SELECTING RESEARCH AND DEVELOPMENT PROJECTS THROUGH CLASSIFICATION

by

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CHAPTER ONE:

INTRODUCTION

Since the beginning of time, man has yearned for the ability to predict the future. If the future could be predicted accurately, appropriate plans could be made to prepare for future circumstances. From a modern business standpoint, the ability to predict the future would mean that the organization would be ready to utilize state-of-the-art technology as soon as it is available and could make the necessary plans to meet the future demands of its customers. Without such abilities, though, organizations can only make educated guesses in their attempt to plan for the future.

It is this preparation for the future that is the very essence of research and development. Research and development (R&D), by definition, deals with new ideas and the potential technologies that will form the basis for future products and processes. Therefore, the success of an organization's research and development program will determine the ability of the organization to meet the needs of its customers in the future. Thus, every organization must attempt to predict the future to insure the continuation of its operations. To complicate this problem, the act of predicting and planning for the future effects the future. In other words, the rate of development of new technologies is directly related to the level of resources allocated to this development.

The cumulative effect of these organizational impacts can be seen in the performance of an entire industry. For example, the failure of individual U.S. steel firms to develop more efficient processing technologies has caused the industry as a whole to suffer great losses at the hands of more efficient suppliers. These industry effects, in turn, have an impact on the economy as a whole.

Consequently, the total amount of research and development performed in this country is commonly considered to be an indicator of the long-run health of the economy. In an economy tied to short-run measures such as quarterly profit statements, research and development provides a measure of the performance of the economy 5 to 10 years from now.

A survey conducted on behalf of the National Science Foundation by the Industrial Research Institute concluded that there has been a marked decrease in the amount of basic research performed in this country in the last two decades [N-2]. Although some link this fact to the weakened competitiveness of U.S. industry, it is more likely that the lack of emphasis on applied research or development is a more direct cause of this decline. It is generally accepted that the U.S. has the technology to improve its production efficiency but that other countries' implementation of the technology has been quicker and more widespread. Clearly, a delicate balance of basic research and development must be maintained for a healthy economy.

As can be seen from the previous discussion, the appropriate allocation of resources to research and development is important to individual organizations and to the economy as a whole. This importance is reflected in the amount of literature focused on the research and development project selection problem. The process of R&D project selection is the realization of the total R&D process. It involves the determination of the best means (R&D projects) by which the organization prepares for the future and the actual allocation of resources to these projects.

This report will focus on this key step in the research and development process. First, Chapter Two will define research and development and what is meant by an R&D project selection decision. The definitions of both R&D and the R&D project selection process will be seen to vary according to the setting in which the projects are being considered.

Chapter Three will begin with a discussion of the actual use of management science models for R&D project selection. Although many models exist, it will be seen that most organizations use only basic economic models or no organized selection process at all. This chapter also traces the evolution of modeling from simple checklists through mathematical programming models and project evaluation techniques to a more recent emphasis on group decision making. An example of one of these "modern" project selection models will be presented.

After demonstrating the importance of R&D to individual organizations and to the economy as a whole in Chapter One, describing the many complexities involved in the R&D project selection process in Chapter Two, and, in Chapter Three, realizing the inadequacy of the models proposed in literature, the need for further work in this area becomes evident. An R&D manager who turns to the literature in hopes of improving his/her own selection system will find only a myriad of individual approaches to the problem and little guidance on how choose among them. The next three chapters, then, are designed to organize this information into a simple, logical form that can be immediately understood and applied by an R&D manager trying to improve his/her own R&D project selection process.

Chapter Four proposes a unique approach to the problem which combines group decision making, the classification of R&D projects, and the use of current project selection models. This four-phase model begins with the formulation of statements of the goals of the organization. Classification of R&D projects is proposed to facilitate the use of many current selection models which are only appropriate for certain types of projects. The final phase consists of using a portfolio model as an analytical guide to a committee of decision makers responsible for the final allocation of resources among projects.

Chapter Five discusses a number of classification schemes for R&D projects to be used in the above system. The schemes presented in this chapter are those that are most quoted in the literature and most commonly used in practice. It must be emphasized, though, that the actual classification scheme used by an organization must be based on the specific goals of that organization.

Chapter Six presents a discussion of the organizational factors involved in implementing the proposed system. The system is designed to be a guide for the development of a selection system for all organizations and can be adapted for different organizational types, structures, and sizes.

Finally, Chapter Seven summarizes the advantages associated with the use of the proposed selection system. The classification of projects allows for the more appropriate use of project selection models and for insuring a more "balanced" R&D portfolio. The combination of a group decision making technique and an analytical model offers the advantages of both of these tools. The analytical model helps decision makers better analyze trade-offs between projects and the group decision making technique offers additional advantages such as improved communication, cooperation, and motivation. The system recognizes that each organization has different goals and alternative projects and is designed to adapt to these differences yet provide guidance in the selection process.

CHAPTER TWO:

THE R&D PROJECT SELECTION PROCESS

Any single definition of the research and development project selection process is certain to be subject to scrutiny from academicians and practitioners alike. The lack of any universal understanding of what is meant by "research and development," ignoring any understanding of the selection process, is one of the characteristics that makes the discussion of R&D project selection inherently complex.

The phrase "research and development" has a different meaning for every individual who defines it. Some people just have a "feeling" for the phrase that they have never put into words. Some define the phrase as one entity while others define "research" separately from "development." Further, any attempt to draw a line between the two terms is highly subjective since the actual R&D process is continuous rather than discrete.

Further, the process of R&D project selection is a phrase which takes on widely diverse meanings depending on who defines it. Each individual's understanding of the process is based on the particular environment to which he/she has been exposed. It could be said that the range of definitions derives from the great range of selection practices. But, it could just as well be that the range of practices is the result of the lack of a single definition. Either way, definitions range from the application of a simple economic evaluation method to complex models of the total innovative process.

To simplify the discussion in this report, the definition of the phrase "research and development" will be discussed followed by a detailed description and discussion of what is meant by the "R&D project selection process."

Definition of Research and Development (R&D)

The phrase "research and development" is commonly used by not only technical personnel but by the public at large. As with most commonly used phrases, the meaning often changes each time the phrase is repeated. Almost everyone has been, at one time, exposed to the phrase. Many Americans are concerned with the quality of American R&D verses Japanese R&D. Investors often consider the amount spent on R&D by a firm as an indicator of the future earnings of a firm. Further, the importance of R&D to a firm is evidenced by the involvement of almost every department of the typical business unit: accounting, finance, marketing, sales, production, as well as the actual R&D unit itself.

With each of these groups and individuals defining research and development to match their own understanding and point of view, the confusion underlying any attempt to come up with a single definition is understandable. But since a definition is necessary for a full discussion of this topic, a definition will be presented that is detailed enough to provide the basis for a common understanding of the phrase and general enough to encompass most common points of view.

A very general definition of the overall objective of R&D is presented by Balderston, et al. [B-6] as follows:

> Research, development, and engineering involves the continuous expansion of organized human knowledge, and the application of that human knowledge in devising new approaches to satisfying human needs.

Thus, research and development is the act of gathering and applying new knowledge. A more detailed definition involves differentiating between "research" and "development." This division is the subject of great controversy for which there is no resolve. One such division is presented by Souder [S-7] who differentiates between research and development as follows:

> Research is that set of activities which identifies the new product or process and establishes its parameters and characteristics.
>
> Development is that set of activities which rounds out the new product or process and brings it to commercial readiness.

Understandably, the distinction between research and development in this and most definitions is weakly defined. No consensus will ever be reached as to the "best" way of dividing this continuous process into a finite number of stages. The issue will be dealt with in much more detail in Chapter Four, Section A, which discusses the classification of R&D projects by project life cycle.

Accountants have a unique necessity for a more practical definition of research and development. In order to properly classify expenses as research and development versus other business expenditures, simple guidelines must be devised. For this purpose, the Financial Accounting Standards Board has established the guidelines for identifying R&D activities as presented in Table 1. The first list includes activities that are typically <u>included</u> in the category of R&D. The second list includes those activities that are typically <u>excluded</u> from the category of R&D.

These lists of activities help to develop a more practical sense of the meaning of research and development. Only the activities associated with the discovery and testing of new technologies or the testing of new applications of existing knowledge are included within the category of R&D. Any <u>use</u> of these new technologies in activities involved in regular commercial production is considered to be outside the realm of research and

TABLE 1: Financial Accounting Standards Board's R&D Guidelines. [I-1]

Activities Typically Included in R&D

1. Laboratory research aimed at discovery of new knowledge.
2. Searching for applications of new research findings or other knowledge.
3. Conceptual formulation of design of possible product or process alternatives.
4. Testing in search for or evaluation of product or process alternatives.
5. Modification of the formulation or design of a product or process.
6. Design, construction, and testing of pre-production prototypes and models.
7. Design of tools, jigs, molds, and dies involving new technology.
8. Design, construction, and operation of a pilot plant that is not of a scale economically feasible to the enterprise for commercial production.
9. Engineering activity required to advance the design of a product to the point that it meets specific functional and economic requirements and is ready for manufacture.

Activities Typically Excluded from R&D

1. Engineering follow-through in an early phase of commercial production.
2. Quality control during commercial production including routine testing of products.
3. Trouble-shooting in connection with break-downs during commercial production.
4. Routine, on-going efforts to refine, enrich, or otherwise improve upon the qualities of an existing product.
5. Adaptation of an existing capability to a particular requirement or customer's need as part of a continuing commercial activity.
6. Seasonal or other periodic design changes to existing products.
7. Routine design of tools, jigs, molds, and dies.
8. Activity, including design and construction engineering, related to the construction, relocation, rearrangement, or start-up of facilities or equipment. Pilot plants of a scale economically feasible to the enterprise for commercial production.
9. Legal work in connection with patent applications or litigation, and the sale or licensing of patents.

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development.

In summary, endless definitions exist for the phrase "research and development," depending upon the individual and the environment in which the phrase is defined. For discussion, the phrase will be loosely defined as "the discovery and application of new knowledge and the new application of existing knowledge." Based on this understanding, the subject of the R&D project selection process can now be addressed.

The Selection Process

The quantity of literature on the subject of research and development project selection reflects not only the importance of the topic but also the inherent complexity of this unique decision process. Although many models and decision systems have been proposed to deal with these complexities, none have found the support of more than a small group of individuals or organizations. This section will address the complexities involved in the R&D project selection process and the attempts to deal with them.

It must be first noted that the selection of research and development projects is a subset of an ever-changing innovation process that involves all levels of an organization. One model of this so-called research management cycle is presented in Figure 1. As can be seen from this diagram, all levels of the organization (labeled on the left side of the diagram) are involved in all stages of the research cycle in a cyclical, continuous process. This model includes idea generation, objective-setting, planning, selecting, and controlling R&D projects. Other models have been proposed by Souder [S-6] and Roberts [R-2].

The immediate inclination is to define the selection process as the single outlined box labeled, "PORTFOLIO: PROJECT SELECTION, FUNDING." More realistically, many other elements must be included in a complete selection model. Models vary greatly with respect to the range of activities that are modeled into the selection process. Many consider the total selection process to include the establishment of organizational goals and the evaluation of projects, as well as the actual selection decision.

An explanatory definition of the R&D project selection process is proposed by Baker [B-1]:

> The R&D project selection/resource allocation problem is as follows: Given a set of alternatives (projects and proposed projects) which require common scarce resources (such as dollar budgets, manpower, and facilities), determine that allocation of the resources to the alternatives which will maximize the benefit contribution (value) of the resulting program.

