Evaluating R&D and New Product Development Ventures

An Overview of Assessment Methods

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PREFACE

The purpose of this booklet is to introduce several techniques to assess the business potential of technology projects. These analytical tools range from the extremely simple, which can be used by anyone, to the very complex, with require an understanding of mathematics or statistics and which require extensive input data. The intent is not to teach everyone how to perform all of the calculations, but rather to familiarize decision makers with the range of available techniques.

Although the booklet is written from the point of view of a business making project selection decisions, the principles involved are generally applicable to all those involved in the process of technological innovation: investors, financial intermediaries, individual entrepreneurs, and laboratory personnel who screen projects for possible commercial application.

This booklet is the result of a joint effort of Coopers & Lybrand and the Office of Productivity, Technology and Innovation at the U.S. Department of Commerce. It was prepared by D. Bruce Merrifield, Assistant Secretary of Commerce for Productivity, Technology and Innovation, and Robert L. Bovey, Director of Economic & Policy Analysis in the Washington, D.C., offices of Coopers & Lybrand. Major contributors were Kathleen M. Bybee of the Office of Productivity, Technology and Innovation, U.S. Department of Commerce, and John Gunther-Mohr, Michael P. Huerta, Donna L. Lauer, Lucinda M. Lewis, Yevgeny Okun, and Leslie A. Wiley, all of Coopers & Lybrand. Inquiries concerning the contents of the booklet should be directed to either Dr. Merrifield at (202) 377-1984 or Dr. Bovey at (202) 822-4000.

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INTRODUCTION

The U.S. has always been an inventive nation, with many creative scientific thinkers and inventors. It has also been an entrepreneurial nation, with risk-takers willing to invest both time and money in new ideas, enterprises, and markets. These characteristics are particularly important now, when we are in the midst of a technology explosion unparalleled in history. The pace of change is so dramatic and the economic stakes are so high that individuals, businesses, and governments are increasingly focusing their attention on technology development -- both in the U.S. and internationally. The increased competition in the international marketplace has put new time pressures on technology commercialization. In many fields, incremental improvements are no longer valuable as new technologies leapfrog the old. Nations and businesses now pay a high price for doing nothing.

In the midst of this technology explosion, business planners and research and development (R&D) managers must work together more closely. Business decisions must be made quickly and well; accurate information and its wise use are of paramount importance. This booklet, prepared by Coopers & Lybrand and the Office of Productivity, Technology, and Innovation at the U.S. Department of Commerce, is designed to assist in the process of gathering and analyzing the information businesses need to convert our vast technology resources into new products and processes. With inventiveness linked to effective decision making, U.S. firms and other organizations that screen R&D projects for possible commercial application will be more successful in the increasingly competitive and rapidly changing international marketplace.

BACKGROUND

I. Innovation and Investment

Technological innovation is a necessity in all of U.S. industry, not just the more visible new "high tech" industries such as computers, electronics, and biotechnology. It is especially important for traditional manufacturing industries such as steel, automobiles, and machine tools to introduce state-of-the-art technology if they are to survive. Technological innovation even has a direct impact on service industries like banking and communications. In fact, no business can afford to ignore the effects of new technological developments.

In recent years, private sector investment in technological innovation has increased, partly as a result of new tax laws. This increase in available capital has increased the competition to find good investments; as a consequence, venture capitalists have been funding earlier stages of R&D in order to beat their competitors to a deal. The dramatic returns investors have obtained when some new technology companies have gone public have also added to investor interest in technology-based companies.

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While the investment boom has subsided somewhat, the heightened availability of capital and investor interest in technology continues, in part because of the creation of innovative financing techniques such as the R&D Limited Partnership (RDLP) which provides tax incentives to investors in R&D.

This intensifying activity in technological innovation and technology investment has served to highlight another need: matching money to projects. Many companies must decide which of various competing R&D projects should be funded for development. Also, outside investors need some way to screen early stage investments for their commercial potential. Further, university and federal laboratory personnel need techniques to help identify those projects which should be called to the attention of businesses for possible transfer. It is at this point that information and analysis play a critical role. This booklet examines the role of information in the innovation process and outlines some of the analytical methods that can be used by companies, investors, financial intermediaries and technology transfer personnel to screen technologies for their promise in the marketplace.

II. The Value of Information

The value of information changes over time; generally, the farther a project progresses, the more valuable information becomes. This happens because resources needed at the later stages are significantly greater than at the initial stages. Improved accuracy based on better information becomes more important as the stakes rise.

The following example illustrates this.

A chemical company was considering developing a new product that would affect the biochemical defense mechanism in corn sprouts and predispose the roots to accept certain soil bacteria. A small amount of the new chemical was expected to replace 300 pounds of nitrogenous fertilizer per acre. Before the company could market such a product it had to obtain FDA/EPA approval. It was essential, therefore, to determine as early as possible whether the proposed chemical was environmentally safe. Failure to obtain such information could cost the company dearly at a later date. But to obtain such information at the experimental stages of development, before the chemical was actually produced, would require a series of expensive and lengthy tests. Since only a crude approximation of the future product could be used in such experiments, the results could not be considered conclusive.

Fortunately, a great deal of crucial information often becomes available at little or no additional cost in the later stages of project development. In this case, once the chemical was developed, it would have to undergo numerous tests to determine its effectiveness in various environments. These experiments could provide "side" information about the ecological effects of the new product at no extra cost. The management, therefore, had

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to weigh carefully the costs and benefits of obtaining such information at each stage of development.

Specifically, the company was ready to spend $2 million to develop the new chemical. Given the chemical content of the proposed product, the R&D scientists did not foresee any major ecological problems, but they could not guarantee the product was safe without full testing. They estimated that at this early stage such tests would cost $1 million, would require from 12 to 15 months to complete, and would be only 70% conclusive. By waiting until the product or prototype had been developed, however, the scientists were sure they could resolve the ecological issue with much greater confidence within 10 months at a cost of $700,000.

Confronted with these estimates, management decided to ignore the ecological problem until after the prototype was developed, even though it might mean writing off $2 million if the prototype was later found to be unsafe. It was not worth $1 million dollars and over a year's delay to the company to get only a 70% assurance on a $2 million initial investment. The company moved ahead to develop the prototype, without testing.

The conclusions were different, however, when it came time to move into the production phase. First, the cost of the ecological testing dropped in absolute terms to $700,000 and 10 months as a result of the "side" information obtained while developing the prototype. Second, and most important, the cost of the testing dropped precipitously relative to the amount of money that was now at stake. To set up facilities for production would cost an estimated $30 to $35 million, decreasing the relative cost of the additional information from 50% ($1 million/$2 million) to 2% ($.7 million/$32.5 million). The value of the additional information, thus, had gone up substantially because the funds at stake had also increased.

As a result of the increased value of the information, the company decided to conduct the experiments to determine if the chemical was environmentally safe. Meanwhile, the production phase was put on hold pending the test results. After spending $600,000 and 10 months the company concluded that the product was not environmentally safe and that it was not likely to receive FDA/EPA approval. The project was dropped.

As this illustration shows, the costs and benefits of information can change over time during the technological innovation process. It is, therefore, important to understand that process and anticipate the points at which additional information may be needed so that critical decisions can be made.

III. The Technological Innovation Process

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ety of ways by management analysts in business and academe. Some models tend to be fairly simple and descriptive (see the U.S. Department of Commerce's Guide to Innovation Resources and Planning for the Smaller Business), others are detailed flow diagrams. For example, Robert Cooper, in his article "A Process Model for Industrial New Product Development"[1], describes a model that consists of seven stages: 1) idea, 2) preliminary assessment, 3) concept, 4) development, 5) testing, 6) trial, and 7) launch. Each stage is separated from the others by a "decision node" at which an evaluation and decision to continue or terminate the process is made. The decision nodes can be thought of as the points at which additional information is assessed using one of the assessment methods to be discussed later. A description of these stages follows.

Stage I: Idea

The process begins with the definition of a product. This is basically a screening decision, involving an evaluation of the idea and the initial decision to commit resources to the development of the idea.

Typically, analysts have divided new product ideas into two categories: a) market pull, or b) technology push. Most successful new products are a result of market pull; they are developed as solutions to perceived market needs and are often only incremental innovations added to a current technology. This is generally regarded as the most reliable way to succeed with new products. It typically involves lessened business risk because there is less chance that the fully developed product cannot be successfully sold.[2] This approach requires significant information from outside the organization. Without it a product may evolve that is too similar to competitors' products, with no differential advantage.

Technology push results when the perceived potential of the technology itself is the driving force of the effort. The product idea comes from basic research or a technological discovery. Most truly great inventions fall into this category (e.g., steam turbine, telephone). It is in this area that the U.S. as a whole has historically been the strongest. At the same time, however, the movement of technologies from basic research to the commercial market has been uniquely disjointed in the U.S. The federal gov-

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1/ Cooper, "A Process Model for Industrial New Product Development," IEEE Transactions on Engineering Management, Vol. E-M-30, No. 1, February 1983, pp. 2-11.

2/ Finkin, Eugene F., "Developing and Managing New Products," The Journal of Business Strategy, Vol. 3, No. 4, Spring, 1983. See page 14.

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ernment funds the bulk of basic research in university and federal laboratories, but most of this technology never continues down the innovation pipeline, partly because of sheer volume and lack of adequate screening for its commercial potential. In the case of technology push, then, the availability and use of screening methods such as those in this document are particularly important.

