful and it may be readily concluded, therefore, that their research and development programs have been reasonably successful. The difference in effectiveness between the first five companies and the last five companies of the universe would perhaps be large. However, in a study of this type, where a random sample is taken from the entire universe and averages computed, overwhelming differences in the observations would not normally be anticipated. Where only small differences can be observed between two groups which have been established on the basis of specified characteristics, it is felt reasonable to assume that such differences may be attributed to the different classification characteristics. This assumption is especially applicable to the two categories employed in this study, since entrance into Group A required possessing all three of the specified characteristics. Members of Group B, on the other hand, may possess any two of the three prerequisite traits. The two basic categories were established because of the interactions within the management process and the desire to differentiate between companies having the complete policy profile and those which were incomplete.

A small difference in the predictability between two companies may be insignificant during any given time period. However, if research and development activity is really a major contributor to industrial growth and expansion, a small increase in predictability should result in many more project "hits" and more over-all effective operation in
the long run. It can be strongly inferred, therefore, that increased project predictability will result in increased profitability in the long run.

Reliability of cost estimates. Questionnaire recipients were asked how actual cost and returns generally compared with project estimates. There were provided seven spaces for "check off" as appropriate. Table 27 shows the survey results for the comparison of actual cost versus project estimates.

TABLE 27

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>%</td>
<td>Freq.</td>
</tr>
<tr>
<td>Actuals are much higher than estimated</td>
<td>1</td>
<td>1.96</td>
<td>7</td>
</tr>
<tr>
<td>Actuals are somewhat higher than estimated</td>
<td>21</td>
<td>41.18</td>
<td>22</td>
</tr>
<tr>
<td>Within estimation accuracy, they are essentially the same</td>
<td>13</td>
<td>25.49</td>
<td>11</td>
</tr>
<tr>
<td>Actuals are somewhat lower than estimated</td>
<td>1</td>
<td>1.96</td>
<td>1</td>
</tr>
<tr>
<td>Actuals are much lower</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Relationship varies depending on the past related experience</td>
<td>15</td>
<td>29.41</td>
<td>13</td>
</tr>
<tr>
<td>Can't generalize or other</td>
<td>0</td>
<td>--</td>
<td>2</td>
</tr>
</tbody>
</table>

Within the accuracy normally associated with estimation techniques, approximately 25% of Group A and 19% of Group B generally find that
the actual project costs are essentially the same as the estimates. Approximately the same relative percentage difference exists between the two groups of respondents who acknowledged that the relationship varies depending on past experience in estimating similar projects in terms of technical areas, length of project runs and other factors. The recognition by 29% of Group A and 23% of Group B of the significance of past experience with similar projects as a determinant of reliable cost estimates tends to substantiate the previous inference. One respondent in each group apparently prepares cost estimates which are sufficiently conservative as to preclude exceeding cost limits on given projects. Two per cent more of the Group A respondents (41.18 per cent versus 39.29 per cent) indicated that the actual costs were generally somewhat higher than estimated than did the Group B respondents. However, over 12% of Group B stated that actual costs are much higher than estimates as compared with about 2% of Group A reporting this condition. In total, over 8% more of the Group B respondents reported that actual costs generally exceed estimates than those in Group A. Two Group B respondents stated that they were unable to generalize.

A chi-square analysis was performed on the survey data as it is shown in Table 27. The results indicated only a 63% probability that the observed differences were statistically significant rather than being due to random sampling errors. Since none of the respondents indicated the actual costs were much lower than those originally estimated, the inclusion of this category in the analysis did little more than add a degree of freedom. Additionally, no real
information is gained by including the two Group B respondents who did not answer the question in the manner requested. Therefore, the chi-square analysis was rerun, omitting these categories and appropriately adjusting the size of Group B. These results indicated a 68% probability of the observed differences being statistically significant.

While the differences observed between the two study groups are relatively small in terms of percentages, they are in the direction of supporting the hypothesis, especially if acknowledgement is made of the pertinency of past experience in generating reliable cost estimates. There is no reason to suspect that on the average the general level of capability and experience of the research and development laboratory personnel would vary significantly between the two groups. Also, as mentioned previously in Chapter II there is a certain degree of experience gained in revising estimates when the effort exceeds the limits established. This is true regardless of whether formal appraisal of variance is analyzed in the procedure employed. In addition, the costs associated with production, and to a lesser degree with marketing, interface relatively closely with the end of a development project. Here again, the past experience should be available to both groups, especially in situations where projects have had to be terminated because of excessively high cost in these areas.

In view of the above, the author would reject the null hypothesis, and conclude that, on the average, the Group A respondents tend to formulate more accurate project cost estimates than do those in Group B.
Reliability of forecast returns. The survey results showing the comparison of actual returns versus estimates are presented in Table 28.

**TABLE 28**

<table>
<thead>
<tr>
<th>Comparison of Actual Returns Versus Estimated Returns</th>
<th>GROUP A</th>
<th>GROUP B</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq. %</td>
<td>Freq. %</td>
<td>Freq. %</td>
</tr>
<tr>
<td>Actuals are much higher than estimated</td>
<td>0</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>Actuals are somewhat higher than estimated</td>
<td>3</td>
<td>5.88</td>
<td>2</td>
</tr>
<tr>
<td>Within estimation accuracy, they are essentially the same</td>
<td>13</td>
<td>25.49</td>
<td>12</td>
</tr>
<tr>
<td>Actuals are somewhat lower than estimated</td>
<td>16</td>
<td>31.37</td>
<td>15</td>
</tr>
<tr>
<td>Actuals are much lower</td>
<td>1</td>
<td>1.96</td>
<td>2</td>
</tr>
<tr>
<td>Relationship varies depending on the past related experience</td>
<td>16</td>
<td>31.37</td>
<td>14</td>
</tr>
<tr>
<td>Can't generalize or other</td>
<td>2</td>
<td>3.92</td>
<td>9</td>
</tr>
</tbody>
</table>

About 4% more of the Group A respondents indicated that they were able to predict returns within estimation accuracy than did the Group B respondents. Additionally, Group A reported about 6% higher that results varied depending on past experience with similar undertakings. Approximately 6% of Group A and 7% of Group B reported that actual returns are generally higher than estimates. However, 3 1/2% of Group B reported that actual returns are much higher than estimated, as compared
to no one reporting this from Group A. The largest percentage difference observed between the groups is in regards to those not answering the question in accordance with instructions. Approximately 16% of Group B but only 4% of Group A stated that they could not generalize, or commented in some manner. The following are representative of the statements made on completed questionnaires.

1. Highly variable but the winners cover the losers or we would go bankrupt.

2. Do not use rate of return analysis.

3. Answers vary from project to project.

4. Estimated only for some short-term work.

5. Rates of return are not calculated to the point where significant answers are possible.

6. Can't generalize, not measured, etc.

The respondents who stated that the answers are highly variable from project to project are essentially acknowledging that they do not accurately predict returns and that they tend to both under-estimate and over-estimate them. To a degree, those stating an inability to generalize fall in the same category. Two respondents misinterpreted the question and indicated that they thought it was concerned only with rates of return. Actually, a special attempt was made in development of the question to use returns in such a manner that it could be answered regardless of the way they were calculated by individual companies.

As in the discussion concerning cost, it is pointed out that the predictability of returns is not a measure of profitability.
Rather, it is a measure of the reliability of the estimates and when combined with the cost estimates, represents a measure of the predictability of profits. Again, long-term profitability can be inferred.

It is generally felt that those companies which realize much higher returns than estimated are either lucky or develop exceptionally poor forecasts. Similarly, the companies that experience actual returns which are much lower than estimates are either unfortunately caught in a trend change or other unforeseen happening or they also provide grossly inadequate estimates. Both of the above situations are considered equally bad since they can result either in projects being rejected that should have been undertaken or projects being accepted at the expense of passing over other more profitable ventures.

A chi-square analysis of the data was performed in accordance with the way the survey results are presented in Table 28. The results indicated a 33% probability that the differences observed were due to random sampling errors. In following the same line of thought used in analyzing the estimated versus actual cost relationships, namely that nothing is really known about the group which did not answer as requested, the chi-square analysis was rerun, omitting the last row and appropriately adjusting the group base numbers. The results of this approach indicated a probability of approximately 75% that the differences were due purely to random sampling variations.

On the basis of the latter analysis, one would certainly state that a significant difference between the two groups has not been identified. However, to accept the null hypothesis, and reject
the study hypothesis, would be to effectively imply that long standing management practices which have proven beneficial in other applications are not being effectively applied in industrial research and development.

Many assumptions could be formulated to explain why a larger statistical difference between the two groups has not been observed. For example, relying on a previous inference it could be suggested that those who perform only over-all program appraisal to determine the effectiveness of the total research and development expenditures are relating these results to the question asked. It is entirely possible for a project which results in a highly successful product on the market to more than offset many whose products were market failures. Under these conditions, appraisal of the total research and development program effectiveness could be good. Also, one could simply point to the natural reluctance and hesitancy of people to provide information on their activity which tends to show it in unfavorable light. Another alternate approach would be to note the high level of the business economy at the time the questionnaire was mailed and then to imply that it was preceded by a period of rising activity where many new things were being readily accepted on the market and that the respondent's attitude was consequently optimistic.

A different line of reasoning could be developed by noting that the concept of project level post-appraisal of research and development is a relatively new one. The inference can then be made that, because of the time lag from project initiation to the end of useful life, the experience gained and the benefits to be derived have lagged
in a similar manner, so that the differences are not yet readily apparent. Speculation could also be developed that Group B is perhaps conducting a more routine type of research and development effort which by its very nature is more predictable.