This definition outlines the R&D project selection process as determining the best set of projects for the organization. Although this may be an accurate definition of the

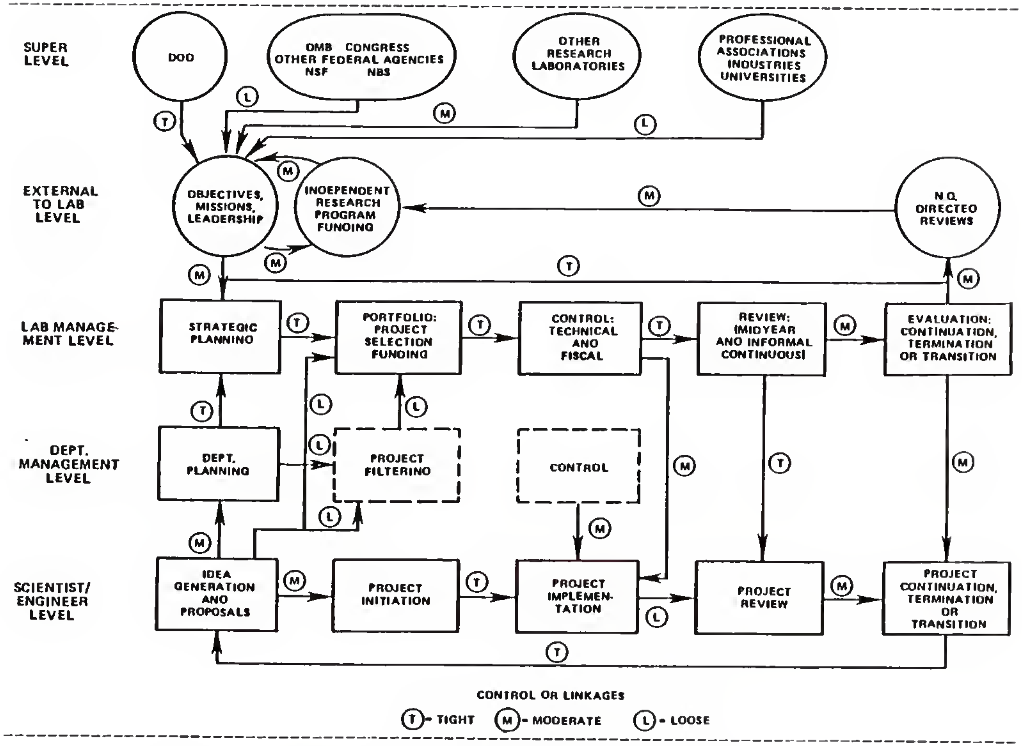

FIGURE 1: The Research Management Cycle. [L-2]

process, the actual determination of what is "best" for the organization is a very complex problem. In fact, many complexities of the R&D project selection are unique and are not commonly encountered in other managerial decisions.

Discussions of these unique complexities are common in literature [B-5][B-11][C-2][G-4][G-5]. Table 2 summarizes these discussions with a list of ten unique complexities of the research and development project selection process.

The first factor is the existence of ever-changing, fuzzy organizational goals. The process of extracting the goals of an organization from all the involved individuals is a very difficult task. It is difficult, even for individuals, to translate these often abstract goals into concise statements. Furthermore, these goals must be translated into statements upon which everyone can agree. Even if this is accomplished, these goals can change quickly if there are changes in either the internal or external environment.

These multiple goals are commonly of a non-quantifiable nature and non-commensurate. Often profit is quoted as <u>the one</u> organizational goal. While profit is often included, other goals are typically listed as equally important. Such goals might include diversification, management satisfaction, improved public image, and so on. Not only are these qualitative goals very difficult to measure, but they are even more difficult to measure <u>on a common scale</u>. This

TABLE 2: Ten Unique Complexities of the R&D Project Selection Process.

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1. Multiple, ever-changing, fuzzy organizational goals.
2. Multiple goals are qualitative and non-commensurate.
3. Various levels of uncertainty.
4. Investments are often large and vital to the future of the organization.
5. Many organizational units are involved whose goals are conflicting.
6. Process is sequential and continuous.
7. Projects have unequal, variable, and uncertain time horizons.
8. Involves a great number of interdependent alternatives.
9. Significant dependence on outside factors.
10. Need to motivate and retain quality R&D personnel.

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complicates the process of determining the trade-offs between competing goals and resource limitations.

The third complexity is the inherent uncertainty in research and development. Costello [C-10] states that, by definition, research involves uncertainty:

> "...lack of information about the future potential of research ideas is one of the features that defines research. If there is enough information available to conduct detailed estimates of costs and benefits, the project can no longer be considered at the research stage."

Additionally, all project selection decisions will involve a mix of R&D projects including those at various stages of development. Therefore, these projects will be subject to various levels of uncertainty. For example, the rewards of a fundamental research project are virtually unpredictable, while the returns of a cost-reduction effort may be easily estimated. These various levels of uncertainty make it difficult to make direct comparisons between projects.

The very nature of research and development projects are that they deal with new knowledge or new applications. Consequently, these projects usually involve new products, processes, or services for the organization. Not only do these projects require significant investment of resources, but the outcome of the projects often weighs heavily on the future ability of the organization to provide adequate products and services.

Additionally, the project selection process often determines the utilization of the major resources of the organization for a significant length of time. Once these resource allocations have been made, organizational inertia makes it difficult to change priorities and allocations. This inertia emphasizes the importance of initial project selection decision.

As noted earlier, research and development involves almost all aspects of the organization from accounting to production. Therefore, each of these units must be involved to provide input into the selection process. The difficulty of integrating the needs of these diverse organizational units is further complicated by conflicts in goals. For example, while finance may want the most profitable alternative, the R&D department may desire a more technologically advanced alternative while production may insist on a easily manufactured alternative. Different levels of the hierarchy of the organization may also be involved. The difficulties involved in the resolution of these conflicting goals is unique to the R&D selection process because of the universal interest in these projects among all major organizational units.

The typical progression from idea generation to commercialization of an R&D project is continuous. Yet, decisions must be made as to the viability of a project at various points of the project's life cycle. The goals and the relative importance of those goals change as the project progresses. These facts complicate the evaluation of even a single project. The organization, though, must be continually searching for new ideas and initiating new projects. Therefore, the selection process must take into account the changing nature of each project and must continually consider the addition of new projects to the pool.

Normal economic evaluation problems involve projects whose lives, if not equal, are comparable in length. Research and development projects, though, may have lives that vary from 3 months to 30 years. More often than not, the time to completion of any given project cannot be stated without at least some uncertainty. The difficulty in comparing the value of the outcomes of projects with such uncertain and different time horizons make the necessary direct comparisons very subjective and complex.

If an organization is effective at idea generation, the number of possible projects is endless. These projects must first be screened according to some criteria to narrow the field to a reasonable number of alternatives. This screening process is often overly subjective and good projects can easily get lost in the shuffle. Also, the selection of many projects will be interdependent upon the acceptance of other projects. Either the projects use the same resources and therefore are mutually exclusive, or projects could be complementary in that they could both benefit from a common research effort. These interrelationships are very difficult to incorporate into a project selection model.

Since R&D projects often are involved with the development of products, processes, or services that will be offered to the customers of the organization, many outside factors can determine the success or failure of the projects. Competitive, economic, and governmental factors often play a major role in the long-term success of R&D projects. These factors must be predicted with much accuracy to insure the correct selection of projects.

Finally, many organizations must make a concentrated effort to retain certain R&D personnel. Often this is done by providing challenging work in the individual's area of expertise, even though this work may not be consistent with other objectives of the organization. The need to motivate certain personnel must also be considered in project selection decisions.

Baker [B-1] offers an excellent discussion of the complications involved in modeling the research and development project selection process. He offers this summary of the process:

> In summary, the R&D project selection decision is a process by which an intermittent stream of changes are made to lists of currently active and proposed projects. The project selection decision process includes generating alternatives, determining the appropriate time to

> make a decision, collecting data, specifying constraints and criteria, and recycling.
>
> The evaluation and comparison of projects and proposals is complicated by multiple decision criteria which have no natural, common underlying measure and whose relative importance varies over time. In addition, the R&D project selection decision may be made at several different organizational levels which are participating in a hierarchical, diffuse budgeting and planning process.

In conclusion, research and development is defined as "the discovery and application of new knowledge and the new applications of existing knowledge." The R&D selection process is complicated by many organizational and external factors. The difficulty of modeling all of these complexities is reflected in the diverse approaches to the problem as proposed in literature. Chapter Three will discuss the different proposed approaches to the R&D project selection decision and their ability--or inability--to account for the above described complexities.

CHAPTER THREE:

R&D PROJECT SELECTION MODELS

Because of the highly complex nature of the R&D project selection decision, the topic has received much attention in the literature. Most of the articles are concentrated in three journals: Research Management, IEEE Transactions on Engineering Management, and Management Science. Although many models have been proposed to deal with the various complexities of the problem, no model has earned the support of more than a few individuals or organizations.

The attention to the problem of R&D project selection began in the 1950s and management science theory has since progressed through simple scoring models, mathematical programming models, and project evaluation techniques to the current trend in modeling using organizational decision methods [S-14]. This chapter will discuss the use of R&D project selection models, the current trend toward group decision making methods, and a new model proposed by Dr. Wm. E. Souder. Chapter Four will introduce an improved project selection system.

Actual Use of Models

The inability of currently proposed project selection models to take into account all the complexities described in the previous chapter is evidenced by the low rate of use of these models. The model makers often are forced to make over-simplifying assumptions in order to model the problem. On the other hand, other model makers demand so much input data that the application of the model becomes impossible. The end result is that most potential users ignore the current literature and continue to use simple economic evaluation methods or no organized selection process at all.

Numerous studies have been conducted in the United States and other nations to determine the use of management science models for R&D project selection [C-1][H-1][L-4][M-2][S-2][S-11]. All of the studies have come to the same conclusion: the models currently proposed in the literature are not being utilized. While a very few organizations use mathematical programming techniques, almost all organizations, that use any organized method at all, use only simple economic evaluation methods such as internal rate of return and payback. These simplistic evaluation techniques fail to take into account <u>any</u> of the complexities of this type of decision. Even in organizations where more sophisticated models have been introduced, the use of the model is most often discontinued as soon as the developer of the model leaves the organization.

Dr. Wm. E. Souder, a Professor of Industrial Engineering at the University of Pittsburgh, is a widely recognized as one of the leaders in the field of R&D project selection.

Souder [S-10] summarizes some of the reasons why management science models are over-simplified compared to the real-world environment. Table 3 lists the assumptions made by typical management science models (left column) and the respective real-world situation (right column). The differences are sharp and help explain the limited use of such models.

Evolution of R&D Project Selection Theory

Since the first real emphasis on R&D project selection, the approach of the management science modelers has changed in four stages. The simple classical models of the 1950s gave way to much more sophisticated mathematical programming models in the 1960s. In the 1970s, modelers introduced various types of project evaluation techniques. Currently, the trend is toward group decision making models, or organizational decision methods.

This division of the progression or evolution of R&D project selection models into four stages was proposed by W.E. Souder and T. Mandakovic in an article entitled "R&D Project Selection Models" published in 1986 [S-14]. This article discusses the progression of management science theory and the weaknesses and strengths of many representative models. Much of the following discussion is taken from this article.

TABLE 3: The View of Management Science Models vs. The Real World Environment. [S-10]

The View of Management Science Models	The Real World Environment
1. A single decision maker, in a well-behaved environment.	1. Many decision makers and influencers, in a dynamic organizational environment.
2. Perfect information about candidate projects; outputs, values and risks of candidates known and quantifiable.	2. Imperfect information about candidate projects; outputs and project values difficult to specify; uncertainty accompanies all estimates.
3. Known, invariant goals.	3. Ever-changing, fuzzy goals.
4. Decision making information is concentrated in the hands of the decision maker, so that he has all information he needs to make the decision.	4. Decision making information is highly splintered and scattered throughout the organization, with no one part having all the information needed for decision making.
5. The decision maker is able to articulate all consequences.	5. The decision maker is often unable or unwilling to state outcomes and consequences.
6. Candidate projects are viewed as independent, to be individually evaluated on their own merits.	6. Candidate projects are often technically and economically interdependent.
7. A single objective, usually expected value or profit maximization, is assumed and the constraints are primarily budgetary.	7. There are sometimes conflicting multiple objectives and multiple constraints, and these are often non-economic in nature.
8. The best portfolio of projects is determined on economic grounds.	8. Satisfactory portfolios may possess many non-economic characteristics.
9. The budget is "optimized" in a single decision.	9. An iterative, re-cycling budget process is used.
10.One single, economically "best", overall decision is sought.	10. The "best" decision for the total organization may not be "best" for each dept.