Before committing resources to the development of an idea, three questions should be considered:

1) Does the proposed product fit in with the company's current business and future plans?

2) Does the company have the needed resources or access to these resources (including technical resources)?

3) Does the venture seem to have superior cost and/or performance characteristics that make it commercially attractive?

If the answers to the above questions appear to be positive, resources are committed to move the project through the next stage.

Stage II: Preliminary Assessment

This step is still fairly qualitative, and is the first in which significant resources are spent to gather information on the feasibility and attractiveness of the project. This stage is divided into two types of assessments: 1) a preliminary market assessment, and 2) a preliminary technical assessment.

The market assessment is based on in-house expertise, secondary data (e.g., a computerized search of the patent, technical and trade literature), and outside sources such as industry experts or knowledgeable potential customers. It should be brief and present an overview of the market, identifying possible segments, market size, and likely prospects for the new product. This assessment also will define the approximate cost and performance parameters for technical success necessary to be attractive to the market.

The technical assessment involves bringing the idea before the company's technical staff for an appraisal. This assessment should give some indication of the technical feasibility of achieving the parameters defined and the resources required to develop and produce the product.

If the market appears to be there, and the product seems technically viable, the project moves on to the next stage.

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Stage III: Concept

The purpose of this stage is to define the product precisely, identify its specific market targets, and determine how it will compete in these markets. This stage is composed of three parts: 1) concept identification, 2) concept development, and 3) concept test.

Concept identification involves a second, more in-depth market study. It is conducted for potential users or buyers and seeks first to identify at least one segment of customers who are dissatisfied with currently available products, a vulnerable or poorly designed competitive product, or a niche where a new technology or new design can gain a competitive advantage. Second, the study identifies what is required to achieve success in this market, such as the desired benefits or features sought in a new and "winning" product, and how the product should be positioned. This study should yield quite detailed product performance specifications for what would be a better product in the eyes of the customers.

Concept development translates the market requirements that have been identified into an operational concept that is technically feasible.

The concept test involves a test of the likelihood of product acceptance in the marketplace. This is a market study similar to the concept identification study, except now there is something specific to show respondents: performance specifications, sketches, diagrams, models, or other descriptions of the proposed product. Here, the object is to determine market acceptance of the new product itself, including levels of interest, preference, and intent to purchase. Respondents may be asked if they would modify the product or if there are any reasons why the product would be unacceptable. This information provides the basis for the market plan, by identifying the target markets, and developing a specific product position in those markets.

At this point, a decision is made about the concept. With estimates of sales from the market study, and of costs from concept development, a reasonable financial analysis can be performed. Again, a decision point has been reached, where the project may be dropped or moved on to the next stage.

Stage IV: Development

The actual physical product development begins at this stage, with a prototype or product sample as the typical result. At this stage a company draws primarily from its technical resources: R & D, engineering, and industrial design. This technical development is pursued milestone by milestone toward the predetermined cost/performance specifications. The project is terminated if milestones cannot be achieved. At the same time, assuming continued technical progress, a formal and complete marketing plan must be

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developed. The results of the previous concept test are shaped into a marketing plan that includes decisions about pricing, distribution, advertising, sales strategy and service. Additional market studies on buyer behavior may be required: how customers buy the product, who the purchase influencers are, and sources of product information. When this stage is completed, the prototype of the product and the marketing plan are evaluated together and a decision is made whether to continue or terminate the development process.

Stage V: Testing

The testing stage is composed of two parts: an in-house test of product prototypes to determine that no technical flaws exist, and a customer test of the product. In the latter test, prototypes are placed with potential customers to test the product's design. The object of these tests is to identify design defects, and, in particular, modifications needed to improve customer acceptance.

This stage is crucial to every new product's development, and is a point at which new products often go back to the drawing board. The customer test may be conducted among the company's nontechnical employees, or among a small number of potential customers. The nontechnical and unbiased tester may often reveal unsuspected hidden flaws.

If the product prototype successfully passes the in-house and customer tests, the process can continue to the next stage.

Stage VI: Trial

This stage represents a dry run of all commercial facets of the project: product design, production, and marketing. First, the results of the product prototype and marketing test must be incorporated into the product design and marketing plan. Then the next three steps of the trial stage can be completed: 1) pilot production, 2) test marketing, and 3) precommercialization business analysis.

A trial or pilot production run tests production methods and processes that will eventually be used for full-scale production. Modifications to the final production facilities or methods are often required in order to alleviate problems uncovered in the pilot production. In addition, more accurate estimates of production times, output, and costs are obtained in the trial run.

A market test assesses not just the product, but all the elements of the marketing mix together. This involves actually selling the product, using the proposed marketing plan, to a selected group of consumers or in a limited geographic area. The market test should identify adjustments needed in the marketing plan and result in a final estimate of market share and expected sales.

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Finally, a precommercialization business analysis and evaluation is made, based on concrete financial data from the test market and trial production. If the new product passes, the next and final stage begins.

Stage VII: Launch

At this point commercial production begins, and market plans are implemented in the full market area. All facets of the launch should have been well-tested prior to this stage. If the tests were properly carried out, and no unforeseen or new circumstances arise in the market, the launch should simply be the execution of a well-designed plan of action.

Periodic evaluations should, of course, be made after the product is launched to be certain the product is on target. Measures such as market share, sales volume, and production costs per unit can be used to gauge the product's progress. Such evaluations help control the effort and signal if corrective action is needed.

It is impossible to eliminate risk-taking from the new product development process, but a systematic, well-controlled approach will help to reduce risk.

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Methods of Assessment

I. Introduction

The methods of assessment introduced here are essentially techniques that can be used to organize information for decision-making. These techniques range from the very simple to the extremely complex. Not all possible methods are presented here, only a few of the more distinct and useful. These techniques are not designed to take the place of the decision maker's judgment; they simply help organize information; they do not ensure accuracy of information or quality of judgment. The expertise of individuals is still the most important element in making business decisions.

The following section examines three basic types of assessment methods: checklists, scoring models, and profitability models. The first type of model, the checklist analysis, is the simplest and is no more than its name implies -- a qualitative list of criteria. The second type, the scoring model, is somewhat more complex since it is an attempt to quantify the criteria identified in the checklist. The third type, the profitability model, is strictly quantitative and doesn't deal with all the factors considered in the other models. Profitability models can be used to produce rough profit estimates when information is scarce, but they can also be extremely complex and used to analyze extensive data, producing very sophisticated quantitative results. As will be explained later, the use of profitability models in isolation is not recommended; they should always be used in conjunction with a broader model which considers qualitative as well as quantitative inputs.

Following the introduction of these three basic methods is a section that outlines further analytical techniques that can be used to refine profitability models. These techniques involve relatively sophisticated mathematical approaches and may require specialized knowledge of statistics, mathematics, or computer modeling. These techniques are presented here only in outline form; complete descriptions of how to perform such calculations are in commercially available textbooks.

Although the more complex models are more rigorous, there is little evidence that any one approach is better than the others under all circumstances. Rather, the decision of which model to use depends largely on how far a project has progressed in the innovation process. This is, as suggested earlier, because of the role and availability of information. First, information is relatively scarce and expensive in the early stages. Second, the more complex the model and precise the output, the greater the amount of information needed as input. And third, the value of information increases as more resources are at stake in the later stages of development. Given these facts, the simple analyses are generally suited to the early stages of innovation when little informa-

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tion is available and precision is usually impossible, and the more complex analyses are suited to the later stages when more information is available and precision is both possible and necessary.

A discussion of the three types of assessment methods follows.

II. Basic Methods

A. Checklist Analyses

A checklist is the simplest form of formal project evaluation. It consists of a list of questions or criteria that are likely to determine the project's success or failure. The list should include technical, economic, financial, environmental, legal, and social considerations. While the ultimate list of pertinent variables will be determined by the nature of the individual company and project, most relevant questions fall into one of the following five categories:

1. Resource compatibility--Will the project fit the company in terms of technical, financial, engineering, production, and management resources available?

2. Project's novelty to the firm--Does the project create for the company a new customer base, new product class, new markets, new technologies, etc.?

3. Nature of the product--What will the product offer to the customer in terms of unique features, cost reductions, increase in productivity, lower price, etc.?

4. Nature of the market--What will the market be in terms of size, competitiveness, level of specialization, regulations, prospects for growth, pace of technological change, etc.?

5. Nature of the project -- Is it "technology push" or "market pull," how innovative is it, what are the magnitude and technical complexity of the project and the time needed for completion, etc.? [3]

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[3] Cooper, "An Empirically Derived New Product Project Selection Model." IEEE Transactions on Engineering Management, Vol. EM-28, No. 3, August 1981, pp. 54-61.

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The following questions are merely examples of the types of questions that might be asked using a checklist approach. The questions were selected from the Coopers & Lybrand booklet, "Checking into an Acquisition Candidate." Whether these or other criteria are selected for any particular project, they should be chosen carefully, since they are the central element of this and other methods of technology selection that will be discussed later in this booklet.