Counter arguments to any of the above could also easily be formulated. It could be noted, for example, that there are additional differences between the two groups besides those upon which they were categorized and that these tend to compensate. It could even be argued that there are other far more significant factors involved which tend to obscure the relatively minor significance upon which the two basic groups were established. Such factors as the quality of management, the organization of the company, the level of the investment, the quality and quantity of the employees, the intensity of selling efforts, the effectiveness of the selling effort, the firm's financial position, and the over-all strength of the economy could be cited. The latter position can even assume an equal distribution of such factors between the two groups.

In view of the fact that large differences were not expected between the two groups, it is considered that the key to whether the study hypothesis is accepted as being reasonably valid or rejected lies in the decision as to whether to include in the analysis those respondents who did not answer the question in accordance with the instructions. As an aid to arriving at such a judgment, a review of how the Group B respondents answered certain other questions, in comparison with how they stated actual project returns generally
compared with estimates, is of assistance. A matrix depicting these relationships is shown in Table 29.

Of the Group B respondents being considered, 4.5% do not formulate any type of quantitative profitability estimate and the remainder do so only on a selected project basis. In addition, one of the respondents indicated that an executive judgment of the potential project profitability is not made. None of the respondents being considered were able to provide a meaningful statement regarding the general minimum of return that their company strives to achieve from successful research and development projects. Finally, it can be seen that seven of the respondents do not conduct any type of post-appraisal, while one evaluates the over-all research and development program effectiveness and the other performs this function only for selected projects.

For the purpose of comparison, a similar matrix showing the relationship of the Group A replies to the same selected questions is presented in Table 30. An analysis of the difference between the two study groups in regards to the selected questions has been discussed in this and previous chapters.

In view of the above, and recalling that some of the written comments effectively acknowledged a lack of predictability, judgment dictates that these respondents must be considered in the analysis. To do otherwise would be to essentially remove from Group B 1.6% of the sample having those traits upon which the basic categories were originally established. This approach would have the tendency of making
<table>
<thead>
<tr>
<th>Indicated Comparison of Actual Returns to Estimates</th>
<th>Much Higher</th>
<th>Somewhat Higher</th>
<th>Within Accuracy</th>
<th>Somewhat Lower</th>
<th>Much Lower</th>
<th>Varies with Experience</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freq. %</strong></td>
<td><strong>Freq. %</strong></td>
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<td><strong>Freq. %</strong></td>
<td><strong>Freq. %</strong></td>
<td><strong>Freq. %</strong></td>
</tr>
<tr>
<td>For all Projects</td>
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<td>1 1.79</td>
<td>5 8.93</td>
<td>4 7.14</td>
<td>2 3.57</td>
<td></td>
<td></td>
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<tr>
<td>Selected Projects</td>
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<td>1 1.79</td>
<td>7 12.50</td>
<td>11 19.64</td>
<td>2 3.57</td>
<td>7 12.50</td>
<td>5 8.93</td>
</tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Formulates Quantitative Profitability Estimates</td>
<td>Yes</td>
<td>2 3.57</td>
<td>2 3.57</td>
<td>9 16.07</td>
<td>13 23.21</td>
<td>2 3.57</td>
<td>13 23.21</td>
</tr>
<tr>
<td>No</td>
<td>3 5.36</td>
<td>2 3.57</td>
<td>1 1.79</td>
<td>1 1.79</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Formulates Executive Profitability Judgment</td>
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<td>1 1.79</td>
<td>1 1.79</td>
<td>7 12.50</td>
<td>9 16.07</td>
<td>1 1.79</td>
<td>9 16.07</td>
</tr>
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<td>Provided Statement of Minimum Desired Return on Successful R&amp;D Projects</td>
<td>No</td>
<td>1 1.79</td>
<td>1 1.79</td>
<td>5 8.93</td>
<td>6 10.72</td>
<td>1 1.79</td>
<td>5 8.93</td>
</tr>
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</table>

TABLE 29

MATRIX OF GROUP B REPLIES TO SELECTED QUESTIONS
<table>
<thead>
<tr>
<th>Conducts Project Post-Appraisal</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
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<tr>
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<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td>5 8.93</td>
<td>1 1.79</td>
<td></td>
</tr>
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<td>On Over-all R&amp;D Program</td>
<td>1 1.79</td>
<td>1 1.79</td>
<td>7 12.50</td>
<td>7 12.50</td>
<td>5 8.93</td>
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<td>1 1.79</td>
<td>4 7.14</td>
<td>6 10.72</td>
<td>2 3.57</td>
<td>3 5.36</td>
<td>7 12.50</td>
</tr>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>Project 2</td>
<td>Project 3</td>
<td>Project 4</td>
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<td>Project 2</td>
<td>Project 3</td>
<td>Project 4</td>
<td>Project 5</td>
<td>Project 6</td>
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<td>Results</td>
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<td>No</td>
<td>No</td>
<td>No</td>
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<td>No</td>
<td>No</td>
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<td>Selected</td>
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<td>Selected</td>
<td>Selected</td>
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</table>

Matrix of Group A Responses to Selected Questions

Table 30
<table>
<thead>
<tr>
<th>Conducts Project Post-Appraisal</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
<th>Freq. %</th>
</tr>
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<tbody>
<tr>
<td>For all Projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>5.88</td>
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<td>5.88</td>
<td>10</td>
<td>19.6</td>
<td>16</td>
<td>31.3</td>
<td>1</td>
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<tr>
<td></td>
<td>1.96</td>
<td>15</td>
<td>15</td>
<td>29.4</td>
<td>2</td>
<td>3.92</td>
<td></td>
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<tr>
<td>On Over-all R&amp;D Program Effectiveness</td>
<td>8</td>
<td>15.7</td>
<td>5</td>
<td>9.81</td>
<td>6</td>
<td>11.7</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Group B possess a larger percentage of the characteristics of Group A. Since only small differences were anticipated initially, this type of situation would result in an even smaller significant difference being expected. Fundamentally, this is what the two chi-square analyses performed has in fact shown.

There are other observations which can be made from a review of the matrix presented in Table 29. For example, of the Group B respondents who indicate that they formulate a quantitative profitability estimate, 26% stated that within estimation accuracy actual returns are essentially the same as the estimates, while 45% indicated that they generally vary from estimation limits. Of those who were able to provide a reasonable statement of the minimum expected return from successful projects, 25% indicated that actual returns compared favorably with estimates; however, 45% of the respondents reported that they generally experienced deviations. Of the Group B respondents who conduct project level post-appraisal, only one indicated a favorable comparison between actual returns and estimated returns, while two respondents who performed this function indicated that actual returns are generally found to be somewhat lower than estimates. It is interesting to note that 55% of Group B who practice project level post-appraisal indicated that the relationship between actual returns and those estimated varies with experience on similar projects. Even looking at the number of Group B respondents who indicate that they formulate an executive profitability judgment during the project selection phase, it can be seen that 21% reported accurate forecasts of returns and 40%
reported that they generally experience variations from the predictions.

In view of the discussions presented in this section, the study hypothesis is accepted and it is concluded that those industrial concerns which select research and development projects in accordance with a written plan, conduct quantitative profitability analysis before the project is undertaken, and perform project level post-appraisal of the results obtained are more accurately able to predict project cost and returns than those companies which do not.
CHAPTER VIII

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Much attention has been devoted to the influence of research and development as a major factor in industrial expansion and economic growth. The competitive market forces that result from research and development activities are of major importance to the individual companies that must operate in the environment and survive by ensuring that they meet the challenge through their own corporate research and development programs. In today's technologically oriented market, long-term corporate growth and profitability cannot be realized without an effective research and development program. However, the pursuit of research and development projects as a competitive weapon requires that the over-all program be effective in providing the desired results. Corporate support of a research and development laboratory, merely for the sake of doing research, can be disastrous, not only because of the lost cost of the research effort itself but because of the potential technological loss to competition.
Much care is required to ensure that meaningful results are achieved through the research and development program and that these support the corporate long-term interest and stated objectives. It is usually found, however, that many more projects are proposed for undertaking than a company can normally support. The first critical problem research and development management must face, therefore, is that of selecting the projects to be undertaken. The effectiveness of any research and development program in achieving the stated corporate objectives is only as good as the criteria employed to screen, evaluate, and select individual projects for undertaking and the adequacy of the techniques used in accomplishing this. After a project has been selected for inclusion in the company program, periodic follow-ups are required in order to evaluate the progress which is being made and to determine if the benefits originally anticipated will still be provided by successful project conclusion.

The purpose of this study was to gather information relative to the current industrial practices in the evaluation and selection of individual research and development projects, with the objective of providing a better insight and understanding of this management decision process. In accomplishing this, an attempt was made to gather information regarding the relative emphasis given the various objectives of the research and development projects, to determine the general methods of project funding, and to establish the degree to which the evaluation process is formalized or preplanned, as well as to specify the major parameters considered in the project selection process and
to identify the frequency and methods used in assessing project progress. Emphasis was placed on the extent to which potential profits are utilized in the evaluation process and on the factors considered essential for incorporation into a meaningful project profitability analysis.

Although primary emphasis of the study was given to the identification of contemporary management practices regarding the evaluation and selection of research and development projects, the following specific hypotheses were investigated:

1. Within the framework of objectives established by the corporate long-range plan (or company policy, whichever is appropriate) potential project profitability is the major single factor in determining whether a research and development project will be undertaken.

2. Current practices for assessing the potential profitability of research and development projects are completely diversified within industry, varying from the use of quantitative and highly sophisticated models which allow the treatment of many pertinent factors, to the subjective or qualitative evaluation of a few selected factors with reliance primarily on composite management judgment.

3. Even in the cases where models, representing a conjectural explanation of the research and development project situation, are used for identification of desirability or profitability, the executive composite judgment is always made and plays a significant part in the final selection.