The classical models were developed to prioritize projects in order to choose the "best" project. Such typical models included profiles, checklists, scoring, and economic indexes. Profiles simply display the decision maker's preferences on a graph. Checklists, on the other hand, solicit a score from the decision maker on a number of selection criteria. The total score for each project is simply the sum of the individual scores for each criterion.

Many of the shortcomings of these models were overcome with the use of scoring models. Like checklists, scores are solicited for each of the selection criteria. The total score for each project using a scoring model is a weighted sum of the scores of the criteria based on the relative importance of the criteria. Even with this improvement, the model remains overly subjective because of the intuitive manner in which both the weights and the scores are derived.

As noted earlier, economic indexes are one of the most common types of project selection methods used today. Yet, these models rely heavily on difficult estimates of the probability of success of each project. These models also disregard most non-economic factors involved in the selection process.

The 1960s saw an increase in the development of portfolio selection models based on mathematical programming. The first models used a linear programming approach. These models were later improved by the introduction of nonlinear, integer, and dynamic programming models. These sophisticated models allowed decision makers to incorporate many of the resource allocation constraints into the model of the problem. The biggest limitation of these models was the excessive input data requirements. Further, because of their complexity, many decision makers could not understand the sometimes overwhelming mathematics and, therefore, rejected the models altogether.

A number of different types of project evaluation techniques have been developed and applied to the R&D project selection problem during the 1970s. These models include goal- or value-contribution models, decision trees, utility theory models, Monte Carlo simulation, and risk analysis. The models are helpful to the decision maker in evaluating individual projects or in understanding the multiple selection criteria involved in the selection process. Many of these methods are still being proposed and tested in the field.

The most recent trend in the modeling of the R&D selection process is the movement toward models that incorporate the role and behavior of the many decision makers in an organizational setting. Souder identifies two such approaches: behavioral decision aids and decentralized hierarchical modeling. Behavioral decision aids include many group decision making methods such as the Delphi Method, Nominal Group Techniques, Q-Sorting, nominal, and interactive group settings. These methods have two aims: 1) to assemble the necessary information from the individuals of the organization to make a project selection decision (using an existing or original project selection method), and 2) by collecting this information in a group decision making environment, to improve communication and motivation in the organization.

Decentralized hierarchical modeling is a method designed to integrate the various organizational units in a hierarchical organization. The method utilizes computer terminals to collect input from all the units involved in the resource allocation process. Once the input is collected, a suggested portfolio is developed and the proposal is submitted to each unit for evaluation [M-3][B-4]. This process is repeated until a consensus is reached. Similar hierarchical models have been proposed based on group decision making methods [L-5].

The evolution of R&D project selection models has progressed from simplistic models that failed to account for the complexities of the problem to the overly-complex mathematical models that ignored the limitations of the decision maker. Only recently has adequate attention been given to the needs and limitations of the decision makers themselves [S-13]. Only with the input and participation of all the key individuals and groups within an organization will the "optimum" portfolio of projects for the organization be found.

Therefore, a need exists for the development of complete project selection systems integrating the collection of data and the solicitation of goals from the decision makers and the use of this information to select a portfolio of research and development projects. The next section will discuss one such system proposed by Souder in 1978 and Chapter Four will be devoted to the introduction of a proposed selection system based on the classification of projects.

Souder's Project Evaluation System

This proposed system is based, to a large extent, on a Q-Sorting/Nominal-Interacting (QS/NI) process which has been tested in the field for use in the R&D project selection process [S-5][S-6]. The use of this process is combined with the use of more traditional project selection models depending on the type of projects under consideration and the type of decision involved.

The project selection process itself is modeled in Figure 2. This simple flow-chart outlines the steps and thought processes involved in the project selection decision. Beginning with the alternative project ideas, the ideas are screened, evaluated, prioritized, and finally combined into an "optimum" portfolio. The necessary

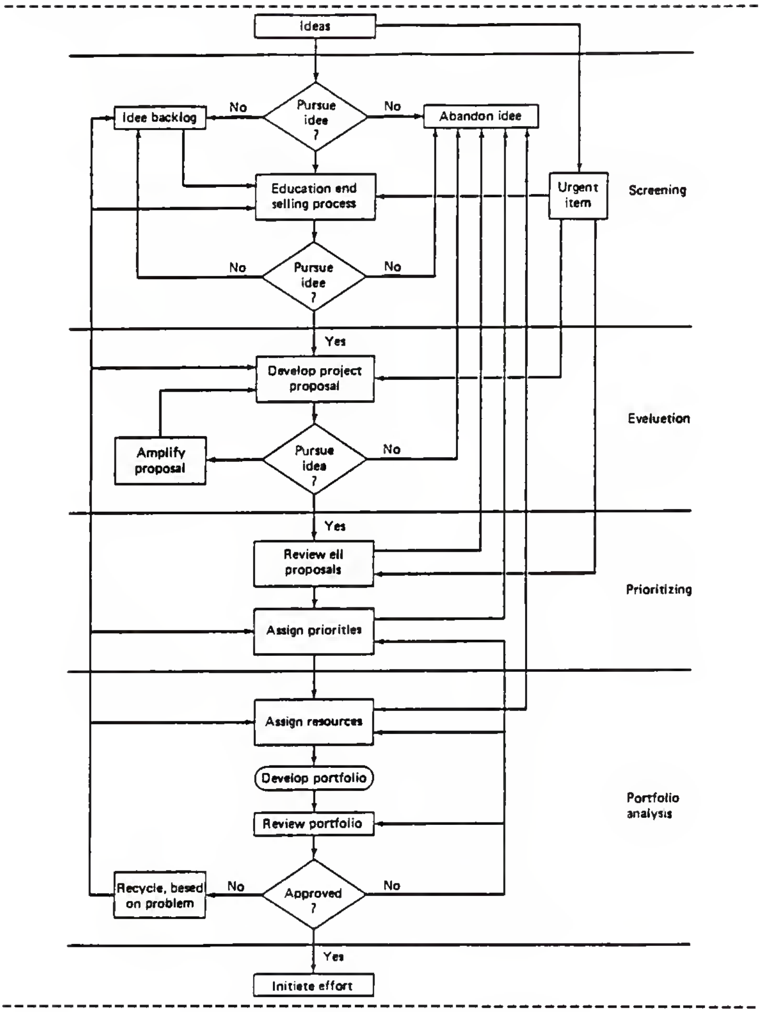

FIGURE 2: Souder's Project Selection Process. [S-7]

feedback loops are included for the abandonment of ideas or the addition of the rejected projects to the organization's inventory of potential project ideas. The final output of the process is the organization's R&D portfolio.

Figure 3 presents a system for using project selection techniques also proposed by Souder. The integration of these two system presents a complete project selection and evaluation system. By following the selection system in Figure 2 and using Figure 3 as a guide at each stage of the selection process, a total evaluation system emerges.

The first step in any decision process, as modeled in Figure 3, is the establishment of a consensus set of goals. This necessary step must precede the use of any project selection method. The rest of the model gives guidelines for the application of R&D project selection methods according to the type of projects being compared and by the type of decision being made.

The top row divides the projects to be compared by project type, or life cycle stage. Exploratory projects are characterized by the lack of evaluative information and consequently require models capable of handling more subjective input data: checklists or profiles. For applied projects, usually some evaluative information is available. For these projects, Souder recommends the use of Q-Sorting to screen the projects followed by the use of an index, scoring, risk analysis, or frontier model for the final

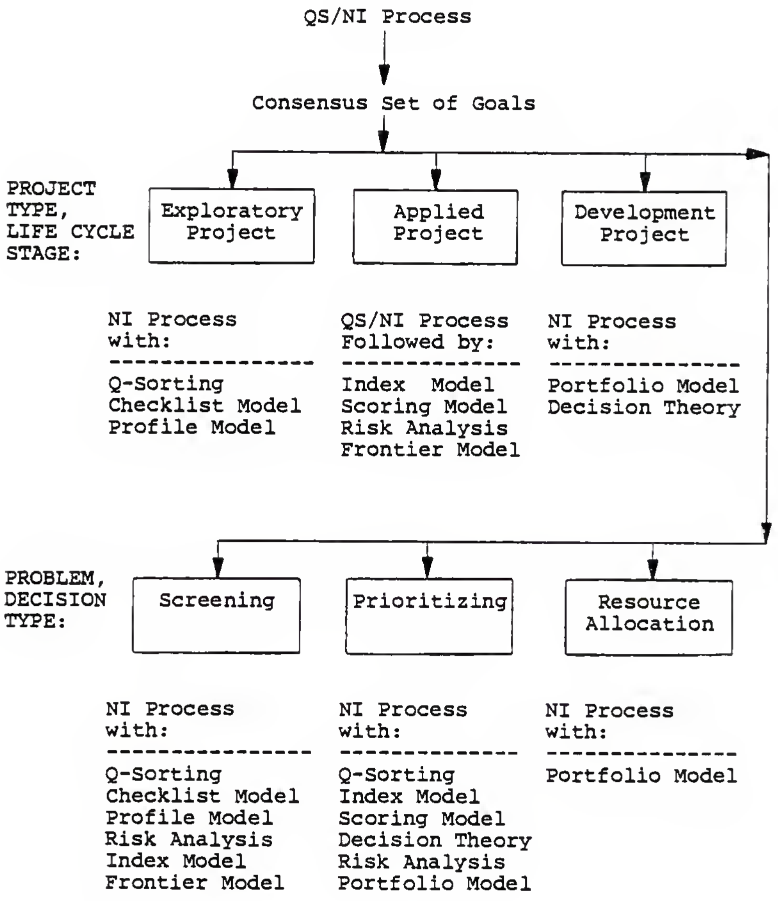

FIGURE 3: Souder's Guidelines for the Use of R&D Project Selection Methods. [S-10]

selection. The availability of a greater quantity of less subjective data on development projects allows the decision maker to apply more sophisticated computerized resource allocation models. The input for the model could be derived using a Nominal-Interacting process.

The second row of Figure 3 divides the use of project selection methods by the decision type. These decision types correspond to the selection stages presented in Figure 2. As the decision maker progresses through the screening, prioritizing, and resource allocation stages of the selection process, he/she may use the guidelines in Figure 3 to choose the appropriate decision method. For screening decisions, only subjective accept/reject decisions are necessary. Almost any model can be used for this stage depending upon the form of the available input information. For prioritizing decisions, more evaluative information is usually available and necessary. Therefore, more sophisticated models could be used for prioritization. Finally, as the selection process reaches the portfolio selection stage, much information has been collected on each of the remaining projects and the use of a portfolio model is possible and justified.

Thus, this total selection process consists of three selection stages and guidelines for carrying out the decisions involved at each of these stages. The QS/NI process is used with other models at each stage to solicit the input of the decision makers.

In conclusion, the inadequacy of R&D project selection models as proposed in literature has been evidenced by the lack of use of such methods in real world settings. Often too many simplifying assumptions are made or, on the other extreme, the input requirements of the model are overly demanding to make the use of the model practical. The solution to the organizational complexities of this decision process is the coupling of group decision making methods with the use of these selection models. One such system proposed by Souder was presented. This system outlined the selection process and provided guidance to the decision maker as to the use of selection methods at the various stages of the process and for different project types.

The following chapter will present a proposed system for incorporating the decision makers in the organization and increasing the effectiveness of R&D project selection methods. This system is based on the classification of R&D projects. This classification of R&D projects will allow many existing models to be used much more effectively. Additionally, the use of group decision making methods will improve the quality of the input data into such methods and will benefit the organization in other important ways.

CHAPTER FOUR:

A PROPOSED R&D PROJECT SELECTION SYSTEM

The selection of research and development projects from an often exhaustive list of project proposals is a uniquely difficult managerial decision. The size of the investment, the importance of the projects to the continued operation of the organization, the involvement of nearly every component of the organizational structure, and the substantial uncertainty in predicting possible outcomes make this decision process uniquely complex. Consequently, much attention has been given to the problem, yet few viable selection systems have been proposed and applied.