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Resource Compatibility

Have you examined:

a. Company's income stream for the duration of the project?

b. Terms of agreements that affect income, e.g. bonus or profit-sharing plans, royalty agreements, long-term leases, sales contracts, and dealership agreements?

c. Financial ratios:

- current assets to current debt?
- net profits to net sales?
- any other ratios that might be helpful?

d. Market trends for your existing products and their impact on income stream?

e. Contingent liabilities?

f. Company's debt structure, both short- and long-term?

g. To what extent the project can be financed by internally generated cash, new equity, bank loans, venture capital, government grants/loans, or any other methods?

h. The relationship with banks and other credit institutions?

i. Existing debt payments and whether they can be covered from operating cash flow?

j. Inflation trends and their implications for project financing?

k. The company's tax liabilities or credits, particularly the impact of investment tax credit on project's financial feasibility?

Does the company have adequate R&D skills?

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Does the company have adequate engineering skills?

Does the company have marketing research skills adequate to perform a full market study?

Are management skills adequate for each stage of product development?

Does the company have adequate production facilities?

Does the company have adequate sales force and/or distribution resources?

Nature of the Project

How new is the product to the market?

Does the product have a high or low per-unit price?

Has the technical complexity of the proposed product been assessed?

Has the the nature of product "idea" been assessed -- e.g., "market pull" or "technology push"?

Is it clear what all the product specifications are?

Is it clear how the technical problems will be solved?

Has there been an assessment of why the company needs to introduce this product?

a. To increase its productivity?

b. To increase its market share?

c. To maintain its market share?

d. To broaden its product line?

e. To penetrate a new market?

f. To improve its general competitiveness?

g. To receive an extraordinary return on investment?

h. Any other reason?

What are the availability and price prospects of key supplies, including raw materials if applicable?

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h. Any other reason?

What are the availability and price prospects of key supplies, including raw materials if applicable?

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If new production facilities are required, has information been obtained on:

a. What percent of total costs are involved in fixed assets?

b. Possible locations and tentative description of required production facilities?

c. Proximity of transportation facilities, material sources, and labor supply?

d. Restrictions imposed on building codes and zoning laws?

e. Utilities, including availability, usage, and rates?

f. Real estate taxes and other fixed costs?

g. Other factors that might lead to an increase in production costs?

Project's Novelty to the Firm

Are the potential customers new to the firm, and if so, would this cause special difficulties in marketing and product servicing?

Would the newness of the product to the company cause extra difficulties in the product's development, production, or marketing?

Is the company familiar with the technology required to develop the product?

Will a new distribution system and/or sales force be required?

What competition will the company face if the proposed product is introduced to the market?

Nature of the Product

Does the proposed product offer unique features or attributes to the customers?

How does the product compare with competing products in terms of satisfying customers' needs?

Does the product permit customers to reduce their costs?

Does the product permit customers to do a job they have not been able to do previously?

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Does the product permit customers to do a job they have not been able to do previously?

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Is the new product of higher quality than competing products (e.g., in terms of durability, longevity, etc.)?

Is the product cheaper than the competition?

Is this the first introduction of this type of product?

Can the proposed product be patented easily both in the domestic and foreign markets?

Does the product expose the company to significant product liability concerns?

Does the product pose any danger to the environment and/or human health?

Does the product require approval from federal, state, or local government or any other governmental agencies?

Has there been an assessment of the impact on the product's development of various government rules, standards, legislation, etc?

Nature of the Market

Does the potential market consist of a few or many customers?

Does the market for the proposed product already exist or is there only a potential demand?

What is the dollar value or unit size of the existing or potential market(s)?

What is the growth rate of the potential or existing markets for the proposed product?

What is the competitiveness of the markets?

a. Are they dominated by one producer?

b. Are there many producers on the market?

c. Are the markets highly price competitive?

d. Is there a strong customer loyalty to existing (competing) products?

e. Are the markets characterized by a high level of technological change?

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f. How rapidly do users' needs change in the prospective markets?

What cyclical and other general factors affect demand for the product?

a. General business conditions?

b. Population change?

c. Advertising or promotional pressures?

d. Government factors -- fiscal/monetary policy, import/export controls, defense activity?

Is there an analysis of the potential pricing policy?

a. Sensitivity of the market to price changes?

b. Whether there is a price leader?

c. Whether the company will be able to pass potential cost increases along to customers?

Has there been an examination of the methods used by the competition to distribute and sell the products, including:

a. The channels of distribution and their relative importance?

b. Nature and importance of the field sales efforts?

c. The manner of compensating sales personnel?

d. Advertising and sales promotion methods for cost and effectiveness?

What major developments have key competitors recently made, particularly in the area of product innovation?

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With limited data, it may be that at the early stages of project evaluation not all of the questions included in such a checklist may be satisfactorily answered. But since the checklist approach is the simplest it is still appropriate for the early stages. The most important result of using this approach is to determine early if there is some aspect of a project that could doom it to failure, such as a more advanced competitor that will hit the market first, or pending legislation that would dramatically increase costs. In general, such an early assessment also could help to establish relative corporate priorities, identify possible problem areas, focus management energies on remedial actions, point to the need for additional information on crucial variables, and establish a framework for more rigorous analysis later on.

This method is flexible as well as simple. It can incorporate a number of pertinent variables such as environmental concerns and social impacts that are difficult to include in many other models. The checklist analysis is also relatively inexpensive and easy to perform. Finally, the checklist method might be the only way to perform a formal assessment of early R&D, because at these stages the subjective opinions of managers are often the only "data" available. The major drawback of the checklist approach is that the method is too cumbersome to use for comparing several projects.

A modified version of the checklist approach is the profile chart method. A profile chart summarizes in a more digestible fashion the information found in a checklist. The method, illustrated in a simplistic way in Figure 1, makes it easier to evaluate the general attractiveness of the project and to compare it with competing ones. Of course, the profile chart must be expanded to include whatever factors are significant to a project. For example, instead of one criterion called "resource compatibility," a practical profile would employ several criteria such as "availability of capital to exploit," "marketing competence," "manufacturing competence," etc. (See both the checklist items given previously and the scoring model criteria, discussed later for illustrations of appropriate criteria.)

Figure 1: Format for a Profile Chart

	Unfavorable			Favorable	
Criteria	very	somewhat	Neutral	somewhat	very
Resource Compatibility		X			
Project's Novelty					X
Nature of the Market					X
Nature of the Project			X		

Resource Compatibility		X			
Project's Novelty					X
Nature of the Market					X
Nature of the Project			X		

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B. Scoring Models

A scoring model is similar to a checklist in that a list of criteria must first be generated; in fact, the criteria may be the same. The scoring model, however, goes on to quantify what the checklist only presents qualitatively. This increased precision requires increased information as input; for that reason scoring models become more useful as projects progress through the innovation process.

Once the criteria have been established for the scoring model, weights and scores are assigned to each criterion. First, weights are assigned, indicating how important each criterion is relative to the others. This can be done in a number of ways, most of which begin by simply rank ordering the criteria so that criterion A is more important than B, B is more important than C and so on. The simplest approach is to assign a number, say between zero and 10, to each criterion that reflects an intuitive sense of its relative importance. Criterion A in Figure 2, for example, would receive a weight of 10 as the most important while F would receive a weight of 1 as least important; a weight of zero, of course, would imply that the criterion is not to be considered.

As a consistency check the relative importance of various combinations of criteria can be assessed. For example, if criterion A is as important as both B and C taken together, but not as important as B, C and D, while B is less important than C and D taken together, the weights assigned to the four criteria should be adjusted to reflect this (see Figure 2). There are many methods for refining the weights assigned to the various criteria. They include various types of paired comparisons, a QS technique, and others.[4]

Then a score is assigned to each criterion. Evidence based on several psychometric studies suggests there should be no more than nine possible scores when subjective judgment is involved. Figure 2 provides a simple example the calculations involved in a basic scoring model; see the following section on constraint analysis for a more realistic presentation of the criteria to be employed.

4/ See, for example, Churchman, Ackoff & Arnoff, Introduction to Operations Research, John Wiley & Sons, N.Y. (1957), pp. 136-154; Fuel, "A Simplification of Hay's Method of Recording Paired Comparisons," Journal of Applied Psychology, Vol 44: pp. 347-348, 1960; and Souder, "Field Studies with a Q-sort, Nominal-Group Process for Selecting R&D Projects," Research Policy, 4 (1975), pp. 172-188.

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Figure 2: Simplified Example of a Scoring Model

	Criteria	Weight	x	Score	=	Criteria Score
A	Compatibility with Current Business	10		9		90
B	Probability of Technical Success	6		5		30
C	Market Competitiveness and Growth Potential	4		7		28
D	Newness of the Product	3		3		9
E	Development Time	2		3		6
F	Profitability	1		9		9

Score: 9 = excellent, 1 = poor   Total = 172

Scoring models can be significantly more informative than checklists or profile charts. They lend substantial rigor to the evaluation of the proposed investment in the absence of accurate financial data. Several features make this method superior to strictly financial approaches to project evaluation, particularly at the early stages of product development. First, qualitative factors pertinent to the decision (corporate prestige, environmental concerns, the indispensability of the product, etc.) which are not easily measured in economic terms, can be readily incorporated into the model. Second, in the early stages of product development, the data-gathering methodology can be relatively inexpensive and straightforward, as the most relevant information may be obtained through interviews with a few key individuals. Third, the assignment of a single numerical score provides for easy comparison with competing projects. Finally, the scoring model can be readily modified to account for changing conditions, such as changes in the marketplace or alterations of management priorities.