4. Techniques are available to permit the development of a general approach to research and development project profitability analysis which allows the incorporation of the essential factors necessary for a meaningful evaluation. However, published models to date are inadequate in terms of their treatment of all the necessary factors or are not sufficiently adaptable to specific industrial situations.

5. Those industrial concerns which select research and development projects in accordance with a written plan, conduct quantitative profitability analyses before the project is undertaken, and perform post appraisal of the results obtained at the project level.
have results which are more predictable than those which do not, in terms of estimated cost and anticipated returns versus actual cost and actual returns.

The broadness of the subject of industrial research and development, involving as it does many disciplines and all organic functions of business operation, necessitates as much limitation as possible. Therefore, the scope of this study has been essentially limited to an investigation of the management functions of research and development project selection and progress evaluation in profit motivated industrial enterprises. Consequently, the study was not primarily concerned with

1. Business organizations not falling into the 500 largest American industrialists as reflected in The Fortune Directory

2. The organization of research and development laboratories

3. A determination of what the corporate basic policy or long-range plan objectives should be in relation to the scope and goals of their research and development program

4. The hiring, training, and utilization of the scientific personnel or the human relation aspects of laboratory operations

5. The quantitative methods or techniques used for obtaining over-all corporate research and development program balance

6. Industrial research not pertaining to the physical sciences, such as marketing research

7. The methods and techniques used in evaluating the technical aspects of proposed research and development projects

Both secondary and primary data were gathered during the course of the study, with an analysis and synthesis of the latter being the most important in development of the final report. The first step was to conduct a comprehensive review of existing literature on the subject
of industrial research in order to become knowledgeable in the area and to provide a frame of reference for continuation of the study.

Three approaches were utilized in essentially a concurrent manner in gathering the primary data. These included (1) conducting intensive interviews with corporate executives in the vanguard of research and development management activities (2) attendance at a Purdue University conference on industrial research and (3) the preparation and distribution of a comprehensive questionnaire to a random sample selected from the universe under study.

Chapter II presented selected concepts of industrial research management and reviewed pertinent portions of related research and the existing body of contemporary literature. Also included in the chapter was a discussion which related the project evaluation and selection process to the basic management planning function and reviewed the planning principles which apply. The basic criterion necessary for the selection of a model or computational method for formulating an estimate of potential project profitability were discussed and a review of the various methods which have been proposed in the literature was presented. The minimum elements necessary for inclusion in a mature model for use by industry today were developed.

Some background relating to the environment in which the research and development project evaluation and selection process takes place was developed in Chapter III. The various organizational arrangements for accomplishment of the research and development function in large corporations were briefly presented. The functions of the
research and development program and the objectives which management might desire to achieve were reviewed and discussed. The order of importance assigned to these by the survey respondents was presented. The basis for allocating the resources necessary to pursue an active research and development program was discussed, together with provisions for obtaining additional funds required to undertake a previously unidentified, but profitable, project. Finally, the importance of maintaining the over-all program balance in relation to certain factors was examined.

Chapters IV and V were concerned with a discussion of the details relative to the project evaluation and selection process. The first dealt with the planning of the selection procedure, the basic elements which constitute such a plan, and the contents of information normally contained in a research and development project proposal. The emphasis which the survey respondents placed on the factors of project selection was reported. A procedure for project selection was synthesized and the relative importance played by executive judgment in this process was discussed. The latter chapter was concerned with the methods and techniques utilized in formulating an estimate of potential project profitability, together with a discussion of some of the more significant factors which must be included for a meaningful analysis. Finally, a discussion was presented relative to the minimum return which companies strive to achieve from successful research and development projects.
Periodic progress evaluations and considerations relating to decisions of whether to abandon or continue a project were presented in Chapter VII. In addition, some of the attributes studied to measure or infer progress were discussed and the more common methods employed in communicating the information necessary for management action to be taken were reviewed.

The final chapter was concerned with project post-appraisal and of the measure of difference in predictability between the two survey respondent groups which were studied for this purpose. Additionally, the sensitivity of profitability estimates to variations in certain cost and return factors was examined. The discussion presented a reflection of the experience of the mail survey respondents as indicated by their questionnaire answers.

**Findings**

As a result of the research conducted and the analyses performed in this study the following findings relative to current industrial research and development management practices may be reported.

1. The process of research and development management, as it has been investigated in this study, is not dependent on the particular industry or scientific area of interest. The process is universal, varying only in detail. When fundamentally reviewed in the broad sense, it is readily apparent that the basic principles of management are applied in much the same manner. The interviews conducted certainly substantiate this statement as does the fact that
questionnaire respondents represented all industries with varying scientific interests. The fact that the selection procedure could be so easily synthesized as representative of company practice offers further validation. While the organizational level of management involved in the process may vary from company to company and the detailed procedures for accomplishing the functions appear on the surface to be different, the over-all process is the same. The logic of such a finding is apparent, since the functions studies are fundamental and must in all cases be performed.

2. The nature of today's industrial research and development program is offensive. It has as its principal objectives, in order of importance, the following.

   a. To develop new materials, processes for products for existing markets.

   b. To develop new materials, processes for products to enter new markets.

   c. To improve the quality of current products.

   d. To effect savings in the cost of production and distribution.

   e. To develop new uses for existing materials, processes, or devices.

   The budget for the level of funding of the research and development program is for the most part a reflection of deliberate and objective top management judgment, relating to short-and long-range plans and objectives of the company and the urgency of identified needs and requirements of both the company and the market. It is derived fundamentally from the corporate long-range planning objectives, but
with certain limitations being imposed such as fiscal cash flow projections and the current number of people in the research and development laboratories.

Even when the budget level and over-all research and development program have been previously established, most companies have provisions for undertaking newly identified and potentially profitable projects. This may be accomplished by internal reprogramming or by allotting additional resources for either internal or external activity on the projects.

All but a very small percentage of the industrial research and development management group review the over-all program to ensure that it is properly balanced to reflect objectives. Primarily they are concerned with program balance from the viewpoint of an adequate level of anticipated profitability as a result of the periodic introduction of new products into the market and the improvement of existing products. Additionally, emphasis is given to the mix of technologies being investigated to ensure a balanced effort across the scientific and technical areas of long-term interest to the corporation. To a somewhat lesser degree, emphasis is also given to the program balance in relation to the distribution of project risk and the length of project run.

3. The majority of companies select research and development projects in accordance with a written plan. Where there is no written plan, the selection process is accomplished in accordance with a verbally understood plan, but only a very small percentage of the companies had no definite plan for project selection.
There is a significant difference in the level of detail to which different companies plan for the evaluation and selection of research and development projects. Almost all, however, differentiate between the type or level of information required on a basic research project versus that required for an applied or developed project because of the more nebulous nature of the former type of activity. Even though there are detailed differences, the same general type of information is considered desirable for review.

The factors considered in the evaluation of individual research and development projects may be logically placed into one of two classifications—intrinsic, those related to the basic characteristics of the project itself, and situational, those factors related to the specific position, policies, and capabilities of the particular company performing the evaluation. Of these two categories, the three most important factors in each are as follows.

a. Intrinsic—

   (1) Potential project profitability.
   
   (2) Technical risk of the undertaking.
   
   (3) Estimated project cost.

b. Situational—

   (1) Long-range plan objectives.
   
   (2) Company’s ability to exploit a successful result effectively.
   
   (3) Compatibility with existing corporate marketing channels.
4. While an executive profitability judgment of some type is almost always formulated before a proposed project is undertaken, quantitative potential project profitability analyses are conducted on a more selected basis. Generally, such a quantitative analysis is performed when the information available on the project is sufficiently reliable to make an evaluation of this type more meaningful than that which can be obtained by subjective judgment. The type of profitability analysis may vary in method and depth in accordance with the level of research activity being evaluated.

The quantitative methods employed for estimating potential project profitability vary significantly within the universe under study. However, approximately 25% of the companies use an average rate of return to average investment analysis while an additional 25% employ the discounted cash flow approach.

The timing aspects associated with proposed research and development projects are often significant. Of the various time periods which must be considered, their relative importance is as follows:

a. The duration of the marketing period during which returns (income) are expected.

b. The time lapse between the start of research and development expenditures and the start of returns, or entry into the market.

c. The length of the period (time) during which the research and development activity is expected to take place.

d. The time lag between the end of the research and development effort and the start of production or application.

e. The total time span of production or use.
In the majority of industrial situations, the intangible benefits associated with successful project completion of a given research and development project is handled quantitatively in only a very small percentage of the cases. About 25% to 30% of the time the value of such factors is ignored completely in the evaluation and selection process. In the majority of the situations intangibles are considered qualitatively by the executive group in developing their assessment of the over-all project desirability.

The risk associated with proposed research and development projects can be conveniently divided into the types of risk involved and the amount of risk involved. At the time of project evaluation and selection, emphasis is given to the type of risk in accordance with the following relative order of importance:

a. Risk of technical success in the research and development program.

b. Risk associated with the total estimated market demand.

c. Profit margin risk associated with the estimated share of the market and potential actions of competitors.

d. The production risk associated with being able to produce at the volume estimated for the cost estimated.

Within the universe studied, the distribution of projects with respect to the amount of risk assumed is probably fairly well approximated by considering that about 25% represent low risk projects, 25% represent high risk projects, and the remainder are in the intermediate risk category.

The companies that compute potential project profitability on the basis of a rate of return generally try to achieve on the average
of 15-16% minimum return after taxes for low risk research and development project undertakings. The demanded rate of return would be appropriately adjusted higher to reflect intermediate risk and high risk projects.