The complex mathematical programming methods have succeeded in many aspects in incorporating many of the complexities of this decision. Yet, as the models incorporate more of the complexities, the data requirements for the models grow proportionately. Since much of this data is of a non-quantitative nature and/or very difficult to estimate, the models soon become impractical. For example, many models require estimates of return per dollar spent, probabilities of technical and commercial success, time to completion, market demand and competitive factors, and complex tradeoffs between multiple objectives and resource constraints. Additionally, no one decision maker has all the information necessary to make these tradeoffs, so the decision must be a consensus of numerous individuals who have conflicting goals, scattered information, and diverse points of view on the total process.

As discussed in the previous section, the only way to provide such stringent data requirements is to provide a structured environment in which all the key individuals in the R&D process can exchange information and work towards a consensus. Once the input requirements are fulfilled, an appropriate model should be formulated and solved. These results are, in turn, presented to the group for further consideration. This method achieves the analytical advantages of using a selection model and the organizational advantages associated with group decision making: improved communication, better cooperation, and intrinsically motivated managers.

One such model was proposed by Souder and was presented in the preceding chapter. This chapter will introduce a project selection system developed by the author to provide the basis for the formulation of goals and the practical application of project selection methods.

This new system shares some characteristics with the "convergent approach" to R&D project selection proposed by Clayton [C-4]. Clayton recommended an approach based on the theory that top management should be responsible for establishing broad organizational goals while the individual

R&D units should determine how these broad goals might be best accomplished.

The proposed system is represented in Figure 1. The system consists of four phases: I) establishing organizational goals, II) classifying the R&D projects into groups, III) choosing or ranking the projects within each class, and IV) pooling the projects from all the classes and selecting a portfolio. The establishment of organizational goals and the selection of the portfolio (Phases I and IV) are carried out by a committee consisting of all of the key individuals in the R&D process. The classification of projects and the choosing/ranking of projects within each class (Phases II and III) is done by the individual R&D units or a group of R&D managers.

Phase I: Establish Organizational Goals

The formulation of a set of organizational goals is a prerequisite for any viable project selection system. Without some agreement and subsequent recording of the goals of the organization, the R&D process cannot be effectively directed to further these goals. Since the R&D project selection process is the most direct means of establishing the current and future orientation of an organization's R&D effort, these goals are critical to the project selection decision.

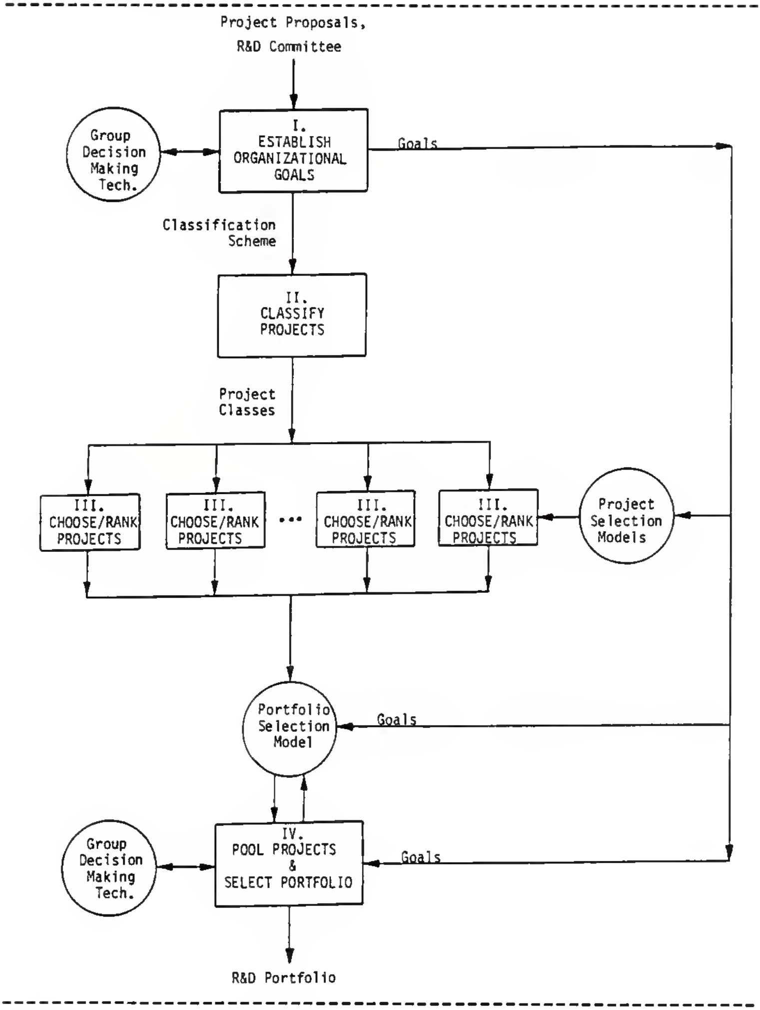

FIGURE 4: A Proposed R&D Project Selection System.

Table 4 lists a number of references for discussions and surveys of organizational goals and R&D project selection criteria. This table lists the reference number, author (or authors), date, and a brief description of the contents of each article. The recommendations of different researchers on project selection criteria vary greatly. Souder [S-7] groups all criteria into four categories: costs, benefits, risks, and suitability. Cooper [C-7] groups criteria into the more long-range oriented categories of impact, feasibility, and intrinsic scientific merit. Of course, each organization must establish its own, unique set of goals. These references are intended to provide a list of possible goals to provide a starting point for decision makers formulating their own goal structures.

The individuals involved in the decision making process must first organize their own understanding of the selection process and criteria before they will be able to provide useful input to the group decision making effort [S-6]. Opportunities for individuals to determine their own goal structures must be provided in the total group decision making process. Once these individual goals are formulated, a consensus must be formed from the group on statements of the goals of the organization.

Since these goals must provide the basis for the formulation of project selection criteria, the statement of these goals must be clear and concise. A set of vague

TABLE 4: References for the Establishment of Organizational Goals/R&D Criteria.

Ref.	Author(s)	Date	Description
B-7	Becker	1980	IRI survey of criteria for research, product & process development.
C-7	Cooper	1978	Discussion of impact, feasibility, and intrinsic scientific merit.
C-8	Cooper	1980	Survey of new product selection criteria.
C-9	Cooper	1981	Extension of C-8.
F-2	Fernelius	1979	IRI survey on innovative process.
M-5	Merrifield	1981	Criteria for commercial success.
R-1	Ramsey	1978	Book: "Research and Development Project Selection Criteria."
S-2	Schwartz	1977	Survey of Canadian top executives.
S-3	Souder	1975	Presents a method of achieving organizational consensus on R&D project selection criteria.
S-7	Souder	1984	Criteria by costs, benefits, risks, and suitability.

statements such as "improve the stability of the company" without specifying how this "stability" is to be measured, offers little assistance to model makers. Possible measures for the suggested goals should always be considered. Finally, some feeling for the relative importance of all the enumerated goals must be established. At a minimum, the goals should be rank-ordered as to their importance.

Numerous group decision making methods have been devised to assist in forming a consensus from a group of individuals. Several have been field tested in the R&D project selection environment and the results have been reported in the literature. The references to these studies are provided in Table 5. An article by Salasin, et al. [S-1], compares the Nominal Group Technique (NGT) and the Delphi method with respect to the amount and quality of the data, cost, and the participant's satisfaction with the process. Souder [S-6] reports the test of the Q-Sorting/Nominal-Group Process in two R&D organizations.

These group techniques should be used with a committee of all the key individuals involved in the R&D process. The composition of this committee will vary greatly according to the size, structure, and type of organization. The committee could range from a meeting of the company president and the R&D manager to a committee composed of 20 to 30 individuals from various components of the organization. Further discussion of these organizational

TABLE 5: Group Decision Making Techniques and Applications in R&D.

Ref.	Author(s)	Date	Description
D-1	Davies & Pearson	1980	Example and advantages of using group decision making/selection model combinations.
D-3	DeSanctis & Gallupe	1987	Future directions and design factors for group decision support systems.
H-2	Hwang & Lin	1987	Comprehensive and detailed review of group decision making under multiple criteria.
K-2	Khorramshagfol & Gousty	1986	Delphic Goal Programming method is proposed.
P-2	Plebani & Jain	1981	A Simple Additive Weighting model using NGT and Delphi is presented.
S-1	Salasin, Entingh, & Thackston	1981	NGT and Delphi are compared on several criteria.
S-5	Souder	1977	Nominal, interacting, and combined nominal-interacting are compared for integrating R&D and marketing.
S-6	Souder	1975	Tests a Q-Sorting/Nominal Group Process in two organizations.
S-10	Souder	1978	Integrates a Q-Sorting/Nominal-Interacting process into a total project selection system.
S-15	Stahl & Harrell	1983	Behavioral Decision Theory is applied to identify operative goals in an Air Force R&D lab.
V-1	Van DeVen & Delbecq	1974	Comparison of NGT, Delphi, and interacting groups.

factors can be found in Chapter Six.

Once the organizational goals have been established and recorded, the committee must decide on a classification scheme for their unique set of R&D projects. There are several reasons why R&D projects should be classified before any selection decisions are made. First, by grouping together projects that share a number of important characteristics, better comparisons can be made between projects. Second, by allocating a certain proportion of the total R&D budget to the various classes of projects, the organization can insure a more "balanced" portfolio of R&D projects. A more detailed discussion of the classification of R&D projects will be presented in the next section.

The committee may then determine the specific fractions of the forecasted R&D budget to be allocated to the different classes of projects. These non-binding guide-lines, will help the committee develop a more balanced R&D portfolio in Phase IV of the selection system.

As already noted, the classification of R&D projects can assist an organization in pursuing a balanced R&D effort. More importantly, the classification of R&D projects is necessary for the effective application of most R&D project selection methods. These models cannot incorporate the diverse characteristics of all types of R&D projects. By classifying projects, some of the differences between projects are removed and more realistic comparisons can be made.

Phase II: Classify Projects

Every time an organization is faced with an R&D project selection decision, the decision makers are faced with a set of alternatives including a vast mix of various types of projects. These projects vary greatly in the amount of uncertainty involved and even the criteria for the measuring the success of each project. Since the direct comparison of all these R&D projects is impossible, most selection methods are designed to deal with only a single project type--often development projects. The classification of projects into similar project types will reduce the number of differences between projects and these methods can be applied within the confines for which they were designed.

Of course, the classification scheme used to make allocations in Phase I should be the same scheme used for project selection. For example, if the coordinating committee feels it needs to insure a balance of projects according to the market to which the project is targeted, this classification scheme should also be used for project selection.

The classification scheme selected by the committee and used in the allocation of the R&D budget is based on a characteristic of the projects which is considered to be uniquely important to the organization. This project characteristic might be the level of risk of various projects, the newness to the firm, the use of key resources, completion time, etc. Since this project characteristic has been defined as being important to the organization, it is only appropriate to use this same classification scheme for project selection. The result is that only projects which share this crucial characteristic will be compared directly [D-1].

Many organizations place significant emphasis on retaining a "balanced" R&D effort. The purpose of this balancing is to spread the risk of project failure over several types of R&D projects, i.e. to diversify. For example, an organization may desire to allocate a fixed percent of total R&D expenditures to basic research versus applied and development efforts. Companies may also want to spread their effort over projects involving existing products and processes versus new lines of business. Other committees may want to balance completion times, new vs. existing markets, risks, long-run vs. short-run profits, or the utilization of key resources. The selection of an appropriate classification scheme is the topic of Chapter Five.

Some typical classification schemes for research and development projects include: 1) stages of the project's life cycle, 2) new versus existing business, 3) product versus process, and various combinations of these schemes. These above schemes are frequently used and are the focus of Chapter Five.

Phase II divided the mix of R&D projects into classes according to the goals of the organization and the unique characteristics of the alternative projects. This step groups projects together that can be evaluated using one of the available R&D project selection methods. The third phase of the process is to use one of these methods to choose among or rank the projects in each class.