A number of shortcomings, some real and some perceived, have limited the usage of scoring models. They are often viewed as a superficial attempt to reduce a complex decision situation to a single numerical solution. Indeed, rote application of the procedures will surely degenerate to this. On the other hand, the discipline of assigning weights and scores can serve to sharpen judgments that otherwise would remain diffuse and to identify issues that would otherwise remain hidden.

Critics also charge that individual project scores are meaningless when considered in isolation because most scoring models

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Critics also charge that individual project scores are meaningless when considered in isolation because most scoring models

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do not have a cutoff criterion, a score above which a project will probably be successful and below which a project will likely be unsuccessful. These critics would argue that only when scoring models are used to choose among two or more projects are they useful analytical tools. In point of fact there are always at least two potential projects. One is to pursue the proposed project. The other is "business as usual." Moreover, this criticism can be mitigated further by the regular use of a consistent approach to project selection so that a track record is developed on which to base a "cutoff" point. This was done for the scoring model variation discussed in the next section, the constraint analysis. A cutoff score has been developed in this model.

Another problem is the subjective and somewhat arbitrary weight assignment discussed above; ideally, weight coefficients should be derived from empirical data on successes and failures of previous projects. This shortcoming, however, might be alleviated soon since a significant number of empirical studies have been undertaken in the past few years. As their results become available, managers will be able to assign weights on a somewhat more objective basis.

Finally, the scoring models are seen as less accurate than other popular methods of project evaluation such as profitability measures because they use interval estimates and subjective value judgments rather than numerical point estimates for sales, costs, etc. In fact, this can be a strength of the scoring model approach, when it is properly used. The use of subjective judgments allows employment of scoring models earlier in the development process than would otherwise be the case. Later, as objective quantitative data become available, they can be substituted for the subjective judgments. Further, there is some evidence in the literature that scoring models employing interval estimates, particularly the ones based on probability distributions, tend to be relatively reliable when used to evaluate projects involving high degrees of uncertainty. Finally, properly developed scoring models literally force the project selection process to address explicitly both the quantitative and qualitative aspects of the decisions in a coherent way.

1. Constraint Analysis

The "constraint analysis" model illustrates the use of a scoring model approach to project selection. The model was developed over many years of venture management by D. Bruce Merrifield, Assistant Secretary for Productivity, Technology, and Innovation at the Department of Commerce. The model assumes that the potential value of a given project will be determined not only by the probability that technical cost/performance objectives can be achieved, but also that there is indeed a viable market for the product or process once developed, in simple terms:

PROJECT "MERIT"	=	Probability of Commercial success	x	Probability of Technical Success

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PROJECT "MERIT" = Probability of Commercial success x Probability of Technical Success

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Since the shelves of research laboratories are cluttered with marvelous inventions for which there was no market, the first step in any new undertaking is to evaluate the probability of commercial success. This analysis also defines the parameters for technical success that must be achieved for a project to be commercially successful.

Once the probability of commercial success is considered to be reasonable, then and only then can the probability of achieving required technical cost/performance parameters be evaluated. Technical development then is initiated on a milestone by milestone basis until technical feasibility is demonstrated or the project is terminated.

The following discussion addresses the assessment of the probability of commercial success only. In the analysis, "intrinsic business attractiveness" is differentiated from "degree of fit or compatibility" with company resources:

Probability of Commercial Success	=	Intrinsic Business Attractiveness	+	Degree of Fit

This differentation is made for pragmatic business reasons, since weaknesses in the "fit factors" can be corrected through joint venture, acquisition, or merger strategies. Weaknesses in inherent business attractiveness cannot.

There are six business attractiveness and six company strength or fit factors, all chosen and weighted equally by using a regression analysis that determined how much various factors contribute to business success. Each factor is scored on a scale of 1 to 10, with a total of 120 points possible. In the experience of a large American corporation which regularly employed this model, a total score of 80 became the cutoff point: projects with a total score of 80 or above proved successful in 8 or 9 out of ten cases of later stage development. Those with a total score below 70 were generally unsuccessful.

Finally, as indicated above, from past experience covering several hundred projects over many years, and as a first approximation, all factors are equally weighted. Individual circumstances might require a more selective weighting. Moreover, there are minimum thresholds for two factors that require go/no-go decisions. The "decision tree," therefore, becomes:

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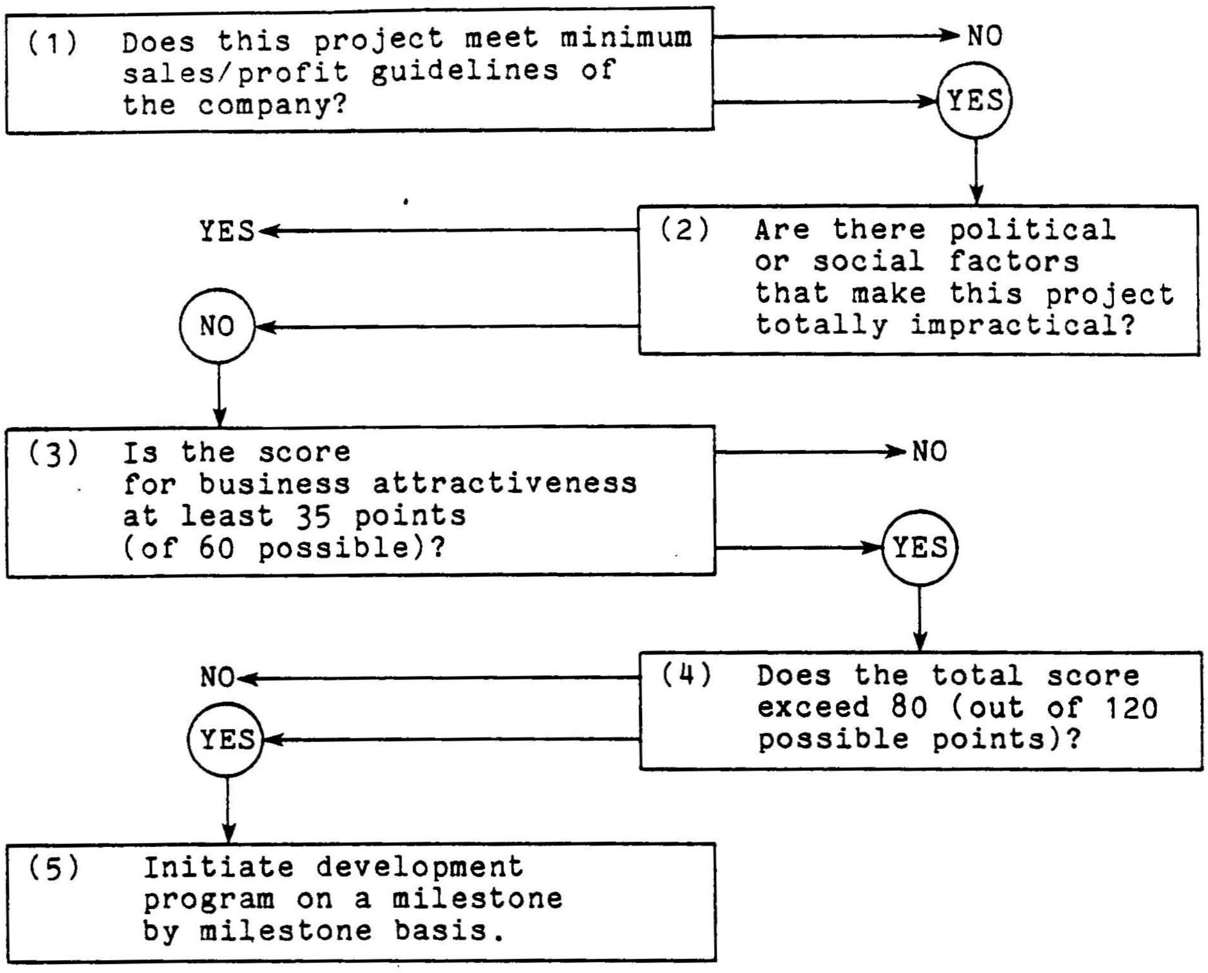
Figure 3: Constraint Analysis Project Selection Logic



Business attractiveness is assessed on the basis of the following six factors:

(1) Sales/profit potential. A new project, to be rated 10 on this criterion, should have a significant effect on the relevant profit center, perhaps increasing sales by 20% within 5 years. Also, it must meet minimum corporate profitability targets. If the project will not be profitable enough, usually a 40% before-tax return (See "Internal Rate of Return" in the following section on profitability models), generally, it should be abandoned and further analysis is unnecessary. But, given an acceptable return on investment, projects are scored according to sales potential. The greater the sales potential, the greater the value of the project, with one exception: at some point the opportunity becomes so attractive to other firms that competition makes survival less likely. How-

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ever, with a sufficiently great sales potential, smaller specialty markets begin to emerge so more competitors can survive.

(2) Growth rate. Since profits are positively correlated with market share, a company does well to win a dominant share of the market. This is more easily done the faster a market is growing; a company in a growing market gains experience (economies of scale) and cuts costs, allowing lower prices that inhibit competitors from entering the market. Also, in a rapidly growing market a company would not be as likely to take business from existing competitors and provoke reactive measures. Growth greater than 10% annually would warrant a score of 10, at 5% the score would be 5, and no growth in the market would be a score of 0.