5. The evaluation and selection of research and development projects is a planning function. As such, it requires the development of planning premises and the use of these premises within an integrated framework of management policies as they relate to the goals and objectives which it is desired to achieve from the research and development program. Any computational method used to formulate an estimate of potential project profitability should be selected in accordance with criteria established on the basis of accepted planning principles. The computation of the present value of the results of successful project conclusion, through the discounting of expected future cash flows, appears to offer an approach compatible with the developed selection criteria and provides the maximum versatility. A profitability selection model of almost equal value can be developed through the use of discounted cash flows and the computation of an over-all rate of return. Similar flexibility can be obtained with both techniques.

6. Research and development project design and scheduling activity is a prerequisite for adequate project progress evaluation and post appraisal. Additionally, it is the only way of ensuring that the most effective research approach to the solution of the problem involved is utilized and of ensuring that the planned activity involved in the undertaking is coordinated throughout the laboratory.
Research and development project progress evaluations are not always accomplished on a periodic basis, but rather are sometimes performed as a result of predetermined milestones or event happenings. Where individual project progress is evaluated on a periodic basis, it is accomplished quarterly in about 40% of the companies, monthly in approximately 30% of the companies, semi-annually in roughly 15% of the companies, and at least annually in the remainder.

There are numerous attributes which can be used to measure progress of research and development undertakings, and there are many ways in which this information can be transmitted to management. Of these, the following relative order of importance is given by the management of research and development laboratories of the universe studied:

a. Attributes to measure progress
   (1) Completion of a previously established list of sub-tasks.
   (2) Expenditures to date versus planned expenditures.
   (3) Estimates by project personnel as to whether the project is "on time."

b. Methods of transmitting information
   (1) Project review meetings.
   (2) Activity reports.
   (3) Other meetings such as general staff meetings.

Informal conversations and discussions as a method of communicating pertinent information was considered to be significant by the persons interviewed. Unfortunately, however, this point was not included in the questionnaire survey.
In arriving at a decision as to whether a project should be continued or abandoned, the two most important factors considered are (1) a revised estimate regarding the ability of the company to exploit successful project results effectively (changes of market estimate) and (2) revised estimates regarding the technical risk of successfully completing the project.

7. Project level post-appraisal is probably conducted by approximately half of the companies in the universe but only on a selected basis. Probably less than 5% of the companies conduct post appraisal for all successful projects. Close to 40% of the companies perform post appraisal of the over-all program in order to determine the effectiveness of the total research and development expenditures and approximately half of these also conduct project level post appraisal on a limited basis. Slightly over 20% of the companies do not feel that the time and effort involved in conducting post appraisals of any type are warranted by the benefits derived and, therefore, do not engage in this activity.

The sensitivity of the over-all project profitability estimate to variations in the different factors upon which it is based will vary in different situations. There are, however, two prerequisites for profit realization— a certain minimum market demand must be present (or created) and the capability must exist for production at a cost which enables market entry at a realistic price level. In general, the significance of factors variations on influencing the over-all
profitability estimates is in accordance with the following relative order of importance:

a. Variations in total demand  
b. Variations in estimated production cost  
c. Variations in estimated share of the market  
d. Variations in research and development cost  
e. Variations in marketing cost  
f. Variations in the cost of capital

While variations in the research and development cost do not influence the project profitability estimate to the same degree as the other factors, it should not be taken as an indication that they are insignificant in the selection process. At the time of project selection the research and development cost estimates are frequently found to be the determining factor in the allocation of resources among alternatives.

Conclusions

As a result of the research conducted and the analyses performed the following conclusions have been reached relative to the study hypotheses.

Hypothesis one. The first hypothesis of this study stated that within the framework of objectives established by the corporate long-range plan (or company policy, whichever is appropriate), potential project profitability is the major single factor in determining whether a research and development project will be undertaken. The validity of this hypothesis was substantiated throughout all phases of this study.
The importance of selecting and pursuing only those research and development projects which will yield results profitable to the sponsoring corporation is appropriately reflected throughout the literature and all of the executives interviewed quickly acknowledged that long-term corporate growth and profitability was a basic objective of industrial research and development programs. Additionally, the speakers at the Purdue-Industrial Research conference, which had corporate research and profitability as its central theme, stressed the significance of this point. In fact, Mr. C. G. Main (Vice President, Finance, Westinghouse Electric Corporation), went so far as to state "A dollar sign has to appear over the research and development door."

The weighted average ranking of the level of importance attached to various factors considered during project evaluation and selection is shown in Table 7. Potential project profitability heads the list. Approximately 71% of the survey respondents ranked this factor of prime importance as is presented in Table 8. Even the prominence of the long-range plan objectives of the corporation as a factor of selection allows an inference to be drawn relative to the significance of potential project profitability, since the natural and legitimate objective of any business organization is to perpetuate its existence, expand, and earn a profit. Derivation of profits from the research and development program would be expected.

Additional substantiation of the hypothesis is available from other portions of the survey results. While only 23% of the respondents indicated conducting a quantitative profitability analysis for proposed
projects and 68% indicated performing them on the basis of selected projects (Table 10), approximately 92% of the respondents indicated that they always formulate a qualitative or subjective executive profitability judgment (reference Table 9). In addition, 83% of the respondents (Table 4) have provisions for obtaining additional resources to undertake a previously identified, but potentially profitable project which is outside of current resource limitations. Finally, it can be seen that the primary factor considered in a decision to continue or abandon a research and development project is the ability of the corporation to exploit successful project results (Table 22). At any point in time, when it is shown or learned that the project for one reason or another will not provide the anticipated returns, it is dropped.

In view of the above, it has been concluded that the hypothesis is valid as stated.

**Hypothesis two.** The second major study hypothesis was that practices for assessing the potential profitability of research and development projects are completely diversified within industry, varying from the use of quantitative and highly sophisticated models which allow the treatment of many pertinent factors, to the subjective or qualitative evaluation of a few selected factors with reliance primarily on composite management judgment. The information necessary for the validation of this hypothesis was also found through all phases of the study effort. Articles describing the approaches utilized by different corporations in assessing potential project profitability are
prevalent in the literature and reflect a wide dispersion of approach and philosophy. The diversification in the techniques utilized to formulate an assessment of potential project profitability was also readily apparent from the interviews conducted and from an analysis of the various project selection plans submitted with completed questionnaires. Additionally, the three companies presenting case histories at the Purdue-Industrial Research conference all described different approaches to establishing estimates of project profitability.

The survey results which depict the variations of respondents in the use of different quantitative methods and combinations thereof in estimating profitability are shown in Tables 11 and 12. The findings obviously support the hypothesis. Also, it was pointed out that the method of quantitatively estimating profitability varies depending on the level of research activity, with the more sophisticated techniques being utilized only at a point in time when the input data are sufficiently accurate to make such an analysis meaningful.

It has been concluded, therefore, that the hypothesis is valid as stated.

**Hypothesis three.** The third hypothesis maintained that even in cases where models, representing a conjectual explanation of the research and development project situation, are used for the identification of project desirability or profitability, an executive composite judgment is always made and plays a significant part in the final project selection. There is almost universal acknowledgment that any quantitative technique utilized in the management process should be considered as a tool and
not as a substitute for executive judgment. All of the executives interviewed acknowledged formulating the composite executive judgment regarding the potential profitability of proposed projects, even though the results of a quantitative analysis were presented in the project proposal. The synthesized procedure for project selection, as depicted in Figure 3, facilitates the review and overlay of executive experience. The case histories presented at the Purdue-Industrial Research conference also emphasized the importance of reviewing quantitative results but of using these only as a guide to arriving at an executive judgment regarding the proposed project.

The survey results (Table 9) show that approximately 92% of the respondents formulate an executive profitability judgment regarding proposed projects, even when a quantitative analysis has been provided. It was pointed out in the discussion in Chapter IV that the profitability analysis incorporates practically all aspects of the analysis and investigations which have been made in preparing the project proposal. An affirmative answer to the question indicates that the executive judgment is made not only in relation to specific factors but also relative to the over-all conclusion. However, when reviews and discussions are held which result in evolving a judgment regarding any phase of the project, it is in effect relating to the potential profitability of the entire venture. When conclusions regarding the individual profitability factors are reached separately, they must subsequently be developed into an over-all profit outlook.
It was concluded that the validity of the hypothesis has been substantiated.

**Hypothesis four.** The fourth study hypothesis stated that techniques are available to permit the development of a general approach to research and development project profitability analysis which allows the incorporation of the essential factors necessary for a meaningful evaluation, but that published models to date are inadequate in their treatment of terms reflecting all necessary factors or are not sufficiently adaptable to specific industrial situations. The investigation of this hypothesis required a knowledge of the situation which exists within industry and an identification of the essential factors necessary for incorporation into a meaningful profitability analysis.

Conclusions regarding the adequacy of published models required the development of a criterion against which such computational methods could be reviewed and evaluated. The attributes of a model that would represent an adequate conjectural explanation of the situation were aligned with accepted management principles and planning premises were developed. These indicated the desirability of selecting a model which would be capable of providing pertinent information at successive project progress reviews and of forming the basis for a project level post-appraisal.

All four sources of information utilized throughout the study were employed. A synthesis of this knowledge into a description of
situation as it exists and an identification of the factors influencing profitability estimates were developed and presented in Chapters III, IV and V. Similar information relative to periodic project progress reviews and project level post-appraisal is contained in Chapters VI and VII. A review was made of the quantitative techniques available and the models which have been proposed for such a profitability analysis as they were reflected in the existing literature. A comparison of the situational requirements with the techniques and models available was presented in Chapter II.

The results have supported the conclusion that the techniques are in fact available to allow the development of a general research and development project profitability model that permits the incorporation of the essential factors identified. However, the second portion of this hypothesis was not supported by the study. The review indicated that the techniques which have been proposed are adaptable to specific industrial situations and permit incorporation of the identified factors with relative ease.