Phase III: Choose/Rank Projects Within Each Class

The first two phases of the project selection system have established the organizational goals (and therefore the project selection criteria) and classified the alternatives into groups of comparable projects. These two important steps have provided the necessary preparation for the appropriate use of many of the currently available R&D project selection methods. These preparatory steps, are necessary to conform to the restrictions of selection models and to insure the appropriateness of the results to the organization.

Many journal articles and books have reviewed a number of the R&D project selection methods presented in the literature and have analyzed the strengths, weaknesses, and applications of each. Table 6 presents some of the more comprehensive discussions in this area. A review of several of these articles and books will quickly introduce the decision maker to the range of models available and the characteristics of each.

Selecting the correct selection method or model is an important and difficult decision. No one method is appropriate for all cases. Some of the factors to be considered when choosing a model include: the nature of the selection criteria, the certainty in the estimates of the probabilities of success and expected returns, and the class of projects being evaluated.

Some models require quantitative data for the measurement of the selection criteria. Other models have the ability to analyze more subjective data such as subjective ratings (say on a arbitrary scale from 1 to 10). Scoring and checklist models are simple models to use with subjective ratings data, especially since the criteria and the relative weight among the criteria have already been determined in Phase I. If only expected return is to be considered, simple decision theory/expected value models can be used.

Most risk analysis and frontier models require a range of estimates of the probability of technical and/or commercial success and the expected return of each project. If this information is obtainable and risk is the main

TABLE 6: Reviews of R&D Project Selection Models.

Ref.	Author(s)	Date	Description
A-2	Augood	1973	Reviews checklists and indices.
B-2	Baker & Freeland	1975	Discusses benefit measurement & resource allocation models.
B-3	Baker & Pound	1964	Well-quoted review of 10 models and detailed analysis of 3 representative models.
B-6	Balderston	1984	Book: gives strengths & weaknesses of 2 types of models.
B-9	Booker & Bryson	1985	A recent and complete review of most types of models.
C-1	Cetron, Martino, & Roepcke	1967	Well-quoted, descriptive review of 30 models.
C-3	Clarke	1974	Literature survey from 1967-73 on the actual use of models.
D-2	Dean & Nishry	1965	Comparison of scoring and profitability models.
J-1	Jackson	1983	Descriptions & examples of most types of models.
O-1	Office of Technology Assessment	1986	Broad OTA study on government & industry research evaluation.
S-7	Souder	1984	Book: brief discussion of most types of models.
S-8	Souder	1972	26 models compared for ease of use, realism, flexibility, capability, and cost.
S-10	Souder	1978	Describes & gives examples for 8 types of models and recommends when they should be used.
S-14	Souder & Mandakovic	1986	Recent discussion of historical evolution of R&D selection methodology and models.

criterion for selection, the problem should be solved using one of these models. Conversely, if the projects have been classified by the level of risk, each project within the class will have a similar risk profile and other criteria should be considered. Single estimates of the probability of success can be incorporated into scoring, index, and decision theory models.

Clearly, the type of projects being evaluated effects the type of models to be used. This is one of the main arguments for classifying the projects before selecting. Most of the differences in project types will be accounted for by the two factors previously discussed: the nature of the criteria and the certainty of the estimates of the probability of success and expected returns. These factors are greatly determined by the project type.

For example, say the projects were classified into basic research, applied research, and development projects. The basic research projects would be characterized by subjective data and great uncertainty in the estimates of the probability of success and expected returns. Only simple models with very limited data requirements could be used here. Some quantitative data is typically available for a project in the applied research stage yet the goals are still non-quantitative. The use of a risk analysis or scoring model may be appropriate. Finally, development projects are typically evaluated on strictly economic criteria since the costs and potential returns are reasonably well known. An expected return or mathematical programming method could be used.

If allocations were established for each class of projects in Phase I, these allocations could be modeled as budget constraints within each class. The best projects would be chosen subject to the amount budgeted to the particular class. The limitation of the budget for each class could limit the number of projects to be considered and, therefore, simplify the selection process. The use of this constraint could also evoke the discussion of possible trade-offs between projects within each class which could be valuable information for the coordinating committee in establishing the overall portfolio in Phase IV.

Once the projects in each class have been selected or ranked, this information is passed back up to the coordinating committee. This committee meets again to establish the final R&D portfolio. A group decision making technique must be integrated with an appropriate portfolio model to arrive at a consensus optimum solution.

Phase IV: Pool Projects and Select Portfolio

The final phase of the project selection system is the selection of the organization's R&D portfolio. In many aspects, an R&D portfolio is much like a financial portfolio. The correct components of the portfolio must be combined in order to maximize the return and minimize the risk to the organization. While a balanced (diversified) financial portfolio reduces the risk of the investment, a properly balanced R&D portfolio will also reduce the risk of project failure to the organization.

All the information from the evaluations conducted in the first three phases of the system are designed to provide all the necessary input for the selection of an optimum R&D portfolio. The allocations made in Phase I and selection decisions made in Phase III can be accepted as given or modified by the committee. Strictly speaking, if the allocations for each class were filled by the best projects in each class, the "optimum" portfolio would already have been determined. Most likely, though, some changes will be made in both the allocations and the selection decisions within each class to maximize the total return on the portfolio (in the opinion of the committee).

Again, it will be necessary to structure the discussion using some group decision making technique. (See Table 5.) Much information will be available to the committee including its own set of goals and possible allocations of the budget among the various classes of projects and the project selection decisions for each class of projects. In order to structure and stimulate the discussion, a portfolio selection method should be formulated to compile a suggested portfolio.

The use of a portfolio selection model will give the decision makers an analytical tool for making trade-offs between alternative projects and funding levels. The model can be used to answer many "what if" types of questions such as: "What if we increase the funding for project A and decrease the funding for project B?" This type of sensitivity analysis can be performed iteratively until the committee comes to a consensus on an "optimum" portfolio.

Table 7 lists references for reviews of different types of portfolio selection models. Typically portfolio models are mathematical programming models, such as goal programming. The characteristic that separates these models from other selection models is the existence of definite budget and other resource constraints that help the decision maker analyze how an increase/decrease in the resources allocated to one project will affect other projects. The first three steps of the selection system--the establishment of goal statements and a classification scheme and the choosing/ranking of projects within each class--have been designed to provide the necessary input data for formulating such a model. Therefore, greatly simplifying the modeling process.

A few applications of this combination of a portfolio model and a group decision making technique have been tested and the results have been encouraging [S-12][C-5][B-8]. The

TABLE 7: Reviews of R&D Portfolio Selection Models.

Ref.	Author(s)	Date	Description
B-8	Booker & Bryson	1985	A recent and complete review of most portfolio models.
C-1	Cetron, Martino, & Roepcke	1967	Well-quoted, descriptive review of 30 models.
G-1	Gear	1974	A good discussion of practical & theoretical weaknesses of several portfolio models.
G-2	Gear, Lockett & Pearson	1971	A thorough discussion of 9 specific portfolio models.
J-2	Jackson	1983	Discussion of adv./disadv. of major classes of portfolio models.
M-1	Madey & Dean	1985	Proposes and solves a mathematical programming model for an aerospace firm.
S-4	Souder	1973	4 mathematical programming models are compared using data from 30 actual R&D projects.
S-11	Souder	1973	3 expected value models are compared for analytical utility and managerial acceptability.

basis of the Souder model described earlier was the integration of a Q-Sorting/Nominal-Interacting process with various selection models including portfolio selection models [S-10]. Another well-quoted article by Souder solicited the necessary input information for a dynamic programming algorithm through polling and interviews [S-9].

A relatively novel combination of a group decision making technique and a multiple objective goal programming model was proposed by Khorramshahgol, et al. [K-2] in 1986. The Delphi technique was used to provide the objectives, the priorities among objectives, the desired level of attainment for each objective (thus transforming it into a goal), and the penalty weights for the under- or over-attainment of each goal. This information was used to formulate a linear goal programming model which was solved for the optimum portfolio.

The use of a mathematical programming portfolio selection model as the sole and final selection instrument has been shown to be an unacceptable option for most managers. Most managers do not understand the complex mathematics behind the model and consequently will not blindly accept the solutions. Therefore, by using the model to stimulate the decision making process of the committee, the model is able to provide valuable analytical support in a manner that is acceptable to most managers.

The result of this final phase is the organization's research and development portfolio. By soliciting the input of the key individuals and groups within the organization, all the relevant evaluative information has been utilized and digested in the selection process. Additionally, and possibly more importantly, the decision process has served to provide long-term benefits to the organization in terms of improved communication, cooperation, and motivation.

An Example Application

The proposed R&D project selection system will now be applied to a hypothetical example of selecting research and development projects for the Strategic Defense Initiative, better known as Star Wars. This example will demonstrate how the system must be adapted to the specific organization and to the unique set of R&D projects under consideration.

Referring back to Figure 4, the four phases of the selection system are as follows: I) establish organizational goals, II) classify projects, III) choose or rank projects within each class, and IV) pool the projects and select a portfolio. Phases I and IV are implemented by the selection committee and, therefore, use a group decision making technique while Phases II and III are implemented by the individual R&D units or managers.

The first step is to choose a group decision making technique and to establish the goals of the organization.

If all of the members of the selection committee can be brought together into one room, a Nominal-Interacting group technique could be used. Otherwise, if the members are geographically disperse, a Delphi Survey would be more appropriate. The committee would work towards statements of the goals of the organization such as the following:

1. Produce politically rewarding results by November, 1988, in order to insure future funding.

2. Establish the feasibility of the system by 1990.

3. Develop a working system by 2010.

4. Balance project completion times to eliminate technical bottle-necks.

The second phase involves classifying projects according to an appropriate classification scheme. Therefore, the committee must first decide how the projects should be classified. An obvious possibility would be to classify projects according to their expected completion times. From the goal statements, it is clear that the committee is integrally concerned with completion times. Projects could be divided which have completion times as follows:

< 2 yrs.	3-5 yrs.	6-10 yrs.	11-17 yrs.	> 18 yrs.
* satellite decoys	* simulated model	* laser power source	* radar systems	* satellite shields
* new plastics	* satellite design	* new metal alloys	* laser control system	* C^3I systems

The third phase of the selection system is to choose or rank projects within each class. Since the projects have been classified according to expected completion time, there are certain differences between the classes of projects that must be considered in choosing an appropriate project selection model.

For those projects which are expected to be completed in the next, say, 5 years, more data will be available with much less uncertainty. Better estimates of factors such as costs, required resources, probabilities of success, and actual completion times will be available for these projects. Therefore, a more in-depth analysis, such as risk analysis, is possible and should be used for the selection of projects within these classes. As the projects' completion times extend further into the future, more of the data available on the projects is of a qualitative rather than quantitative nature. Much of the available evaluative information will be in the form of subjective ratings on important criteria. Therefore, models that can use this type of data, such as scoring models, should be applied for the intermediate-range projects. For those projects with expected completion time greater than 18 years, a simple checklist comparison may be most appropriate.

The fourth and final phase is to pool the projects and select a portfolio. The selection committee is regrouped and the same group decision making technique is applied as was used in Phase I. A model such as Linear Goal Programming could be formulated using mathematical representations of the four goals described in Phase I. The attainment of these goals could be optimized subject to alternative budget constraints and alternative funding levels. The model would allow the decision makers to analyze the impact of not only changes in which projects are included in the portfolio, but in changes in the funding levels in future budgeting periods. The sensitivity analysis would continue until the committee could agree on a set of projects.

This example demonstrates how the proposed system can be adapted to any organization by integrating the specific goals of the organization into the total selection process. Additionally, the selection of an appropriate classification scheme according to the organizational goals insures that the project selection process is implemented in a manner consistent with those goals.

From the example above, it is evident that in order to effectively utilize this project selection system, a reasonable classification scheme must be determined for the specific organization and the characteristics of the mix of projects under evaluation. Although there are an infinite number of possible classification schemes, a few schemes have dominated the literature. These schemes will be discussed in detail in the following chapter.

CHAPTER FIVE:

CLASSIFICATION SCHEMES

The diversity of the research and development projects being considered by any organization at any one point in time causes decision makers to directly compare projects that have only a few common characteristics. The mix of projects depends not only upon the organization, but each organization will face a completely different mix every time a project selection decision is made. This diversity of alternative projects greatly complicates the selection process to a point of unmanageability.