(3) Competitor analysis. Three factors are important in analyzing the competition. The first is the ability of a competitor to take defensive measures; a well-managed company with low costs and a strong cash flow might easily fend off competitors. The second is patent protection; an innovation is likely to have more success if it has strong patent protection against competitors. The third is the pace of change in the technology; if innovation occurs quickly in an area, a new development may be obsolete in only a few years. The score for this criterion is broken down by these three factors; low competitor strength would be given 4 points, high patent strength a possible 3 points, and a low technology activity index a possible 3 points.

(4) Risk distribution. The possible applications of a new technology should be varied enough so that the commercial success of the project does not depend on a narrow line of production and marketing. If one application is superceded by a competitor's technology, for example, other applications should be possible. Score 2 points for each possible application for up to 5 significant applications of this technology.

(5) Opportunity to restructure the industry. A new entrant can become the dominant competitor when it makes technological breakthroughs in a stagnant industry, particularly when the new entrant has strong patent protection and competitors are small and fragmented. Also a basic innovation in an existing market offers opportunities to capture downstream use or application markets. (For example, a low cost, very-high-energy density battery could not only capture battery markets but restruc-

makes technological breakthroughs in a stagnant industry, particularly when the new entrant has strong patent protection and competitors are small and fragmented. Also a basic innovation in an existing market offers opportunities to capture downstream use or application markets. (For example, a low cost, very-high-energy density battery could not only capture battery markets but restruc-

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ture automobile, locomotive, and many other use markets.) Ten points should be assigned for a major restructuring opportunity and fewer for lesser degrees of such opportunity.

(6) Special factors. Other elements that can affect the potential commercial success of a project include regulatory legislation, social activist protests, international trade restrictions, geographical distribution factors, cultural bars, possible subsidies, etc. Assign 5 points if there are neither negative nor positive factors; fewer points if there are negative factors (See, however, Figure 3. Here we assume the project has passed the basic go/no-go test.) and more (up to a maximum of 10 points) if subsidies are available.

On the basis of the business attractiveness assessment, the business may appear to be a good one. But if it is to be good for the company, the company must be able to meet additional business requirements. Company strength or fit factors are equally important.

(1) Capital requirements/availability. The company must have enough resources to sustain itself during the early periods of negative cash flow. If a company has little capital available, it can be at a serious disadvantage if it enters a capital intensive area. A company with a great deal of capital available, on the other hand, has an advantage. In an inflationary economy, the higher the capital intensity the more difficult it is for a project to break even in "real" (inflation-corrected) terms. For example, with 7 to 10 percent inflation, no project using more than 60¢ of depreciating assets per dollar of sales can break even. To score, assign one point for each 10¢ of depreciating assets per dollar of sales below 60¢, up to 6 points. Assign the remaining points as follows: 4 points if all cash is available internally, 2 points if 25% must be borrowed, and no points if more than 50% must be borrowed.

(2) In-house marketing capabilities. If a company must wait for additional marketing capabilities before commercialization can be achieved, it loses much of the time advantage it could have had. In assigning a point value to marketing strength, the strength of the competitive environment should be considered. For instance, if the competitive environment is weak, even moderately strong internal marketing resources would be sufficient. Assign 10 points if the existing marketing capability is sufficient, and fewer points for a weaker capability.

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(3) In-house manufacturing capability. Here again the time required before commercialization is the issue, and already having the capability greatly speeds up the process of getting to market. In scoring this factor, assign 10 points if existing capabilities meet full manufacturing requirements, 5 points for an "interim" manufacturing capability.

(4) Strength of the technology base. The stronger the company's functional base in the technology, the more quickly it can react to innovation in the industry, and the more easily it can overtake established but stagnant technologies. Five functions are considered in the assessment: 2 points are scored for each function if the percentage of effort needed is matched by the percentage of effort allocated. If there is a significant difference between need and allocation the score should be 0 or 1 (see Figure 4).

(5) Materials availability. The more certain the supply of necessary raw materials or components, the greater are the chances of business success. Backward integration is least risky; using several suppliers, long-term contracts, and politically insensitive materials also helps decrease risk. Score according to accessibility of raw materials, with a maximum of 10 points.

(6) Skills availability. Two types of in-house skills are important in the effective commercialization of technology. The first type includes functional skills: legal, financial, and other management skills. The second type is the skill of the advocate, the manager who champions a project through development and works with people in all functional areas. Potentially successful projects frequently die for lack of an advocate. For top-notch talent in all categories, score 10.

Once the total score is tallied, the project can be plotted on the identity chart (see Figure 5).

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FIGURE 4: Analyzing the Strength of the Technology Base in Functional Terms.

Nature	Function	% Effort Allocated	% Effort Needed	Score
Product-Maintenance	Market support or customer service	---	---	---
	Manufacturing support, quality control, and product or process improvement	---	---	---
	New systems development to maintain product viability	---	---	---
New Product Development	New component development of proprietary advantage (sometimes fundamental research)	---	---	---
	Science support of applied R,D & Eng. objectives above.	---	---	---
Total:		100%	100%	(up to 10)

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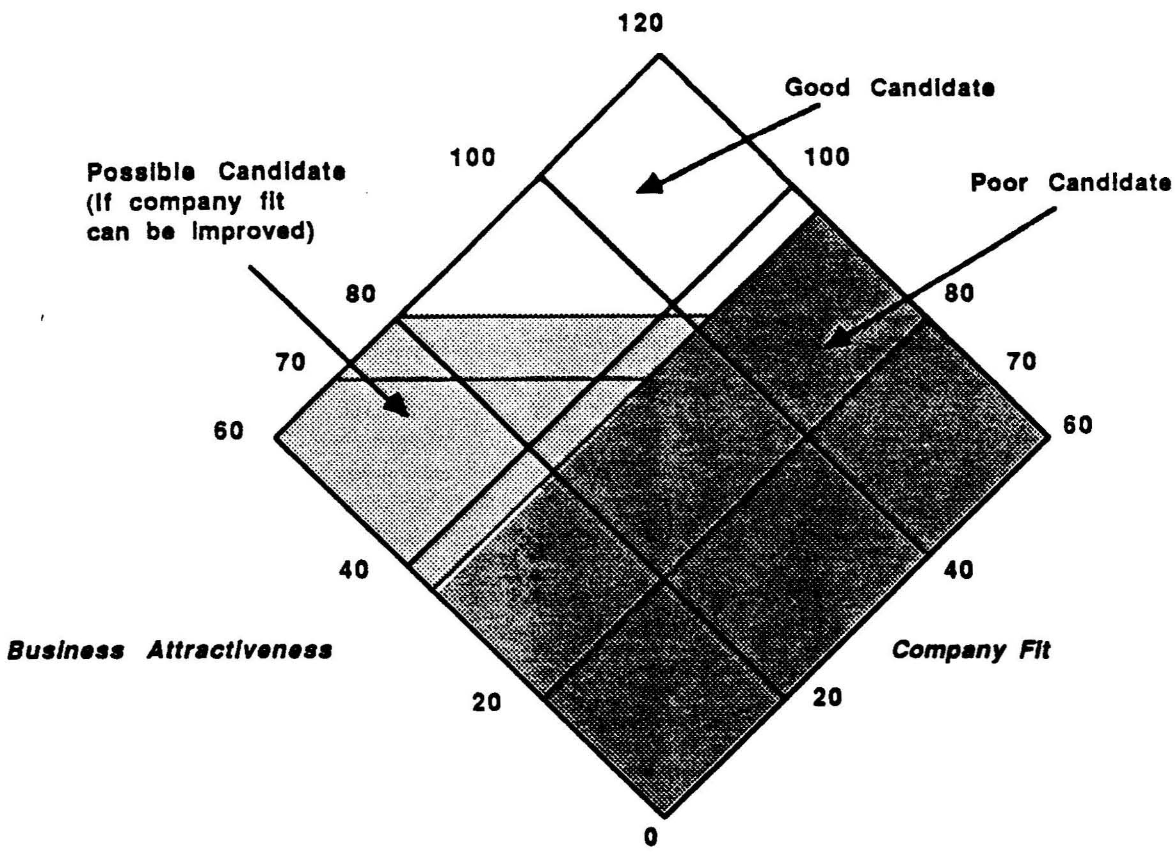
Figure 5: New Venture Scorecard



(Rate each factor on a scale of 1 to 10)

<u>Business Attractiveness</u>	Score
1. Sales/profit potential	___
2. Growth rate, %/year	___
3. Competitive situation	
• Competitor reactivity	___
• Activity index of technology	___
• Patent position	___
4. Risk distribution (segments)	___
5. Opportunity to restructure an entire industry	___
6. Special political and social factors (e.g. Antitrust, Ecology, OSHA, FDA, Energy, Foreign exchange, Geography, Soverign rights	___
Total	___

<u>Company Fit</u>	Score
1. Capital requirements	___
2. Marketing capabilities	___
3. Manufacturing capabilities	___
4. Technology base	___
5. Raw-materials availability	___
6. Skills availability (Champion, Technical, legal, financial, etc.)	___
Total	___

OSHA, FDA, Energy,
Foreign exchange,
Geography, Soverign
rights
Total ___

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In the experience of the company that has used this model the most, projects with total scores of more than 80 should be accepted; those with total scores of less than 70 points should generally be discarded, with one exception: if business attractiveness factors are given high scores (at least 35 out of a possible 60 -- see Figure 3), but the fit factor scores are low, the company might want to consider a joint venture with a partner that has complementary skills and resources to boost the total score to an acceptable level.