Hypothesis five. The last major study hypothesis stated that those industrial concerns which select research and development projects in accordance with a written plan, conduct quantitative project profitability analysis on at least a selected basis, and perform project level post-appraisal of the results obtained have results which are more predictable than those companies which do not. As used here the predictability of results is expressed in terms of estimated cost and anticipated returns versus the actual cost and returns. In contrast to
the preceding hypotheses, which could be tested in all phases of the study effort, validation of the fifth hypothesis relied solely upon the mail survey results. The respondents were classified either into Group A or into Group B, depending on their answers to predetermined questions.

The responses of these two groups to the question of how their actual cost and returns generally compared with project estimates were analyzed. Table 27 shows the survey results for the comparison of actual cost versus project estimates and Table 28 shows the group comparison of actual returns versus estimated returns.

Within the accuracy normally associated with estimating techniques, approximately 25% of Group A and 19% of Group B generally find that the actual project costs are essentially the same as the estimates. About 29% of Group A and 23% of Group B acknowledged the significance of past experience with similar projects as a determinant of reliable cost estimates. An adjusted chi-square analysis performed on the survey data indicated approximately a 32% probability that the differences observed between the two groups were due to random sampling variations.

Approximately 4% more of the Group A respondents indicated that they were able to predict returns within estimation accuracy than did the Group B respondents. Additionally, about 6% more of the Group A respondents reported that results varied depending on past experience with similar undertakings than did Group B. Approximately 6% of Group A and 7% of Group B reported that actual returns are generally higher.
than estimates. However, 3½% of Group B reported that actual returns are much higher than estimated as compared to no one reporting this from Group A. A chi-square analysis of the data indicated an approximate 33% probability that the differences observed between the two study groups were due to random sampling errors.

Although statistical analyses of the data collected do not completely substantiate the hypothesis, the results are in the direction of supporting it. Other factors which have been presented and discussed also lend to its creditability. In view of the fact that large differences were not expected to be found, it has been concluded that the study hypothesis is valid as stated.

Recommendations

As a result of the knowledge acquired during this study some recommendations are considered appropriate for those industrial concerns which actively support a research and development laboratory. First, however, it should be pointed out that in the pursuit of any organized research and development program it is essential that consideration be given not only to the over-all funding level, but also to the detailed planning of each individual undertaking. Management must be responsible for the planning, organizing, and controlling of the work being performed and should guide the efforts of the scientists and engineers in the proper direction. This can be effectively accomplished by the application of fundamental management principles and concepts, appropriately modified to meet the specific requirements of any given organization.
1. The individual projects which constitute the over-all research and development program should, for the most part, be directly in support of both the intermediate- and long-range corporate plans and objectives. Project proposals should be prepared which are pertinent to achieving this end and the budgetary allocation should be established at that level which supports the program formulated to achieve such long-range goals. An upper funding limit should be established on the basis of the long-term ability of the company to exploit successfully research and development project results and/or on the basis of a projected cash flow for the next fiscal period, both of which should include considerations of borrowed capital. The lower limit on the research and development budget should be established in accordance with that amount necessary to support the current level of activity, in terms of the number of people within the laboratory.

2. If an industrial organization expects to realize optimum benefits from its research program, each proposed project should be thoroughly evaluated in order to determine its relative merits before it is officially approved for the laboratory to undertake. It is felt that this can be best accomplished by the evaluation and selection of individual projects in accordance with a written plan. The fact that research and development activities cannot be made to fit a set pattern is acknowledged. However, it should be possible for management to establish a general procedure to assist in selecting the projects to be undertaken and efficiently integrate the work on approved projects into the over-all operations of the laboratory and to assist in
evaluating and controlling the research effort once it has begun. In order to maintain the desired flexibility, the written plan should be variable to allow for the different treatment of various types of projects proposed. Project proposals should be formally prepared for all candidate undertakings. For applied research and development projects the proposal, as a minimum, should include the following:

a. A statement of the project objectives
b. An identification of the scope or impact of successful results
c. A preliminary technical analysis of the proposed efforts
d. A manufacturing analysis
e. A market or applications analysis
f. A statement of the project resource requirements
g. Some type of profitability estimates

3. A quantitative project profitability analysis should be conducted at the earliest time at which sufficiently reliable information becomes available to make such an analysis meaningful. This indicates that some projects will be undertaken and actively pursued for a given period of time on the basis of executive judgment. Until such time as the project results can be reasonably described and the probability of success estimated, it may not be possible to formulate even relative estimates of production costs and market demands. Therefore, management judgment must, and should, be relied upon.

Projects at the basic research end of the research and development spectrum will always involve some degree of risk and uncertainty. The
careful selection of projects should not mean that all elements of risk and uncertainty have been removed but rather that they have been appraised and judged to be acceptable in view of the potential gains. The rejection of a sound and desirable project for lack of information or from an unwillingness to accept risk certainly makes such a project no less sound, nor does it reduce the importance that such a project could have in the corporation's future.

Quantitative estimates of project cost and a forecast of potential returns should be generated as soon as it is realistically possible, at which time a profitability analysis should be conducted. It is recommended that the computational method employed for analyzing potential profitability be the same for all proposed projects, and that the techniques selected be capable of adjusting for differences in the reliability or input data. For this purpose it is felt that the use of discounted future cash flows, to compute either the present worth at a demanded rate of return or the over-all rate of return through the end of the expected recovery period, offers the best modeling approach for simulating anticipated future occurrences. Such a model should be used in conjunction with detailed written procedures, processing formats, and accounting systems and should fit within the integrated framework of management policies as they relate to the objectives which it is desired to achieve from the research and development program.

4. Careful consideration must be given to project design and scheduling. This is important not only from the viewpoint of ensuring
that the necessary effort is accomplished in an efficient manner but also because it forms the basis for subsequent progress evaluation and post-appraisal.

Before an actual schedule can be formulated, it is necessary that all of the problems involved in successfully completing each major work phase, or project task, be carefully analyzed and studied in order to determine the best methods of attack that should be followed in performing the work. Estimates must then be made of the time required to complete the work in each area, and the optimum personnel assignment for the methods and procedures that have been selected must be determined. When the project schedules are established, care should be exercised to see that they are not too tight and that proper allowances are made for the inevitable contingencies which arise.

5. After a project has been evaluated and selected for undertaking, the approach to be followed has been laid out and scheduled, and the research effort has begun, a continuous management function should be that of reviewing and evaluating the progress of the work being performed, encouraging efforts in the right direction, tapering off and discontinuing work in directions where the outlook has become less promising, and re-evaluating the value of the project to the organization in light of the changing scientific, economic, and market conditions. As a minimum, individual research and development projects should be re-evaluated before each successive investment commitment point. In the majority of situations this would probably be at the
time of the annual program review when older projects compete with the new ones for funding and other resources. However, in some situations this may occur in between the over-all program review, as when a project goes from an applied research stage to the development phase, or from development into a production commitment.

Project progress, on the other hand, should be reviewed and evaluated more frequently and should trigger an over-all project re-evaluation when warranted. Perhaps the most effective way to evaluate project progress is at that point in time when a predetermined and scheduled milestone event was to have occurred. These, unfortunately, are sometimes found to be too infrequent for the purposes of maintaining adequate follow-up and control in terms of the progress being made towards accomplishment of the milestones. In these cases it is recommended that individual project progress be evaluated no less frequently than on a semi-annual basis, preferably on a quarterly basis.

In general the evaluation of project progress should be in terms of quantitative rather than qualitative inputs. Reliance solely on the latter means that management has not established an effective way to measure project progress. The identification of the completion of a previously established list of sub-tasks at points in time, the number of manhours input versus those planned, and expenditures to date versus the programmed funding represent a much sounder basis for evaluation than estimates by project personnel as to whether the project is "on time."
In any over-all re-evaluation of the project, consideration must always be given to revised estimates of the technical risk associated with successfully achieving the stated objectives, revised predictions regarding the feasibility of economic production, and current forecasts of market preferences and trends, as well as to the over-all timing of the project in relation to the strategy of market entry.

6. As the periodic accounts audit is considered essential by corporate controllers, the project level post-appraisal is believed to be a mandatory procedure for effective research and development management. Project post-appraisal is felt to be the most effective way of improving the predictability of estimated research and development project cost and forecast of anticipated returns. Meaningful post-appraisal, however, requires a baseline against which the actual results can be evaluated. This is best accomplished by a profitability analysis which compares the actual returns attributed to the project with the total cost of the undertaking in the same manner as the original estimate of potential project profitability was computed.

It is not necessarily recommended that post-appraisals be conducted on all projects. However, wherever it becomes obvious or it is strongly suspected that a significant variance has occurred in either direction from the estimated cash flows, such a detailed evaluation is felt to be warranted. In addition, successful selected projects where estimates closely correlated with the actuals
experienced should be subjected to post-appraisal. In order to provide a basis for guiding future activity, the reliability of the original estimates should be evaluated and related to the techniques used in formulating them, the assumptions upon which they were based, the methods of project design and scheduling, and the tendencies of the personnel who provided such estimates to either understate or overstate them. Such an approach must cover not only the estimates generated for the research and development cost but also those provided for production costs, cost of capital, marketing cost, estimates of total demand, and estimates of the company's share of the market.

In addition to the above, a recommendation concerning future study is felt to be appropriate. While it is recognized that many of the subjects broadly covered in this study could be undertaken as a study unto themselves, and probably will be in the future, additional study in the area of predictability, considered to be outside the scope of this study, is recommended. While only two general management profile groupings are investigated in this study, at least three additional categories could be formed—one having all of the attributes necessary for entrance into Group A, a Group B having two of these attributes, a Group C possessing one of the attributes, and a Group D having none. The predictability of cost and returns of these respective groups should be correlated with the following:

1. The time during which they have possessed the attributes being studied.
2. The principle objectives of their research and development program.