This problem can be simplified if some of the major differences between projects are eliminated before evaluative comparisons are made. This is accomplished by grouping the projects into like groups, i.e. classifying the projects. All the projects in each class will share enough characteristics that they can be realistically compared. The selection process is, therefore, simplified to allow for the more practical application of R&D selection methods.

The second advantage of classifying projects is helping to insure a balanced R&D portfolio for the organization. By classifying projects according to the strategic goals of the organization, it can be assured that each strategic class of projects is represented in the organization's final portfolio of R&D projects. The end effect is a more "balanced" R&D portfolio.

Since each organization will classify projects according to its own set of strategic goals, the number of classification schemes is just as great as the number of unique sets of organizational goals. The Industrial Research Institute made a similar conclusion in a study on basic research conducted for the National Science Foundation [N-2]:

> The manner in which each firm categorized its R&D activity was typically tailored to their own organizational structure and function. In addition, in only one industry--aerospace--did the investigators find any two firms with the same generic categories. However, given this diversity of descriptors, could any set of categories achieve industrial acceptance? Probably not.

Therefore, no <u>one</u> set of categories will be proposed or recommended for use by all organizations. Each organization must, after establishing its own unique statements of its goals, decide on an appropriate classification scheme.

The following sections will discuss several common classification schemes for research and development projects. Almost all discussions in literature in this area that refer to the classification of projects use one of the following schemes.

The Industrial Research Institute, in an attempt to devise a universally acceptable classification scheme, considered classifying R&D projects by how the work is done (fundamental, basic, applied), by where it is done (central labs, divisional outposts, semi-works, bench), by whether the research is product or process oriented, or by why the work is done (exploratory, high risk business development, support of existing business) [G-3]. The how, why, and product/process schemes are discussed in the following sections. The question of where the work is done will be taken up in the following chapter on organizational factors.

Life Cycle Stage

By definition, the term "research and development" suggests a differentiation between projects according to their life cycle stage--from research to development. Many obvious, and some not so obvious, changes take place in the evaluative information and criteria as a project progresses from an idea to an actual product or process. Liberatore and Titus [L-4] suggest some of these changes that take place in the evaluation of R&D projects as they progress from "R" to "D":

> Therefore, the organizational context in which R&D resource allocation occurs must be considered by management scientists in the development of appropriate methods. For example, the availability and reliability of data, the level of detail for the statement of project goals, the time horizon for project activity, the criteria for successful project completion and the structure of the R&D and supporting groups, among other

factors, are quite different in "R" and "D" environments.

Divisions based on the different stages of the project's life are the most commonly used in literature. This transition from "R" to "D", though, is not a discrete process with well-accepted and divisible stages. Rather, the process is continuous with each author or organization having a different opinion on the number and definition of the intervening stages.

For example, Baker [B-5] summarizes a project's life into the following stages: research, development, engineering, and manufacturing. Ansoff [A-1], in an analysis of applied projects, suggests three divisions of R&D projects: basic, applied, and product development. Finally, Balderston [B-6] proposes more detailed classes: basic research, applied research/exploratory development, advanced development, engineering development, production engineering, and product or service projects. Each of these divisions differ with respect to the level of the following attributes: internal scope, external relatedness, need for integration, state of the art, team experience, and the need for flexibility.

Several papers have concentrated on describing the differences between projects in various life cycle stages. Nason [N-1] in his paper, "Distinctions between Basic and Applied in Industrial Research," summarizes the results of three studies in this area [N-2][F-2][P-1]. More recently, Leifer and Triscari [L-1] compared the aspects of managing research versus development projects.

Easily the most notable use of this classification scheme is by the National Science Foundation (NSF). The NSF proposes dividing projects among basic research, applied research, and development. These categories are defined as follows [N-2]:

> Basic Research: Original investigations for the advancement of scientific knowledge not having specific commercial objectives, although such investigations may be in fields of present or potential interest to the reporting company.
>
> Applied Research: Investigation directed to the discovery of new scientific knowledge having specific commercial objectives with respect to products or processes. This definition differs from that of basic research chiefly in terms of the objectives of the reporting company.
>
> Development: Investigations which represent technical activity concerned with non-routine problems which are encountered in translating research findings or other general scientific knowledge into products or processes.

These categories and definitions are used by companies in reporting research and development expenditures. The Industrial Research Institute (IRI) confirms that most organizations use these categories for external reporting but use their own categories for internal reporting [N-2].

The same 1978 study reports the percent of expenditures allocated to each of these categories as follows:

	I.R.I. Study	N.S.F. Estimate
Basic Research	5.3%	3.7%
Applied Research	28.6%	22.0%
Development	66.1%	74.3%

Expenditures for research and development in these three areas is also reported by industry. Clearly, expenditures for development projects dominate the total R&D expenditures while basic research projects make up only a small fraction of the typical R&D portfolio.

Thus far, only the changing nature of R&D projects as they progress from basic research to commercial production has been proposed as a justification for dividing R&D projects by their life cycle stages. Ramsey [R-1] suggests an additional aspect of a projects life cycle that supports this classification scheme. Ramsey's new product process stage model is presented in Figure 5. In addition to the division of the life cycle into 6 stages, Ramsey proposes 4 decisions related to the evaluation of projects as they progress from idea generation to market introduction.

Decision I is concerned with the screening of ideas to pick the ones for which to perform a business analysis. The second decision (II) involves choosing projects for technical development. Decision III reviews the projects from decision II to determine if the project should be continued. Finally, the purpose of decision IV is to review

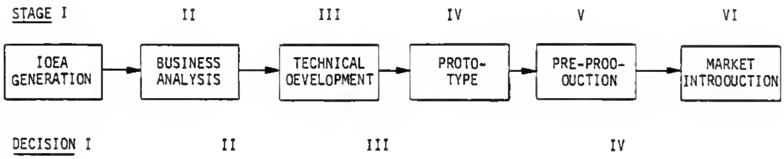

FIGURE 5: Ramsey's Decision Stages. [R-1]

the projects before commercialization to determine if any projects should be terminated to minimize losses.

The division of a project into the stages of its life cycle can help an organization in the analysis of the feasibility of continuing work on the project. It is not necessary to use the exact divisions proposed by Ramsey in order to identify the key decision stages of an R&D project. These decision stages could be identified on any alternative division of the stages of the project's life cycle depending on the evaluation process of the particular organization.

Most authors, when they introduce or review R&D project selection models, suggest the type of projects for which the models are most suited. This concern over the applicability of any certain model is justified by the many unique characteristics of the projects at different stages of development. A summary of some of these changing characteristics would include changes in the amount and certainty of evaluative information, the goals of the project, the time horizon for completion, and the structure of the R&D group.

The Industrial Research Institute [N-2] stressed the importance of separating basic research projects from other projects for selection purposes. Their study showed that return on investment (ROI) methods are increasingly being used in industry. "The extent of 'quantification,' in an ROI rather than mathematical programming sense, in private sector R&D management has essentially placed basic research efforts in direct competition with development efforts--but this game is played with rules which, by definition, favor development."

Both Souder [S-8][S-10] and Krawiec [K-3] suggest different models for use in evaluating projects during the stages of the project's life. Cetron et al. [C-1] reviewed 30 models in 1967 and rated each on its applicability to projects in the research, exploratory development, advanced development, and engineering development stages. Baker and Pound [B-3] evaluated the use of three representative models (scoring, expected value, and dynamic programming) for the selection of basic research, applied research, and development projects. Moore and Baker [M-6] recommend a scoring model for research and exploratory development, economic or constrained optimization for advanced and engineering development, and risk analysis for new product decisions.

Although the classification of R&D projects by the stages of the project life cycle is most often used in literature, there has more recently been a trend toward classifying projects by their business objective. The Industrial Research Institute has been instrumental in changing the thinking of many researchers toward this classification scheme. The following section will discuss this so-called "business classification."

New vs. Existing Business

The approach of any decision maker toward any decision is based upon his/her past experience and knowledge in the area of the question at hand. Clearly, if the decision maker has no past experience with a certain project, a higher level of risk is involved in the evaluation of that project. On the other hand, if the project is concerned with a simple extension of existing operations, the decision maker will be in a better position to estimate the outcome of the project. For these reasons, projects are often classified by the "newness" of the project to the organization.

This classification scheme is often referred to as classification by the objective of the project. This scheme is largely based on the different levels of information available to the decision maker. Without the experience and historical data on which to base forecasts, estimates of the probability of technical and commercial success, time to completion, and expected costs and revenues will contain much more uncertainty. All of these estimates are important inputs into any project selection model.

The Industrial Research Institute (IRI) is a group of approximately 250 industrial firms designed to collect data and perform research on the industrial research activities of its members. The group has struggled with this classification scheme throughout the 1970s and 1980s. In 1971, IRI rejected all other classification schemes in favor of classifying R&D by the objective of the work (why it is done) [G-3]. The three divisions identified by IRI were as follows:

<u>Exploratory Research</u>:

For advancing knowledge of phenomena of general company interest

For finding major new high risk business developments

<u>High Risk Business Development</u>:

Specific major programs aimed at new businesses or other developments of potentially high impact, and which involve higher-than-normal risk

<u>Support of Existing Business</u>:

For maintaining or improving the profitability of established business

Two of the common characteristics of exploratory research projects are: 1) the responsibility for the selection of projects lies within the R&D department; and 2) the selection process tends to be simple, unsophisticated, and qualitative in nature.

Projects classified as supporting existing business usually involve cost-reduction or manufacturing process efforts or the development of products to round out the current product line. The selection of such projects is characterized by the availability of much quantitative data that is used in simple economic projections.

The level of decision making and the risk involved are two of the prominent characteristics of high risk business development projects. Since these projects imply a new direction for the organization, it is not uncommon for such decisions to be made at very high levels in the hierarchy of the organization. Although a few more sophisticated selection methods are used here, standard economic projections are still the norm. Clearly, the risks associated with these projects is much higher than for the previous two categories.

In 1978, IRI modified their classification scheme to include both the business objective and the life cycle stage of each project. This matrix classification scheme will be discussed in the "Combinations" section below. IRI also divided the "support of existing business" category into "maintenance or modifications" and "major products and/or new techniques" and redefined the category "high risk business development" as "diversification" [I-1].

Currently, the Institute uses similar classifications in an annual survey of its members on the changes in the funding levels for 3 categories of R&D (as well as other statistics on R&D). The classifications currently used are as follows:

1) Support of Existing Business

2) Directed Basic Research

3) New Business Projects

The 1987 survey reported that a number of members planned to increase their support for projects dealing with new business projects. The other two categories of R&D were less assured of receiving more support [M-7].

The lack of information available to evaluate new business projects increases the risk to the organization of adopting these projects. This factor accounts for most of the differences cited among projects with different business objectives. Gee [G-3] reports the conclusions made by the 1971 IRI committee on the differences between projects with different business objectives as do several other authors [C-3][B-10]. Keefer [K-1] proposes a similar classification scheme and outlines a rating scale for various criteria associated with each class of projects.

Although, like the stages of the project life cycle, the business objectives of various projects can be described and divided an endless number of ways, the business classification schemes usually share two common characteristics. First, a category for basic, fundamental, or exploratory research is separated from the other categories. Secondly, a clear distinction is made between projects that are concerned with improving or expanding existing products or processes versus those projects concerned with diversifying into new business lines.

Clearly, this classification scheme would not be appropriate for certain types of organizations such as government agencies, non-profit organizations, and educational institutions.

After life cycle stage and business objective, the next most popular classification scheme in literature is the one that separates projects that involve the development of new products from those concerned with new processes. As will be discussed in the next section, these differences between these two types of projects can often be limited to the extent to which outside factors effect the success of the project.

Product vs. Process

The distinction between product and process R&D efforts seem to be one of the first classification schemes to be proposed. More recently, this distinction is often made only as a sub-classification for another classification scheme. A few of these combination schemes will be discussed later in this chapter.