It is worth noting again that the portion of the constraint analysis described above assesses only the chances of <u>commercial</u> success; it does not consider the probability of <u>technical</u> success. As previously pointed out, demonstration of technical feasibility can only be treated as a staged process that is initiated milestone by milestone after reasonable probability of commercial success has been agreed upon. Issues of manufacturing competence, deliverability, etc., are included within company strength factors. If basic technical feasibility is a serious question, the final "index of merit," is calculated by multiplying the probability that a project will be commercially successful with the probability that it will be technically successful. As will be indicated in Section III-D these probability judgments can be enhanced by a combination of additional analyses and judgments to aid in project selection.

One of the virtues of the constraint analysis (and other properly constructed scoring systems) is that it is performance focused, and can be used to organize and determine the importance of many different types of information about a project. Also, it is relatively simple and can be readily understood by those in a number of different disciplines, rather than just the financial staff, for example. At the same time, more technical or complicated analyses can be used to augment it; as mentioned earlier, profitability analyses are an integral part of the first business attractiveness criterion. Also, a sensitivity analysis can be performed to show which project cost and market factors have the greatest impact on return on investment. (Descriptions of profitability measures and the sensitivity analysis follow the next section.)

2. Environmental Scoring Model

The constraint analysis is, of course, not the only scoring model that can be used for project evaluation. Many others are discussed in the research managment literature. If none of the existing models fits the environment in which a company is operating, there are techniques for developing an appropriate scoring model. For example, as a result of recognizing that a project's specific environment plays an important role in the project's outcome, J.R. Moore and N.R. Baker designed an "environmental scoring model," which is essentially a method to allow analysts to create their own models uniquely tailored to their needs. While

existing models fits the environment in which a company is operating, there are techniques for developing an appropriate scoring model. For example, as a result of recognizing that a project's specific environment plays an important role in the project's outcome, J.R. Moore and N.R. Baker designed an "environmental scoring model," which is essentially a method to allow analysts to create their own models uniquely tailored to their needs. While

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the discussion that follows draws on the Moore and Baker paper,[5/] it is more general and does not agree with them in all aspects.

The first step in designing a scoring model for a specific type of project is, as discussed earlier, to select the criteria that will have an impact on the outcome. For instance, criteria such as project cost, income or cost savings, technical and managerial familiarity with the research area, and market penetration are frequently selected as criteria. While there is no "best" list of criteria, the list selected should be: (1) complete, with no important factors overlooked; (2) relevant, to prevent unnecessary data collection and analysis; (3) measurable, with some way to judge performance; and (4) as little overlapping as possible. Moore and Baker believe five to ten criteria should be adequate. The list in the sections on the checklist and constraint analysis methods of assessment suggest possible criteria.

Once the criteria have been selected, the next step is to assign weights indicating the relative importance of each of the criteria. Weights can be determined in a number of ways, including simple rank-ordering and more complicated comparisons. (See the introduction to scoring models.) The weights should reflect current priorities of management, and can be changed over time as priorities shift.

The next step is to choose a performance measure and impose a scale for each factor. For instance, the performance measure for some criteria such as income or cost can be readily put in terms of dollars, while others such as market penetration or growth might be percentages. Still others might be qualitative.

After choosing the performance measure for a criterion, a scale must be devised for scoring. In establishing such a scale, Moore and Baker argued persuasively that the scoring should reflect, to the extent possible, past experience. To accomplish this, they suggested that a probability distribution should be constructed, reflecting the range of possible outcomes and the probabilities of those outcomes, by consulting company or industry records for information about similar types of projects in the past. (For a more detailed discussion of probability distributions, see sections on "Risk Analysis" and "Probability Assessment.") For instance, the distribution shown in Figure 6 illustrates a type of project with an expected (or mean value) income of $100,000, with a relatively low probability of an income higher than $150,000 or lower than $50,000. Once the probability distribution is determined, an interval table can be imposed on the

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5/ Moore & Baker, "An Analytical Approach to Scoring Model Design - Application to Research and Development Project Selection," <u>IEEE Transactions on Engineering Management</u>, Vol. E-16, No.3, 1973.

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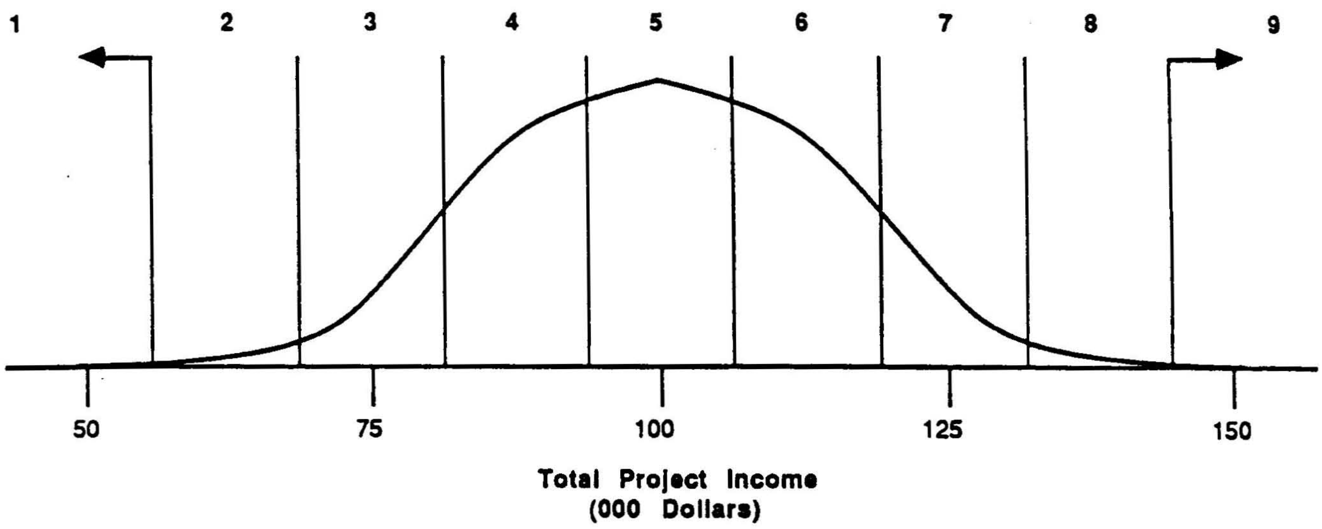
curve. In Figure 6 there are nine intervals centered around the mean. Each interval represents a particular score; a specific project that is expected to produce an income of $125,000, for example, would be given a score of 7.

Figure 6. Scored Project Performance Distribution
(Partitions centered on mean)



Unfortunately, historical records are rarely available for new technologies or R&D projects. Even if they were, one would be loath to accept without question the idea that scores should be equally spaced around the mean of the distribution of historical results; although any reasonably available historical data should be used to establish benchmarks, assigning scores to particular intervals is still a matter of judgment. Also, qualitative performance measures will require scores that are determined more subjectively. A practical way to develop standards in these cases is to conduct a series of interviews with experts and managers. Their opinions can then be used to construct subjective distributions and interval tables. The scoring pattern does not always have to follow the pattern shown in Figure 6. For instance, if there are fewer than nine possible outcomes or the accuracy of the distribution is questionable, there may be a different pattern of scores, say 1, 3, 5, 7, and 9 for a performance measure with only five possible outcomes. Or a pattern of 1, 3, 6, and 10 would reflect the relative importance of different possible outcomes where the scale is not continuous (e.g., (1) definite foreseeable regulatory problems --> 1; (2) possible regulatory problems -->

have to follow the pattern shown in Figure 6. For instance, if there are fewer than nine possible outcomes or the accuracy of the distribution is questionable, there may be a different pattern of scores, say 1, 3, 5, 7, and 9 for a performance measure with only five possible outcomes. Or a pattern of 1, 3, 6, and 10 would reflect the relative importance of different possible outcomes where the scale is not continuous (e.g., (1) definite foreseeable regulatory problems --> 1; (2) possible regulatory problems -->

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3; (3) regulatory problems highly unlikely --> 6; (4) prior government approval already obtained --> 10).

Finally, after the criteria are selected and weighted, the performance measures are chosen and put on a probability distribution, and the intervals and scoring system are imposed on the distribution, then the resulting environmental scoring model can be used to assess potential projects. Scores assigned each criterion are multiplied by the weight and totaled; the project with the highest score is the leading candidate for selection.

In summary, the environmental scoring model is an approach that can be used to modify an existing scoring model or to develop a new one suited to a particular environment. It provides an approach to incorporating historical data or the results of computer simulation models in order to make more objective evaluations possible. It also provides the flexibility to allow updating and revising a scoring model to increase its accuracy as more and more "hard" data become available.

C. Profitability Measures

Almost any project selection process will include a profitability analysis as a central feature. There are several techniques that can be used to project profitability; three of the most commonly used are payback period, internal rate of return, and discounted cash flow (or net present value).