3. Both the type and amount of risk assumed by the companies in each group.

4. The distribution of effort in each group along the research and development spectrum.
APPENDIX A

DATA ON PARTICIPATING COMPANIES

Information relative to the research and development activities of the companies participating in the study is presented in this appendix in the following order:

1. Companies presenting case histories at the Purdue University-Industrial Research Conference (Table 29)
2. Companies interviewed during the study (Table 30)
3. Questionnaire respondents (Tables 31 through 34)
4. An alphabetical list of participating companies

The list of participating companies includes those which were visited for on-site interviews but excludes those giving case histories at the Purdue Conference, unless they were included in the random sample selected for the questionnaire mailing and subsequently replied. The total number of companies shown is larger than the sum of the number of firms visited and the number of questionnaire replies utilized for the study analysis. Several returned questionnaires were eliminated during the editing process, because of a lack of pertinency or completeness, particularly in regards to certain key questions. Two were received after the established tabulation cut-off date. A few of the recipients did
not complete the questionnaire but did forward other useful information such as company plans and procedures, copies of speeches, and reprints of published articles. The contributions of all such corporations are acknowledged.
### TABLE 31

**DATA ON CORPORATIONS PRESENTING CASE HISTORIES AT THE PURDUE UNIVERSITY INDUSTRIAL RESEARCH CONFERENCE**

<table>
<thead>
<tr>
<th>CORPORATION</th>
<th>R&amp;D TECHNICAL PERSONNEL</th>
<th>1965 R&amp;D BUDGET ($ - MILLIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westinghouse Electric Corporation</td>
<td>About 8,000 in total with approximately 1,400 at the Corporate Central Laboratory in Pittsburgh, Pa.</td>
<td>Approximately 300 with about one-third being corporate financed and two-thirds under Government Contract</td>
</tr>
<tr>
<td>B. F. Goodrich Company</td>
<td>About 400 technical personnel at the Corporate Research Center (Brecksville, Ohio) where approximately 20% of the total company R&amp;D effort takes place. Each of the eight operating divisions have their own research and development laboratories</td>
<td>No information given or readily available</td>
</tr>
<tr>
<td>Xerox Corporation</td>
<td>Corporate Research and Engineering Division is comprised of four laboratories. Fundamental Research, Applied Research, Exploratory Development, and Development and Design Engineering</td>
<td>30-8</td>
</tr>
</tbody>
</table>
## TABLE 32

DATA ON COMPANIES INTERVIEWED

<table>
<thead>
<tr>
<th>CORPORATION</th>
<th>TECHNICAL PERSONNEL</th>
<th>1965 R&amp;D EXPENDITURES ($ - MILLIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>125</td>
<td>3.50</td>
</tr>
<tr>
<td>Company B</td>
<td>91</td>
<td>2.46</td>
</tr>
<tr>
<td>Company C</td>
<td>460</td>
<td>7.55</td>
</tr>
<tr>
<td>Company D</td>
<td>800</td>
<td>27.50</td>
</tr>
<tr>
<td>Company E</td>
<td>36</td>
<td>0.48</td>
</tr>
<tr>
<td>Company F</td>
<td>560</td>
<td>18.50</td>
</tr>
<tr>
<td>Company G</td>
<td>370</td>
<td>8.23</td>
</tr>
<tr>
<td>Company H</td>
<td>1,500</td>
<td>60.50</td>
</tr>
<tr>
<td>Type of Project Effort</td>
<td>GROUP A</td>
<td>GROUP B</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Basic or fundamental research</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>General applied research</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>Exploratory or feasibility studies</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Product development</td>
<td>15</td>
<td>80</td>
</tr>
<tr>
<td>Process development</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Engineering or troubleshooting</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>60</td>
</tr>
</tbody>
</table>

|                                          | Low     | High    | Average      |
|                                          | 1       | 20      | 4.93         |
|                                          | 2       | 80      | 18.62        |
|                                          | 3       | 20      | 10.27        |
|                                          | 3       | 80      | 37.72        |
|                                          | 5       | 60      | 15.14        |
|                                          | 3       | 82      | 12.93        |
|                                          | 1       | 5       | 0.38         |

Low High Average
<table>
<thead>
<tr>
<th>Duration</th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
<th></th>
<th>TOTAL SAMPLE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Average</td>
<td>Low</td>
<td>High</td>
<td>Average</td>
</tr>
<tr>
<td>Short term projects (up to 1 year)</td>
<td>5</td>
<td>90</td>
<td>34.74</td>
<td>5</td>
<td>80</td>
<td>34.25</td>
</tr>
<tr>
<td>Intermediate term (1 to 3 years)</td>
<td>7</td>
<td>60</td>
<td>34.74</td>
<td>10</td>
<td>80</td>
<td>33.81</td>
</tr>
<tr>
<td>Long term projects (over 3 years)</td>
<td>5</td>
<td>50</td>
<td>18.62</td>
<td>5</td>
<td>50</td>
<td>17.83</td>
</tr>
<tr>
<td>Indefinite terms (constant area of investigation)</td>
<td>3</td>
<td>90</td>
<td>12.15</td>
<td>5</td>
<td>80</td>
<td>13.92</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**TABLE 34**

**DISTRIBUTION OF R&D ACTIVITY BY PROJECT DURATION, PERCENTAGE**
<table>
<thead>
<tr>
<th>Group</th>
<th>Low</th>
<th>High</th>
<th>Average</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>0.20</td>
<td>300.0</td>
<td>24.14</td>
<td>1,062.02</td>
</tr>
<tr>
<td>Group B</td>
<td>0.10</td>
<td>750.0</td>
<td>38.50</td>
<td>1,616.82</td>
</tr>
<tr>
<td>Total Sample</td>
<td>0.10</td>
<td>750.0</td>
<td>31.07</td>
<td>2,678.84*</td>
</tr>
</tbody>
</table>

*NOTE: Only 86 of the 107 respondents whose replies were utilized in this study provided the requested funding information.
<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>HIGH</th>
<th>AVERAGE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td>5</td>
<td>8,000</td>
<td>477</td>
<td>21,941</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td>6</td>
<td>12,500</td>
<td>912</td>
<td>45,583</td>
</tr>
<tr>
<td><strong>Total Sample</strong></td>
<td>5</td>
<td>12,500</td>
<td>705</td>
<td>67,624*</td>
</tr>
</tbody>
</table>

*NOTE: Based on 96 of 107 respondents providing the data requested.*
<table>
<thead>
<tr>
<th>Desires information relative to:</th>
<th>Group A</th>
<th></th>
<th>Group B</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Percentage</td>
<td>Frequency</td>
<td>Percentage</td>
<td>Frequency</td>
<td>Percentage</td>
</tr>
<tr>
<td>Questionnaire summary</td>
<td>6</td>
<td>11.73</td>
<td>5</td>
<td>8.93</td>
<td>11</td>
<td>10.28</td>
</tr>
<tr>
<td>Availability of the final report</td>
<td>18</td>
<td>35.25</td>
<td>10</td>
<td>17.86</td>
<td>28</td>
<td>26.17</td>
</tr>
<tr>
<td>Both of the above</td>
<td>13</td>
<td>25.48</td>
<td>28</td>
<td>50.00</td>
<td>41</td>
<td>38.31</td>
</tr>
<tr>
<td>Neither</td>
<td>14</td>
<td>27.42</td>
<td>13</td>
<td>23.21</td>
<td>27</td>
<td>25.24</td>
</tr>
</tbody>
</table>
CORPORATIONS PARTICIPATING IN THE STUDY