Often the division between projects on the basis of whether they involve products or processes is not interpreted literally. Sometimes what is implied by this distinction is similar to the business objective scheme proposed above. Under this interpretation, "product-oriented" projects are those involving marketable products to be offered to the customers of the organization. "Process-oriented" projects are those concerned with the manufacturing or other organizational processes, i.e. cost-reduction efforts.

The main difference between projects under these definitions is the extent to which factors outside the organization (competition, demand for products, etc.) affect the project. For example, cost-reduction efforts can be undertaken without any analysis of the business environment whereas such an analysis is vital to the success of the so-called "product-oriented" project.

A 1978 survey by IRI on successful innovations [F-2] provided some insights into the appropriateness of this classification scheme. The survey respondents were asked to classify their "successful innovation" as concerned with a product, a process, or both. Fifty-nine percent of the projects were classified as dealing with products and 19% were processes. The interesting result was the response of 22% of those surveyed who reported that their projects dealt with both products and processes. Additionally, one innovation was labeled as a "service".

These results cast some doubt on the practicality of this classification scheme. First of all, since 22% of the projects were both products and processes, these classes are not mutually exclusive. Similar to both of the schemes discussed above, the divisions between the classes are again continuous, not discrete. Secondly, the possibility that R&D projects are solely concerned with the development of new services introduces another weakness of this scheme. Perhaps a third category for services should be included to account for this increasingly important area of research in our economy.

The advantage to this classification scheme is the separation of "process" projects for which only factors internal to the organization must be included in the selection model. The evaluation and selection of these projects would be greatly simplified. Whaley and Williams [W-1] discuss the basic differences between product and process-oriented projects. Disman [D-4] proposes selecting projects according to a return on investment (ROI) model; a different model for products and processes. The IRI Research on Research Committee has recommended possible criteria for research, product development, and process development. These recommendations are reported by Becker [B-7].

As discussed earlier, there are several key weaknesses in the product/process classification scheme. In fact, any attempt to classify the diversity of R&D projects into a finite number of categories will never be complete. All three of the proposed classification schemes discussed thus far (those most cited in literature) tend to be both subjectively defined and often incomplete in coverage. To overcome this problem, some authors have proposed classification schemes based on a combination of two of the above schemes. Several of these schemes will be presented, including a well-documented matrix by the Industrial Research Institute.

Combinations

Certain authors have proposed using not one of the above classification schemes, but combining two of them in order to more narrowly define the categories of research and development. These more detailed classification schemes may be necessary for a detailed analysis of the overall R&D effort on an organizational scale, or when the number of alternative projects is so large that 3 to 4 categories will not divide the pool of projects into groups of manageable size. The IRI has proposed such a combination in a matrix form that combines the stages of R&D with the business objective of the projects.

Liberatore [L-3] proposed a unique approach to classifying projects in his paper on the analytical hierarchy process (AHP). The typical classification of product vs. process vs. exploratory are modeled as one level of a hierarchy while another level of the hierarchy contained the business objectives: maintenance vs. expansion vs. diversification. All possible combinations of the two sets of categories are diagrammed.

Becker [B-7] reports the classification scheme devised by the IRI Research on Research Committee in 1980 which combines a business objective classification divided among product and process efforts as follows:

Research
Product Development--Maintaining Business
Process Development--Maintaining Business
Major Product Modification--Business Expansion
Major Process Modification--Business Expansion
Product Development--New Business
Process Development--New Business

Except for the lone category of "Research", this scheme could easily be modeled as a 2 X 3 matrix with Product and Process efforts on one axis and the three business objectives (Maintaining Business, Business Expansion, and New Business) on the other axis.

The IRI in 1978 published a report entitled "Definitions of Research and Development" [I-1]. This report outlined another matrix combining the business objectives with what it calls the "R&D Dimensions." See Figure 6. The latter set of categories included research, development, and technical service. The Institute defined these terms as follows:

> <u>Research</u> is planned search or critical investigation aimed at discovery of new knowledge with

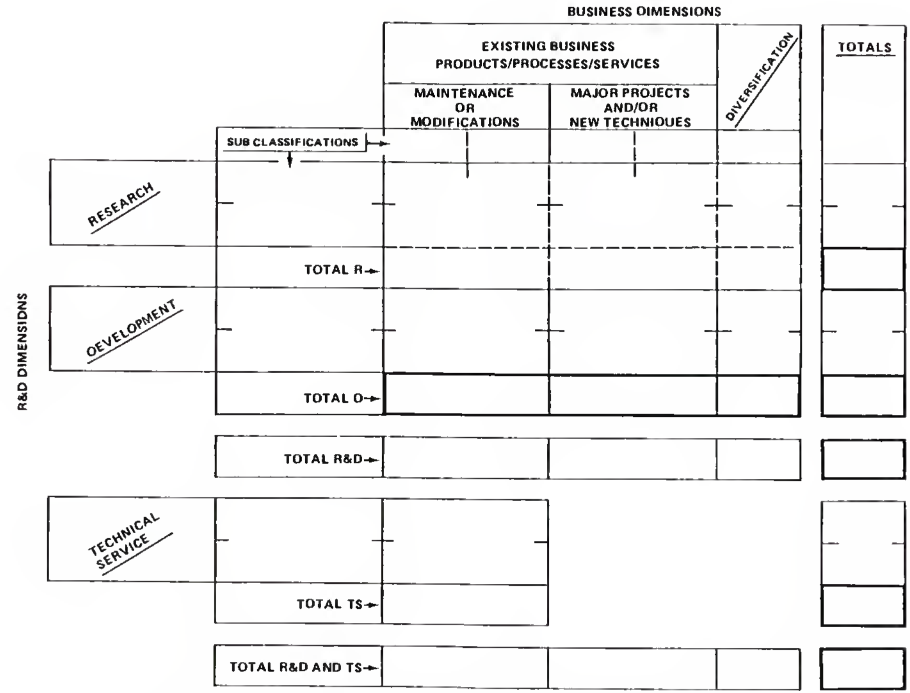

FIGURE 6: IRI Definition of R&D. [I-1]

the objective that such knowledge will be useful in developing new products/processes/services, or in bringing about a significant improvement to existing products/processes/services.

Development is the translation of research findings or other knowledge into a plan or design for new, modified, or improved products/processes/services whether intended for sale or use. It includes the conceptual formulation, design, and testing of product/process/service alternatives; the construction of prototypes; and the operation of initial, scaled-down systems or pilot plants. It does not include routine or periodic alterations to existing products, production lines, manufacturing processes, service, and other on-going operations even though those alterations may represent improvements.

Technical Service is work performed by R&D personnel (usually requested by other areas of the company, such as manufacturing, marketing, or corporate management). It involves the application of existing technology to company problems in the existing business.

The business dimensions, Existing Business and Diversification, are listed on the top of the figure. The Existing Business is further divided into Maintenance or Modifications and Major Products and/or New Techniques.

The matrix has numerous features which are designed to help organizations in defining their R&D projects. Notice that the technical service category falls only under the Maintenance or Modification column. According to the definition of technical service, this work involves only improvements in the existing operations of the business. The dotted line separating the business dimensions in the research row indicates that some research will not have a defined commercial purpose at the outset. Therefore, the division of research efforts between existing and new business may not be discernible. Additionally, the research and development rows contain slashes to allow the addition of sub-classifications as desired. Finally, the heavy boxes represent totals that IRI suggest should be used by all companies as a tool for analyzing R&D expenditures and budgets.

This matrix is possibly the most complete classification scheme proposed in literature. By combining the two most used classification schemes and clearly defining each of the categories used, the scheme could promote some level of uniformity among IRI-member organizations. Yet, with the allowance for each individual firm to use its own sub-classifications and totals in the matrix, the scheme becomes a tool for a firm in defining the classification scheme that best fits its own particular needs.

Recommendations

From the multitude of possible R&D project classification schemes, the three most used schemes, as well as some possible combinations of the three, have been presented and discussed in this chapter. None of these schemes are going to earn the acceptance of all R&D-performing organizations or even a majority of them. Each has its own advantages and disadvantages. Each may be best suited for applications other than project selection. These schemes should be used as a base point from which organizations can decide upon an appropriate classification scheme for their own organization and set of R&D alternatives.

Although the research and development process is continuous, it is common among practitioners to break up this process into a finite number of stages. Even the division between research and development is such a classification. The many changing aspects of projects as they progress through these stages--however they are defined--make the classification of projects by stage a natural one. The changes in projects as they develop include the availability and certainty of input data, the goals for successful completion of the project, the time horizon for completion, and the structure of the R&D and supporting groups.

The classification of projects according to their business objectives (new vs. existing business) is based upon differences in the experience of the decision makers between projects concerned with new versus existing businesses. The degree of risk associated with new business efforts must also be considered when modeling selection decisions. This scheme will have no relevance to many public and non-profit organizations.

The IRI matrix is clearly the most complete and best defined classification scheme presented in literature. It combines the two most popular schemes in a logical, practical manner. Yet, IRI recommends that at least seven categories be used by all companies. Unless an organization feels a need for this level of detail, the increase in the number of categories will proportionately increase the amount of work involved in project selection. This increased workload will come without any significant additional benefits. It is important to remember that the IRI matrix was designed for reporting and analyzing R&D expenditures, not for project selection purposes. A somewhat simpler scheme probably would be preferable for the purpose of project selection.

The classification schemes presented in this chapter should be seriously considered when choosing from the endless number of possible schemes for several reasons. First, these schemes have been most commonly proposed in the literature and most used in practice. Secondly, model makers will find that much more information is available on the applicability of selection models with respect to these classification schemes than any others.

It cannot be over-emphasized that the classification scheme used by each organization must be designed to best aid the decision makers in reaching the goals for their specific organization. When choosing a "best" classification scheme for a particular organization, the committee must consider the set of alternative projects, the structure of the R&D unit(s), and how the classification scheme can help the organization best "balance" its R&D effort in terms of its strategic goals.

Some of the typical differences in the approaches of the various organizations that perform R&D is the topic of Chapter Six. The type, structure, and size of the organization will all impact the manner in which the overall proposed selection process is implemented.

CHAPTER SIX:
ORGANIZATIONAL FACTORS

The research and development project selection system proposed in Chapter Four is often defined in relatively indefinite terms. The reason for this design is to encourage different organizations to develop their own specific system to meet their own specific needs. An overly detailed system would only be helpful for a few specific organizations that happen to be faced with a selection decision like the one modeled. This chapter is designed to introduce a number of organizational factors that affect the way in which different organizations see the R&D project selection decision and, therefore, how they should apply the proposed R&D project selection system.

The first organizational factor is the type of organization. A governmental agency and a small research firm will approach the problem from completely different standpoints and, therefore, must adapt the system in different ways to make it work for them. Additionally, the structure and size of the organization have unique effects on the application of the proposed R&D project selection system.

Type of Organization

Although much of the literature has focused on the R&D project selection decisions facing large corporations or federal agencies, there are a number of different types of organizations that perform research and development. All of these types will face R&D project selection decisions but within dramatically different contexts.

Table 8 lists and briefly describes seven classes of organizations that do most of the research and development in the United States. The main difference between these types of organizations is the goal structure of the organization. For example, a significant difference is found between the profit-maximizing corporate R&D laboratories and government laboratories. The reliance on federal R&D expenditures is a significant aspect of the functioning of many of these organizations such as government laboratories, federal contract research centers, and educational institutions. Contract/customer relationships also play an important role in some types but are completely unrelated to others.

The political considerations inherent in any R&D organization dealing with the federal government often play a significant role in the R&D project selection process. The availability of funds in certain areas of research often dominate the selection process for an organization that

TABLE 8: Seven Types of R&D Organizations. [F-3]

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1) Government Laboratories: government owned facilities whose budgets and objectives are set by the federal government.

2) Federal Contract Research Centers: have a principal (although not necessarily exclusive) and continuing obligation to one sponsoring federal agency.

3) Not-for-Profit Institutions: publicly or privately owned; occupy a position midway between academic research and R&D as performed in a profit-making organization.

4) Independent Nonprofit Organization: truly independent nonprofit research organizations which are funded by private supporters and donations.

5) Corporate R&D Laboratories: for the purposes of supporting manufacturing and marketing operations; are funded largely from corporate profits; tend to be more applied, product-oriented.