The payback period method has one advantage: it is simple. It can, however, be misleading. This method is based on the amount of time it takes for an investment to be recovered in full. For instance, if a company invests $10,000 in Project A, the resulting income stream might be $2,000 the first year, $8,000 the second, and $7,000 the third. In this case the $10,000 would be returned in full by the end of the second year. If the company had a payback rule of two years, it would accept the project; if it had a payback rule of one year, the project would be rejected. More generally, a company will accept any project that returns the investment in full within a specified period of time.

While this method has been used frequently by businesses in the past, it is now generally considered too crude a measure. Suppose Project B, an alternative $10,000 investment, resulted in a three-year income stream of $2,000, $7,000, and $25,000. If the company followed a two-year payback rule it would accept Project A but not Project B.

Project A	Project B
2,000	2,000
8,000	7,000
7,000	25,000

Intuitively, this would not be a wise decision, since substantial later cash flows are ignored. Or say Project C, a

Project A	Project B
2,000	2,000
8,000	7,000
7,000	25,000

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\$10,000 investment, returned an income stream of \$8,000, \$2,000, and \$7,000; following the payback rule it would be considered equally as good an investment as Project A. It is intuitively obvious here, however, that the more rapid return of cash with Project C is more desirable.

Project A	Project C
2,000	8,000
8,000	2,000
7,000	7,000

Clearly, then, the payback rule suffers from two major deficiencies: it ignores later-year cash flows, and it does not take into account the timing of returns (the "time value of money"). If payback period is incorporated as one criterion in a scoring model, these deficiencies can be alleviated by assigning scores that reflect the desirability of shorter payback periods. For example, a payback period of one year or less might receive a score of 10, one to two years a score of 7, two to four years 3, and longer payback periods zero. Alternatively, a more sophisticated measure of profitability can be employed whether or not a scoring model is used.

One measure that is more sophisticated is the internal rate of return (IRR), sometimes called the discounted rate of return. This technique recognizes the time value of money by calculating the rate of return implied by an income stream. For instance, say a \$10,000 investment returned \$12,000 after one year. The internal rate of return is 20%. It is calculated as follows, where r = the rate of return:

$$\$10{,}000(1+r) = \$12{,}000$$ (value of investment after one year)

or

$$\$10{,}000 = \frac{\$12{,}000}{(1+r)}$$ (value of investment today, or present value)

$r = 20\%$

If, however, a \$10,000 investment returns \$12,000 only after <u>two</u> years, the internal rate of return is calculated as follows:

$$\$10{,}000(1+r)(1+r) = \$12{,}000$$ (value of investment after two years)

or

$$\$10{,}000 = \frac{\$12{,}000}{(1+r)(1+r)}$$ (value of investment today)

$r = 9.5\%$

two years)

or

$$\$10{,}000 = \frac{\$12{,}000}{(1+r)(1+r)}$$ (value of investment today)

$r = 9.5\%$

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(These calculations may be more intuitively obvious if they are compared to a $10,000 deposit in a bank where interest is compounded annually. Each year interest of r% will be added to the principal.)

Since most income streams are multi-year, the calculations frequently are cumbersome. Usually, a calculator or computer will be used to help determine the rate of return. Using the three-year income streams from the earlier examples, we calculate the following internal rates of return (remember, these income streams are all worth $10,000 today):

Project A

$$10{,}000 = \frac{2{,}000}{1 + r} + \frac{8{,}000}{(1+r)^2} + \frac{7{,}000}{(1+r)^3}$$

$$IRR = r = 26.7\%$$

Project B

$$10{,}000 = \frac{2{,}000}{1 + r} + \frac{7{,}000}{(1+r)^2} + \frac{25{,}000}{(1+r)^3}$$

$$IRR = r = 60.6\%$$

Project C

$$10{,}000 = \frac{8{,}000}{1 + r} + \frac{2{,}000}{(1+r)^2} + \frac{7{,}000}{(1+r)^3}$$

$$IRR = r = 34\%$$

The decision rule when using the internal rate of return is to consider only projects when the return is higher than the company's cost of capital, often called the "hurdle rate." If the company's cost of capital were 15% the company would make money on all three projects; all three might well be accepted. The internal rate of return method works well in this case, when there is no limit to available capital. All projects where the return is higher than the cost of capital are profitable and will be acceptable by this rule. Note that in making the comparison, such as in establishing a hurdle rate, care is required to ensure against "comparing apples and oranges." The rates of return, cost of capital, and interest rates used must be based on consistent treatment of taxes, inflation, currency valuation, etc., in order for valid comparisons to be made.

When only a limited number of profitable projects can be accepted, or if certain projects are mutually exclusive, the internal rate of return method is not the best way to compare projects. For example, although the following two projects are both profitable -- the returns are greater than the cost of capital -- if only one could be chosen the internal rate of return rule would

for valid comparisons to be made.

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probably not be the best criterion to use in choosing between them.

	Investment	Return (1 yr.)	IRR
Project X	50,000	62,000	24%
Project Y	100,000	120,000	20%

While one might instinctively choose project X because it has a higher IRR, the size of the project should be, but is not, taken into account. For example, if the company had only $100,000 to invest and it invested $50,000 in project X, it would then have another $50,000 to invest. If the additional $50,000 could also be invested for a 24% return, Project X should be accepted because the total return would be 24%. But the chances are that a marginal project would have a rate of return nearer the company's cost of capital. At 15%, the total return on the investment would probably be closer to $50,000 (1.24) + $50,000 (1.5), or $119,500, which is only a 19.5% return on total investment -- not as good as the 20% return available with Project Y. (Because of the mathematics involved, the internal rate of return decision rule also breaks down if projects have negative cash flows in later years.)

The technique that best overcomes these deficiencies is the net present value (NPV), or discounted cash flow (DCF), analysis. This method of measuring profitability allows the comparison of alternative investments taking into account the time value of money and the size and timing of cash flows. With NPV, as with the internal rate of return, later cash flows are discounted; a dollar received next year is not worth as much as a dollar received today, because money available now can be invested immediately. If money can earn 15% a year, then the opportunity cost of waiting one year to receive $100 is $15. Put another way, $115 received in one year is worth the same as $100 today, or the *present value* of $115 in one year is $100 if the interest, or *discount, rate* is 15%.

$$PV = \frac{\$115}{1+r} = \frac{\$115}{1.15} = \$100$$

Of course, money received after two years could have earned two years' return and must be discounted further; $115 received after two years would have a present value of $87.

$$PV = \frac{115}{(1+r)^2} = \frac{115}{(1.15)^2} = \$87$$

In this case, no one would invest more than $87 today if the expected return was only $115 after two years. The net present value (NPV) of an $87 investment that returned $115 in two years is 0.

$$NPV = -87 + \frac{115}{(1.15)^2} = 0$$

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Whenever the discounted cash flow from an investment is greater than the amount invested, the net present value will be greater than zero. The net present value decision rule, then, is to consider only projects that have a NPV greater than zero. If capital is limited, the rule is to focus on the combination of projects that has the highest NPV.

	Investment	Return (1 yr.)	IRR
Project X	50,000	62,000	24
Project Y	100,000	120,000	20
Project Z	50,000	57,500	15

$$NPV\ (X+Z) = -100,000 + \frac{119,500}{1.15} = \$3,913.04$$

$$NPV\ (Y) = -100,000 + \frac{120,000}{1.15} = \$4,347.82$$

Project Y would be chosen over X and Z.

One particular difficulty in calculating NPV is how to choose the discount rate. The discount rate is sometimes called the "cost of capital" or "opportunity cost" -- what the company pays for the use of outside capital, or the return that is foregone on other investments in order to invest in the project under consideration. One reason it can be difficult to choose an appropriate discount rate is that generally the rate incorporates the level of risk involved in the project. To illustrate, assume a person could invest $100 either in a project that would almost certainly return $115 in one year, or in a project that had only a slight chance of returning $115 in one year. If they were both discounted by the same rate and chosen on that basis alone, it wouldn't matter which one was chosen because they would appear to be equally valuable. In reality, of course, no one would choose the riskier project unless the return was expected to be higher. It is misleading, then, to choose among projects of differing risk only on the basis of an NPV calculation using the same discount rate for both projects. One way to compare them would be to discount the less risky one by a lower rate and the more risky one by a higher rate to reflect the fact that people demand a higher return for more risky projects. The discount rate used must be the return that would be expected from an alternative investment of equal risk. If there were no risk involved in the project, the correct discount rate might be the risk-free Treasury bill rate, since that would be a comparably risky investment. But with riskier projects, the discount rate must be adjusted upward accordingly.[6]

While a risk-adjusted discount rate is often used in NPV calculations, there are other ways of incorporating risk into a project selection analysis that uses financial criteria. These methods are discussed in the section on "Risk Analysis."

6/ For a more extensive discussion of these and related issues see James E.Hodder and Henry E. Riggs, "Pitfalls in Evaluating Risky Projects," Harvard Business Review, Vol. 63, No.1 Jan-Feb 1985, pp. 128-135.

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III. Further Analytical Techniques

While relatively simple screening methods such as checklists and simple profitability measures are frequently used to assess projects at every stage of the innovation process, other analytical tools are more informative in the later stages of the process. Most of these more rigorous techniques require both specialized knowledge of statistics, mathematics, or computer modeling, and more detailed input data. (These techniques are only introduced here; further explanation can be obtained in commercially available textbooks.) Again, it should be noted that all analytical techniques, the complex as well as the simple, are useful in augmenting a decision maker's judgment, not in replacing it. Such techniques enhance the intuition of a decision maker and make some of the parameters around the decision less abstract.