ACF Industries, Inc., New York, New York
Agway, Inc., Syracuse, New York
American Can Company, New York, New York
American Cyanamid Company, Stamford, Connecticut
American Enka Corporation, Enka, North Carolina
American Metal Climax, Inc., New York, New York
American Motors Corporation, Detroit 32, Michigan
American Radiator & Standard Sanitary Corporation, New York, New York
American Sugar Company, New York, New York
Anchor Hocking Glass Corporation, Lancaster, Ohio
Archer-Daniels-Midland Company, Minneapolis, Minnesota
ARMCO Steel Corporation, Middletown, Ohio
Armstrong Cork Company, Lancaster, Pennsylvania
Arvin Industries, Columbus, Indiana
Atlantic Refining Company, Philadelphia, Pennsylvania
Bethlehem Steel Corporation, Bethlehem, Pennsylvania
Black and Decker Manufacturing Company, Towson, Maryland
E. W. Bliss Company, Swarthmore, Pennsylvania
Boeing Company, Seattle 24, Washington
Borg-Warner Corporation, Chicago, Illinois
Brunswick Corporation, Chicago, Illinois
Budd Company, Philadelphia, Pennsylvania
Burlington Industries, Inc., Greensboro, North Carolina
Carrier Corporation, Syracuse 1, New York
Cerro De Pasco Corporation, New York, New York
Champion Spark Plug Company, Toledo, Ohio
Chicago Bridge and Iron Company, Oak Brook, Illinois
Clevite Corporation, Cleveland, Ohio
Colgate-Palmolive Company, New York, New York
 Consolidation Coal Company, Pittsburgh 19, Pennsylvania
Container Corporation of America, Chicago 3, Illinois
Continental Oil Company, Ponca City, Oklahoma
Corning Glass Works, Corning, New York
Cummins Engine Company, Columbus, Indiana
Cutler-Hammer, Inc., Milwaukee 1, Wisconsin
Dan River Mills, Inc., Danville, Virginia
Deere & Company, Moline, Illinois
R. R. Donnelley & Sons Company, Chicago 16, Illinois
Dow Chemical Company, Midland, Michigan
E. I. duPont de Nemours and Company, Inc., Wilmington 98, Delaware
Eaton Manufacturing Company, Cleveland, Ohio
Electric Storage Battery Company, Philadelphia, Pennsylvania
Emhart Corporation, Bloomfield, Connecticut
FMG Corporation, San Jose 10, California
Flintkote Company, New York, New York
Ford Motor Company, Dearborn, Michigan
Gardner-Denver Company, Quincy, Illinois
General Aniline & Film Corporation, New York, New York
General Electric Company, Schenectady, New York
General Foods Corporation, White Plains, New York
General Mills, Inc., Minneapolis 26, Minnesota
General Motors Corporation, Detroit 2, Michigan
General Precision Equipment, Pleasantville, New York
Genesco, Inc., New York, New York
Georgia-Pacific Corporation, Portland, Oregon
Gerber Products Company, Fremont, Michigan
W. R. Grace & Company, New York, New York
Handy & Harman, New York 22, New York
Harnischfeger Corporation, Milwaukee 46, Wisconsin
H. J. Heinz Company, Pittsburgh, Pennsylvania
Hewlett-Packard Company, Palo Alto, California
Hooker Chemical Corporation, Niagara Falls, New York
Hoover Company, North Canton 20, Ohio
George A. Hormel & Company, Austin, Minnesota
Ideal Cement Company, Denver 2, Colorado
Inland Container Corporation, Lafayette, Indiana
Inland Steel Company, Chicago 3, Illinois
Interlake Corporation, Chicago, Illinois
International Milling Company, Inc., Minneapolis 2, Minnesota
International Minerals & Chemical Corporation, Skokie, Illinois
International Pipe & Ceramics Corporation, Wharton, New Jersey
Johns-Manville Corporation, New York, New York
Joy Manufacturing Company, Pittsburgh 22, Pennsylvania
Kellogg's, Battle Creek, Michigan
Kerr-McGee Oil Industries, Inc., Oklahoma City 2, Oklahoma
Eli Lilly, Indianapolis, Indiana
Lily-Tulip Cup Corporation, New York, New York
Ling-Temco-Vought, Inc., Dallas 22, Texas
Link-Belt Company, Indianapolis, Indiana
Thomas J. Lipton, Inc., Englewood Cliffs, New Jersey
P. Lorillard Company, New York, New York
McDonnell Aircraft Corporation, St. Louis, Missouri
Mead Corporation, Chillicothe, Ohio
Merck & Company, Inc., Rahway, New Jersey
Minnesota Mining & Manufacturing Company, St. Paul 6, Minnesota
Monsanto Chemical Company, St. Louis, Missouri
Motorola, Inc., Franklin Park, Illinois
National Cash Register Company, Inc., Dayton, Ohio
National Gypsum Company, Buffalo 2, New York
North American Aviation, Inc., Los Angeles 45, California
Olin Mathieson Chemical Corporation, New York 21, New York
Owens-Illinois, Toledo 1, Ohio
Parke, Davis & Company, Detroit, Michigan
Pennsalt Chemicals Corporation, Philadelphia, Pennsylvania
Phelps Dodge Copper Products Corporation, New York 22, New York
Phillips Petroleum Company, Bartlesville, Oklahoma
Pittsburgh Plate Glass Company, Pittsburgh 22, Pennsylvania
Polaroid Corporation, Cambridge 39, Massachusetts
Procter & Gamble Company, Cincinnati, Ohio
Pure Oil Company, Palatine, Illinois
Quaker Oats Company, Chicago, Illinois
Radio Corporation of America, New York, New York
Ralston Purina Company, St. Louis, Missouri
Rath Packing Company, Waterloo, Iowa
Rayonier, Inc., New York, New York
Raytheon Company, Lexington 73, Massachusetts
Reichhold Chemicals, Inc., White Plains, New York
Republic Steel Corporation, Cleveland 1, Ohio
Rex Chainbelt, Inc., Milwaukee, Wisconsin
Reynolds Metals Company, Richmond, Virginia
Richfield Oil Corporation, Los Angeles, California
H. H. Robertson Company, Pittsburgh 22, Pennsylvania
Rockwell Manufacturing Company, Pittsburgh 8, Pennsylvania
Sinclair Oil & Gas Company, Tulsa, Oklahoma
A. O. Smith Corporation, Milwaukee 1, Wisconsin
Socony Mobil Oil Company, Inc., New York, New York
A. E. Staley Manufacturing Company, Decatur, Illinois
Standard Pressed Steel Company, Jenkintown, Pennsylvania
Sterling-Winthrop Research Institute, Rensselaer, New York
Stewart-Warner Corporation, Indianapolis, Indiana
Swift & Company, Chicago, Illinois
Texaco, Inc., Beacon, New York
Texas Instruments, Inc., Dallas 22, Texas
Union Bag-Camp Paper Corporation, New York, New York
Union Carbide Corporation, South Charleston, West Virginia
Union Oil Company of California, Los Angeles, California
United Aircraft Corporation, East Hartford, Connecticut
United Biscuit Company of America, Melrose Park, Illinois
United States Gypsum Company, Chicago 6, Illinois
U. S. Rubber Company, New York, New York
United States Steel Corporation, New York, New York
Upjohn Company, Kalamazoo, Michigan
Vulcan Materials Company, Birmingham, Alabama
West Virginia Pulp & Paper Company, New York, New York
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania
Weyerhaeuser Company, Tacoma, Washington
Youngstown Sheet & Tube Company, Youngstown, Ohio
Preamble

The following questionnaire is designed to provide primary research information for a doctoral dissertation in the PhD program of The Ohio State University. This thesis will present the results of a study of current industrial practices in the selection and evaluation of individual research and development projects. The findings from a survey of recent literature and information obtained from interviews with selected company executives will be incorporated into the final report.

In examining the body of criteria used to screen and evaluate individual projects for incorporation into the company research and development program portfolio, emphasis will be placed on the extent to which potential project profitability is utilized in the evaluation process. Applications of this concept to periodic progress reviews and re-evaluations to decide whether or not a project should be kept or abandoned will also be explored.

The following questionnaire is a combination "fill in" and "check off" answer type. Some questions should require more than one answer. If you feel that a narrative response or attached exhibit would help to clarify company practice in some area, please attach
supplemental material as desired. In case an individual question implies a non-relevant concept, please mark it N/A (not applicable) and provide any comments that you feel may be appropriate.

All replies will remain anonymous in the final report and no information will be divulged or published that will permit disclosure of data relative to specific corporations.

A. GENERAL INFORMATION

Does your company have a definite plan for selecting proposed individual research and development projects? FREQUENCY

<table>
<thead>
<tr>
<th>Written</th>
<th>Verbally Understood</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>21</td>
</tr>
<tr>
<td>42</td>
<td>No</td>
</tr>
</tbody>
</table>

If you have a written plan, can a copy be obtained for use in this study?

<table>
<thead>
<tr>
<th>Copy Enclosed</th>
<th>Not Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>4</td>
</tr>
</tbody>
</table>

B. MANAGEMENT PRACTICE INFORMATION

1. Within the framework of the established objectives of the R&D program, what is the rank (1 = most important, etc.) of emphasis given the following factors? WEIGHTED AVERAGE RANK

<table>
<thead>
<tr>
<th>Improve Quality of Current Products</th>
<th>Develop New Materials, Processes or Products for Existing Markets</th>
<th>Develop New Uses for Existing Materials, Processes or Devices</th>
<th>Effect Savings in Costs of Production or Distribution</th>
<th>Assist in Standardization</th>
<th>Improve Customer and Public Relations</th>
<th>General Applied Research</th>
<th>Exploitation of High Yield Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.31</td>
<td>1.96</td>
<td>4.0</td>
<td>3.86</td>
<td>8.08</td>
<td>7.06</td>
<td>5.58</td>
<td>5.18</td>
</tr>
<tr>
<td>2.78</td>
<td></td>
<td>7.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td></td>
<td>5.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.05</td>
<td></td>
<td>6.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 ranked No. 1 and 1 ranked No. 8
2. What is the basis for establishing the amount available for the research and development program (check more than one if applicable)? **FREQUENCY**

- **29** percentage of sales
- **25** number of people in the R&D activity
- **14** cash flow projection
- **3** other (specify)
- **10** percentage of profit
- **70** as necessary to support long range plans
- **31** anticipated return on investment

3. Please rank in accordance with the level of importance (1 = most important; 2 = secondary; 3 = general consideration) any of the following factors which are considered and evaluated when reviewing a proposed research and development project for incorporation into the company's program. **WEIGHTED AVERAGE RANK**

- **1.75** company policy
- **1.86** compatibility with product lines
- **1.96** compatibility with R&D skills
- **2.04** estimated project cost
- **2.43** length of project run (time)
- **1.95** technical risk of the undertaking
- **1.53** company's ability to exploit a successful result effectively
- **2.92** extent of standard parts used in new products, processes, etc.
- **2.61** response by competitors
- **1.74** long range plan objectives
- **1.74** compatibility with marketing channels
- **2.11** compatibility with production facilities
- **2.56** projected plant loading
- **1.44** potential project profitability
- **2.13** concentration of resources required for timely completion
- **2.23** interaction with other projects currently in work
- **1.74** urgency of company or market requirement
- **2.31** patent situation
- **2.23** interaction with other projects currently in work

4. Do you utilize some type of quantitative method in formulating an estimate of potential project profitability? **PERCENTAGE**

- **23.4%** Yes, for all proposed projects
- **68.2%** Yes, but on a selected basis
- **8.4%** No (IF NO, SKIP QUESTION 5)
5. Which quantitative technique(s) do you use in estimating project profitability? FREQUENCY

<table>
<thead>
<tr>
<th>Technique</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>computation of gross profit</td>
<td>10</td>
</tr>
<tr>
<td>net operating profit (before taxes)</td>
<td>6</td>
</tr>
<tr>
<td>net profit before taxes</td>
<td>8</td>
</tr>
<tr>
<td>net profit after taxes</td>
<td>26</td>
</tr>
<tr>
<td>contribution to profit analysis</td>
<td>7</td>
</tr>
<tr>
<td>other (please briefly describe)</td>
<td>2</td>
</tr>
</tbody>
</table>