6) Educational Institutions: tend to have more modest capital equipment investments but can perform certain kinds of fundamental R&D of high-quality and (generally) at less cost.

7) Private Profit-Making Institutions: purpose of making a profit on contract R&D; have advantage over educational institutions in that they devote their entire resources to R&D.

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relies on government funding. Government agencies must also consider the political funding process. The Office of Technology Assessment published a report in 1986 entitled, "Research Funding as an Investment: Can We Measure the Returns?" [O-1]. This study provides an excellent survey of the practice of R&D project selection and management in both the public and private sectors. Applications of R&D project selection techniques in government settings are also discussed by Brickman [B-9] and Cook and Seiford [C-6].

In addition to the concentration of literature on industry as a group, certain specific industries receive more attention than others. Typically, this concentration of interest is based on higher-than-normal expenditures on research and development for that industry. Most obviously, these industries stand to gain more by making better selection decisions. Additionally, some papers are written by employees or consultants in these industries who have tested selection methods and are reporting the results in literature.

An IRI survey in 1977 [N-0.3] reports the expenditures of about 40 industries on basic and applied research, and development. More recently, IRI reports the annual R&D expenditures as a percent of sales for selected industries each year in its Annual R&D Trends Survey [M-7.5]. More specifically, the pharmaceutical [F-1][B-7.5], petroleum [M-5], and chemical [W-4] industries have received special attention in the literature.

As noted before, these types of organizations differ mainly in their goal structures. Therefore, it is important that these differences are accounted for in the implementation of the proposed project selection system. During the first phase of the system, the organization will formulate the statements of its goals. It is important to note that these goals will then be incorporated into all three of the remaining phases of the selection system. Therefore, the proposed system automatically adapts to different types of organizations.

Even within each "type" of organization, the context in which the project selection decision takes place will vary. Many of these differences can be grouped into differences in the structure and the size of the organization.

Organizational Structure

In applying the proposed R&D project selection system, the structure of the organization will sometimes dictate the best way to implement the system. For example, the question of what groups are responsible for the evaluation of the different classes of projects is mainly a question of organizational structure. The classification scheme will often be dictated by the organization's structure. On the other hand, the functioning of the main committee should be reasonably independent of the organizational structure.

A good summary of possible views of the structure of organizations is presented by White [W-3]. White has identified four major types of organizational structures as follows:

1) discipline,
2) product/project,
3) stage/phase, or
4) matrix.

A discipline structure groups together the technical disciplines in order to create a so-called "center of excellence." These centers enjoy the scientific asset of collective genius but fail in respect to developing marketable projects since projects are often chosen solely on scientific criteria. Many corporations are organized in this way. For instance, a company may be divided into electronics, aerospace, and materials groups.

Product/project structures offer the advantage of combining necessary disciplines (scientists, engineers, marketers, etc.) together to insure a smooth transition of each project throughout the various phases of its life. An example of a product/project structure could be a corporation with automotive, computer, and helicopter divisions.

The stage/phase structure is designed to allow those scientists or engineers who are better skilled in a certain phase of the R&D process (basic, applied, development) to concentrate on this phase. This structure is more likely to be found in a research-oriented firm which has basic research, development, and manufacturing divisions. Baker and Sweeney [B-2] expand on the differences between what they call phase-dominated versus project-dominated organizational models. See Figure 7.

Finally, the matrix organizational structure is any combination of the above three structures. Most organizations would probably fall under this category since there are an endless number of structures that fall into this "matrix" category.

The implications for the application of the proposed project selection system are clear. If a discipline structure is used, classifying projects by discipline might be the obvious and best classification scheme to use. This would allow each of the discipline groups to evaluate the R&D projects in their specific areas. Not only is each group uniquely qualified to evaluate their own projects, but they are the ones with all the evaluative information to make such comparisons. Additionally, if the organization is structured by discipline, then this may be an indication that a balance of R&D projects by discipline may be a reasonable organizational goal. Similar arguments can be made for considering product/project or stage/phase classification schemes based on the structure of the organization.

Another difference in the organizational structure is

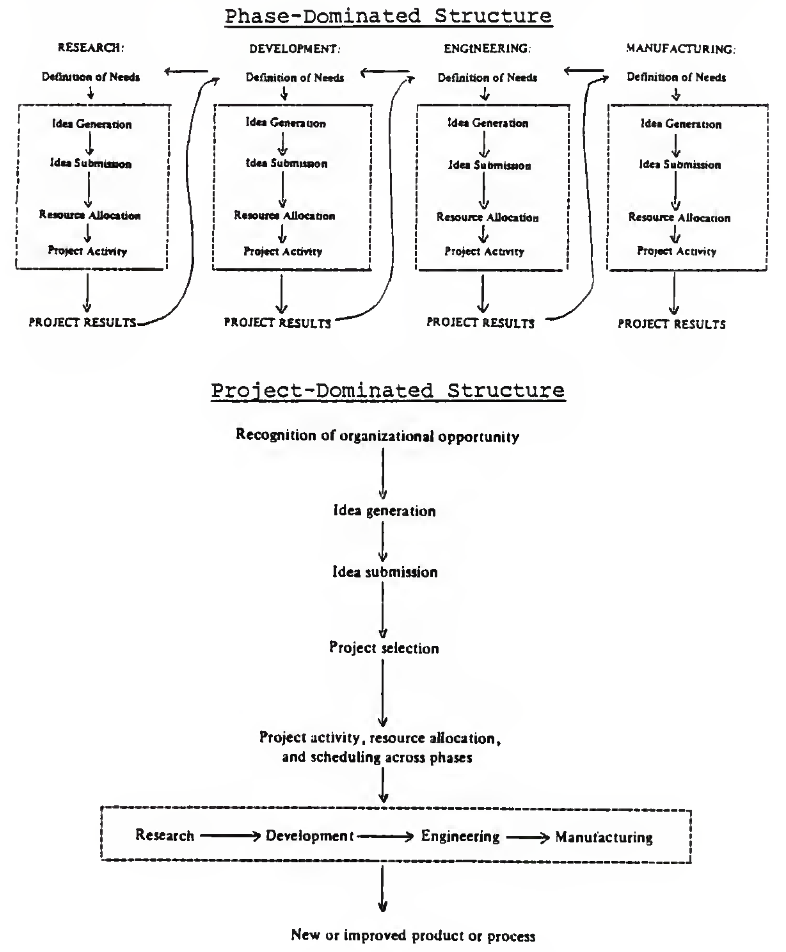

FIGURE 7: Phase-Dominated vs. Project-Dominated Models.[B-5]

the amount of centralization of the R&D function. Most notably, an IRI study conducted for the National Science Foundation [N-0.3] concluded that the more centralized the R&D function, the greater the tendency to perform basic research. If this tendency is part of the goal structure of the organization, this presents no problem, but organizations with highly centralized or decentralized R&D functions should be aware of this trend. This is especially true since IRI's 1987 survey [M-7.5] indicates a recent trend toward decentralized R&D efforts that could have a deleterious effect on basic research.

Therefore, the structure of the organization can often dictate the best classification scheme to use and how the project selection system is utilized. In the many matrix organizations, the decision may not be immediately clear but decision makers should consider the structure of the organization when determining an appropriate classification scheme.

Size of Organization

A few changes could be made to the proposed project selection system depending on the size of the organization. Obviously, the size of the committee will vary with the number of key players in the R&D process--a function of the size of the R&D effort. For a very small organization, the committee could consist of as few as two people and the use of a group decision making technique would not be necessary. On the other hand, if the organization is very large and geographically dispersed, the Delphi Method may be the only practical decision making mode.

Additionally, it may not be justified for a small organization to carry out the phases of the proposed selection system concerning the classification of available projects and selecting projects within each group. If the resources or expertise of the organization is very limited, so might be the number of alternative projects. An organization that performs R&D by contract only, and thus must restrict its alternatives to available contracts, might also face a limited number of alternative projects. For these situations, an application of a portfolio selection model with all alternative projects included in the model may be more appropriate.

Therefore, the proposed R&D project selection model is designed to guide organizations in developing a sensible project selection system. No one best system can ever be designed for all organizations or even all selection decisions within the same organization. Many variables are involved in each selection decision that must be appropriately modeled into the system.

Some of the most important considerations are discussed in this chapter. The careful selection of an appropriate classification scheme will help organizations more effectively use R&D project selection methods and retain a strategic balance of R&D efforts. Since the type of organization determines the generic goals of the decision makers, these considerations play a major role in the selection process. Finally, the implementation of Phases II and III are often dictated by the structure and size of the organization.

CHAPTER SEVEN:

SUMMARY AND CONCLUSIONS

The need for more practical approaches to research and development project selection is well noted in literature and practice. Most models developed in the past have focused on the quantification of the selection process. While these models do improve the decision-makers' understanding of the projects and the selection criteria, the models _themselves_ cannot _solve_ the problem. The selection decision contains too many subjective factors that cannot be completely "modeled." With few exceptions, the individuals involved in the R&D process are unwilling to give up the responsibility for the final allocation of resources to projects to a pure mathematical selection method.

Consequently, the recent literature has begun to focus on needs of the decision-makers themselves. More researchers are testing the use of various group decision making methods in this environment. These tests are revealing the value of this approach--especially when combined with a more analytical approach to stimulate discussion among the participants.

The selection system proposed in this report offers several advantages over purely analytical models. First of all, the establishment of the goals of the organization before the selection process is begun insures that the decision-makers concentrate on the needs of the organization. During this process, the individuals representing the various units within the organization work together to a common understanding of the goals of the organization. This group effort offers much longer-term advantages in the form of improved communication, cooperation, and motivation.

Secondly, the classification of projects improves the selection system in several ways. Since most management science models are most applicable when dealing only with similar projects, the classification of projects before choosing or ranking insures the appropriate use of these models. Additionally, the decision-makers are forced to consider the need for a balanced R&D portfolio. Balancing an R&D portfolio involves insuring that each of the different classes of projects are represented according the the objectives of the organization. A properly balanced portfolio should maximize the returns to the organization while minimizing the risk of project failure.

Finally, the combination of the use of a portfolio model and a group decision-making technique offers the advantages of both tools. The portfolio model is used as an analytical tool to provide useful information on the trade-offs involved in various portfolios that otherwise would not be available. The group decision-making technique is used with the recognition that the individuals are the final decision-makers and that a structure for the discussion is necessary.

The final output of this selection system is that set of projects that will best meet the goals of the organization. The system recognizes the needs of the decision makers for a tool to assist in making complex trade-offs between goals while recognizing their ultimate responsibility for the selection decision. This system, once adapted to the specific organization, will serve as an effective tool in aiding decision makers faced with the selection of research and development projects.

Future research in this area must be concerned with the application of the proposed selection system for various types of organizations and sets of project alternatives. Several representative applications could be identified and the organizational goals, classification scheme, project selection models, portfolio selection model, and group decision making technique would be selected to best meet the needs of that particular organization. These applications would give insight to the similarities and differences in the manner in which the proposed system is applied. These similarities and differences could then be categorized to form a type of expert system to aid R&D managers in determining how to best apply the proposed system to their particular situation.

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SELECTING RESEARCH AND DEVELOPMENT PROJECTS THROUGH CLASSIFICATION

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ABSRACT

Research and development (R&D) is defined as the discovery and application of new knowledge and the new application of existing knowledge. The importance of R&D to individual organizations and the economy as a whole is evidenced by the attention in literature given to the R&D project selection decision. Although many models have been proposed to deal with the complexities of this decision process, very few have been actually employed. This paper proposes a more practical selection system based on the classification of R&D projects. The four stages of the system are as follows: 1) establish organizational goals, 2) classify projects, 3) choose/rank projects within each class, and 4) pool the projects and select a portfolio. The classification of projects insures a more appropriate use of R&D project selection models and helps to establish a more balanced R&D portfolio. The combined use of an analytical model and a group decision making technique is used to select the optimum portfolio. The model provides the decision makers with a format for the analysis of trade-offs between projects, goals, and resource limitations. The group technique offers additional organizational benefits in terms of improved communication, cooperation, and motivation.