6. Do you form a subjective or qualitative executive profitability judgment when evaluating proposed R&D projects? PERCENTAGE

<table>
<thead>
<tr>
<th>Choice</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>91.6%</td>
</tr>
<tr>
<td>No</td>
<td>8.4%</td>
</tr>
</tbody>
</table>

7. Rank any of the factors considered pertinent to your management approach. WEIGHTED AVERAGE RANK

<table>
<thead>
<tr>
<th>Factor</th>
<th>Weighted Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>length of period (time) during which R&amp;D expenditures are expected to occur</td>
<td>2.74</td>
</tr>
<tr>
<td>time lag between the end of R&amp;D effort and the start of production (or use)</td>
<td>2.89</td>
</tr>
<tr>
<td>time lapse between the start of R&amp;D expenditures and the start of returns</td>
<td>2.23</td>
</tr>
<tr>
<td>total time span of production (or use)</td>
<td>3.12</td>
</tr>
<tr>
<td>duration of the marketing period during which returns (income) are expected</td>
<td>1.90</td>
</tr>
</tbody>
</table>

8. Indicate the relative importance (1 = most important, etc.) of any of the following factors which you consider in evaluating individual R&D projects. WEIGHTED AVERAGE RANK

<table>
<thead>
<tr>
<th>Factor</th>
<th>Weighted Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>technical risk of not obtaining successful project results</td>
<td>1.50</td>
</tr>
<tr>
<td>ability to hold estimated production costs</td>
<td>2.50</td>
</tr>
<tr>
<td>risk of potential changes in total demand or market preferences between time of R&amp;D project initiation and the projected marketing period</td>
<td>1.94</td>
</tr>
<tr>
<td>changes in profit margins during the marketing period depending on relative saturation, entry of competitors, and volume of production</td>
<td>2.21</td>
</tr>
</tbody>
</table>
9. How do you handle intangibles such as increased customer goodwill, the service of providing a complete product line, improved corporate image, etc.? PERCENTAGE

2.80% evaluate such factors, assess their worth to the company, and assign a monetary value which is then considered as an actual dollar return from projected results

29.91% ignore any specific value which might be assigned these factors, requiring that projects meet given profit criteria before intangibles are considered.

66.35% a qualitative evaluation is made and considered in assessing over-all project desirability

.94% other (explain briefly)

10. If a potentially profitable project is outside of resource limitations, are there provisions for obtaining the additional funds or resources needed? (Please use: I = internal sources; E = external sources; B = both kinds available) FREQUENCY

<table>
<thead>
<tr>
<th></th>
<th>long-term funds</th>
<th>short-term funds</th>
<th>intermediate-term funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>31</td>
<td>147</td>
<td>40</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>19</td>
<td>16</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>technical R&amp;D personnel</th>
<th>specialized facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>E</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>B</td>
<td>33</td>
<td>30</td>
</tr>
</tbody>
</table>

11. What percentages of your total R&D effort are represented by these classes? PERCENTAGE

23.7% both costs and returns can be estimated with a high level of confidence

12.9% returns (but not costs) are estimated with a high degree of certainty

36.2% costs (but not returns) are estimated with a high degree of certainty

27.2% neither costs nor returns can be predicted with confidence
12. Indicate any of the following aspects of the over-all research and development program which are reviewed to assure proper balance on at least an annual basis. **PERCENTAGE**

67.5 distribution of high- and low-risk projects

75.6 emphasis on product innovation or improvement

75.6 "mix of technologies" being investigated

65.0 short-run versus long-run projects

75.6 development of new products

78.3 costs of R&D versus returns

13. Indicate how frequently individual project progress is formally reviewed? **PERCENTAGE**

31.8% Monthly; 42.9% Quarterly; 14.3% Semiannually; 11.0% Annually

14. Rank in order of importance any of the following attributes which are studied to measure or infer progress on research and development projects. **WEIGHTED AVERAGE RANK**

1.94 completion of a previously established list of sub-tasks

4.23 completion of tasks not necessarily previously identified

3.31 activity reports

1.95 project review meetings

4.52 number of manhours input

4.06 other meetings, such as general staff meetings

3.20 expenditures to date

3.67 estimates by project personnel of percentage completion of tasks

4.11 remaining funds versus planned workload remaining

3.76 estimates by project personnel as to whether project is "on time"

5.30 PERT or other CPM system

4.91 remaining time versus planned workload
15. Indicate the relative level of importance (1 = most important; 2 = secondary importance; 3 = general consideration) of any of these factors considered in decisions to continue or abandon R&D projects. **WEIGHTED AVERAGE RANK**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatibility with existing internal technical capabilities</td>
<td>2.18</td>
</tr>
<tr>
<td>Estimated cost to completion</td>
<td>2.14</td>
</tr>
<tr>
<td>Cost to date versus prior estimates</td>
<td>2.62</td>
</tr>
<tr>
<td>Estimated time to completion</td>
<td>2.46</td>
</tr>
<tr>
<td>Technical risk of successful completion</td>
<td>1.56</td>
</tr>
<tr>
<td>Time spent to date versus initial estimated length of project run</td>
<td>2.72</td>
</tr>
<tr>
<td>Current state of the art</td>
<td>2.10</td>
</tr>
<tr>
<td>Interaction with other projects in work and proposed</td>
<td>2.22</td>
</tr>
<tr>
<td>Ability to use successful results effectively</td>
<td>1.43</td>
</tr>
<tr>
<td>Extent of use of standard parts in result</td>
<td>3.12</td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
</tr>
</tbody>
</table>

16. In making a decision to continue or abandon an individual research and development project, are expenditures to date:

**PERCENTAGE**

- 63.6% considered in re-evaluation
- 33.6% treated as sunk costs
- 2.8% given other consideration (specify)

17. In comparing actual costs and returns with project estimates, how do they generally relate? **PERCENTAGE**

<table>
<thead>
<tr>
<th>Returns</th>
<th>Costs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.87%</td>
<td>7.18%</td>
<td>actuals are much higher than estimated</td>
</tr>
<tr>
<td>4.67%</td>
<td>40.19%</td>
<td>actuals are somewhat higher than estimated</td>
</tr>
<tr>
<td>23.36%</td>
<td>22.43%</td>
<td>within estimation accuracy, they are essentially the same</td>
</tr>
<tr>
<td>28.97%</td>
<td>1.87%</td>
<td>actuals are somewhat lower</td>
</tr>
<tr>
<td>2.80%</td>
<td>0</td>
<td>actuals are much lower</td>
</tr>
<tr>
<td>28.04%</td>
<td>26.16%</td>
<td>relationship varies depending on the past experience in estimating similar projects in terms of technical area, length of run and other factors</td>
</tr>
<tr>
<td>10.28%</td>
<td>1.87%</td>
<td>other or can't generalize</td>
</tr>
</tbody>
</table>
18. Rank the following factors in accordance with how variations influence the over-all profitability estimates (in other words, in accordance with how sensitive profitability estimates are to factor variations). Use a scale from 1 to 10, with 1 being the most significant and 10 being of little, if any, significance. Mark any factor not considered during evaluation of R&D project profitability with an X. **WEIGHTED AVERAGE RANK**

<table>
<thead>
<tr>
<th>RANK</th>
<th>FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>research, development and engineering costs</td>
</tr>
<tr>
<td>X</td>
<td>production costs</td>
</tr>
<tr>
<td>XXX</td>
<td>cost of capital</td>
</tr>
<tr>
<td>XXX</td>
<td>marketing costs</td>
</tr>
<tr>
<td>X</td>
<td>estimate of total demand</td>
</tr>
<tr>
<td>XX</td>
<td>estimate of company's share of the market</td>
</tr>
</tbody>
</table>

19. Do you conduct financial analysis for post appraisal purpose of R&D projects in order to compare estimates of costs and profits with actuals? **PERCENTAGE**

<table>
<thead>
<tr>
<th>PERCENTAGE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.67%</td>
<td>yes, for all successful projects</td>
</tr>
<tr>
<td>52.37%</td>
<td>yes, but only for a limited number of projects</td>
</tr>
<tr>
<td>38.28%</td>
<td>yes, for all projects to determine effectiveness of total R&amp;D expenditures</td>
</tr>
<tr>
<td>22.41%</td>
<td>no, it is not felt to be of significant value</td>
</tr>
</tbody>
</table>

0. QUALIFYING INFORMATION: The following data is required in order to provide a meaningful statistical description of the R&D activities of participating companies.
20. For the following classifications, please indicate the percentage distribution of effort which you generally have in your R&D program. **PERCENTAGE**

- **6.57%** basic or fundamental research
- **18.86%** general applied research
- **10.06%** exploratory or feasibility studies
- **35.98%** product development
- **15.02%** process development
- **10.68%** engineering or troubleshooting
- **2.81%** other

21. How many technical people did you have working full time on your R&D program last year? **Low - 5; High - 12,500; Average - 705**

22. What was the approximate amount spent for research and development by your company in your fiscal year 1965? **Low - $250,000; High - $750 Mil.; Average $31.07 Mil.**

23. What general **minimum** return does your company strive to achieve from successful R&D projects? **See Text for discussion.**

24. Please check if you wish to receive information concerning the outcome of this study. **FREQUENCY**

- **52** copy of questionnaire tabulation
- **69** availability of complete report

---

**FIRM CODE NUMBER**

(for statistical classification purposes only)
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Suits, Dr. C. G. Keynote Address at the First Annual National Conference on Industrial Research, Purdue University, January 10-11, 1966.


**Government Publications**


Bibliographies


Unpublished Materials