The next sections briefly address the basic concepts involved in the following techniques:

- Sensitivity Analysis, to ascertain if more sophisticated analysis is merited.

- Risk Analysis, to identify the probability distributions of important inputs and to assess their impact on project profitability.

- Decision Analysis, to further define the available project options.

A. Sensitivity Analysis

Because the more complex analytical techniques are often difficult and costly to use, they are worth using only when a precise analysis is important to the decision-making process. One way to determine if such further analysis is necessary is to perform a sensitivity analysis to identify factors that have the greatest impact on the success of a project. For example, the analysis can show which input factors, e.g., wages or raw materials, have the most impact on the expected rate of return. The risks related to the factors with the greatest impact, then, can be analyzed in more detail, and resources will not be wasted on analyzing factors that are not significant to the outcome.

The starting point of a sensitivity analysis is a financial model (usually on a computer) that calculates how changes in various market and cost factors affect some measure of business performance, such as the return on investment. Then sensitivity anlysis consists of varying each identified factor over a fairly wide range and recording the resulting measure of the profitability. Typically, such an analysis reveals that profitability is more sensitive to some factors than to others. The more important factors are then analyzed in greater depth.

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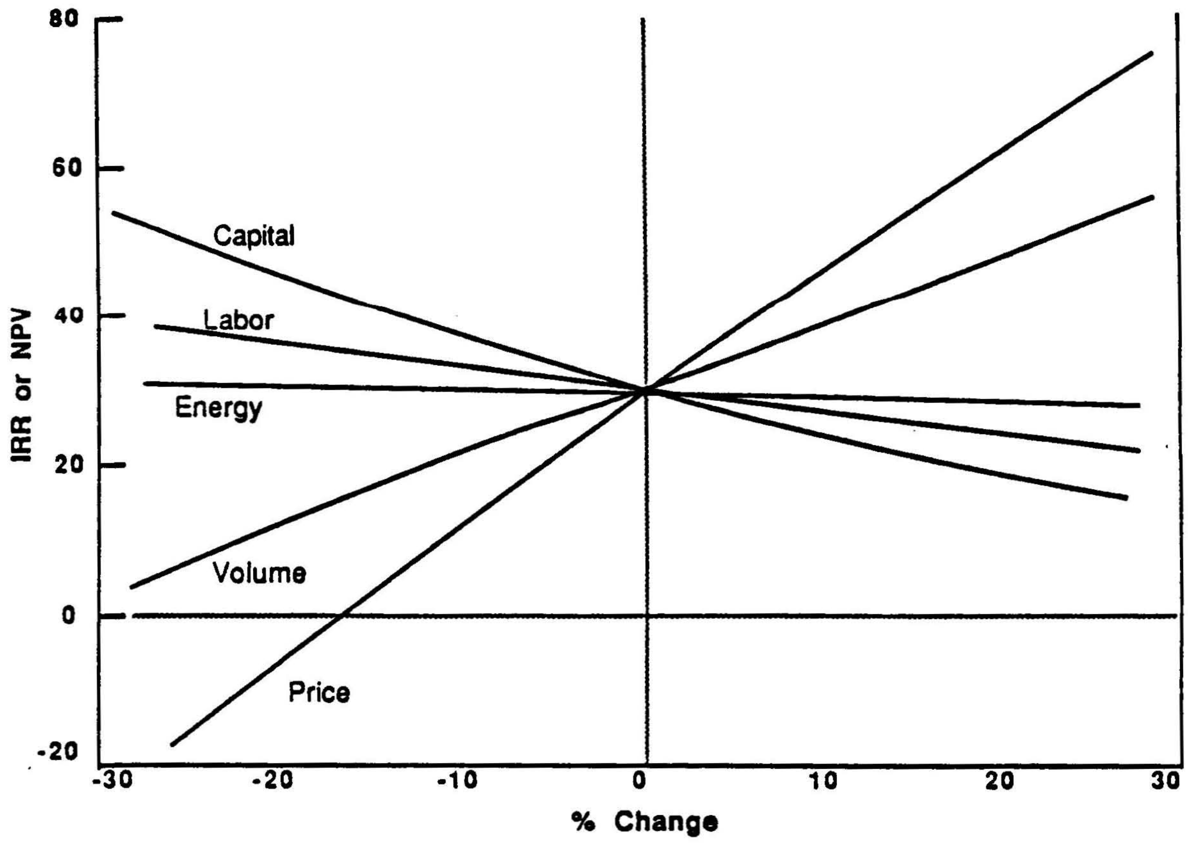
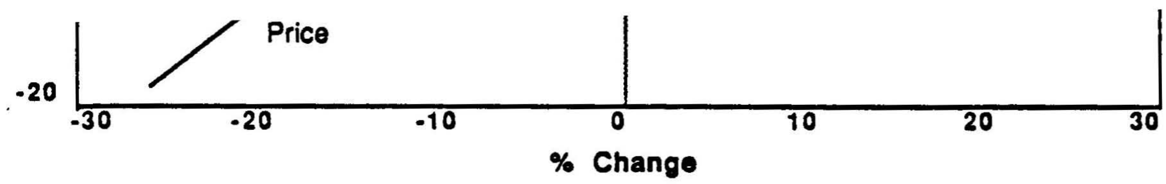
Technology and Innovation, illustrates the general approach to sensitivity analysis. For example, the model can be used to show how the rate of return on investment over the first five years of operations changes as labor costs, price or whatever is varied, one at a time, over the range of -30% to +30%. Graphs can be produced from these calculations to show the sensitivity curves for the various factors. Figure 7 displays the results of such a sensitivity analysis. The slope of each factor line indicates how sensitive the return is to changes in the factor; the steeper the slope, the more sensitive is the relationship.

In this case, the return is most sensitive to product price changes, and also to changes in volume and capital costs. It would be useful to analyze the risks of those three factors, or, in other words, to determine the probabilities that the values of those factors will not be what the company expects. The next section discusses some of the techniques that are available to analyze risk. (See Figure 7.)

Figure 7. Sensitivity Analysis - Graphic display of computer simulation





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B. Risk Analysis

Risk analysis isolates the sources and effects of risk in a project, and explicitly incorporates these effects into the valuation of a project. The first step in risk analysis is the sensitivity analysis discussed in the previous section; it identifies the market and input factors that have the greatest impact on a performance measure such as profitability.

Once the most significant variables are identified, the next step is to determine probability distributions for them. Sales, for example, might be estimated as a probability distribution with a range from X to Y and an expected mean or average value. (How the probability can be determined for each is discussed in the section on "Assessment of Probability.") With a probability distribution determined for the input variables, a probability distribution can be constructed the the NPV or other profit measure which provides more information than does the single-point estimate derived using traditional financial analysis. This provides good information as to the likelihood that the project will return significant profit, and, more importantly, the probability that it will lose money.

Two methods that can be used to construct probability distributions for the NPV or other profit measure are risk simulation and the use of normal approximation. Another method to explicitly account for risk is decision analysis. Descriptions of these methods follow.

1. Risk Simulation

The most common way to combine the probability distributions of the input variables is through risk simulation, which is a computer-assisted sampling procedure. Its use presupposes that a financial model of the project has been constructed on the computer; this model relates the significant input variables to the desired profitability measures such as NPV or IRR.

First, the probability distributions of all the input variables are estimated. These distributions are divided into a number of intervals, and the probability of each variable falling within each interval is calculated. This provides an approximation of the shape of each distribution and when programmed into a computer, enables the computer to replicate the distribution when it performs its calculations. The, after the computer calculates the input distributions, a random number program is used to draw points from each distribution and combine them (in a financial model) to calculate the NPV or the IRR. For example, one time the computer might draw $40,000 in sales, $35,000 in costs, etc., with a resulting IRR of 10%. The next time sales might come up as $25,000, costs as $23,000, etc., with a resulting IRR of 4%. This process is typically repeated serveral hundred times. The result will be many different values estimated for the performance measure, such as a probability distribution for the IRR, based on

points from each distribution and combine them (in a financial model) to calculate the NPV or the IRR. For example, one time the computer might draw $40,000 in sales, $35,000 in costs, etc., with a resulting IRR of 10%. The next time sales might come up as $25,000, costs as $23,000, etc., with a resulting IRR of 4%. This process is typically repeated serveral hundred times. The result will be many different values estimated for the performance measure, such as a probability distribution for the IRR, based on

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probability distributions of the input variables. Through the use of the computer simulation, it is possible to provide a clearer picture of what the distribution of the NPV or the IRR is likely to be. Dependencies in the risk simulation approach will complicate the process, but can be handled by sampling from conditional probability distributions given a value or range of values chosen for the independent variable. It is useful to draw up a decision tree (see the section on "Decision Analysis and Decision Trees" below) before performing a risk simulation to identify the critical points of a project and to provide insights into the full range of decisions and probabilities.

2. Normal Approximation

A "normal distribution" is a bell-shaped curve like the one shown in Figure 6 that shows the distribution of a variable symmetrical around a mean or average value. Not all distributions are normal, but many variables do tend to have this distribution. Furthermore, it is an attractive option for preliminary risk analysis because it is quite easy to use. First, if the normality assumption is reasonable, it is easy to estimate the distributions of input variables. It is sufficient to say something like, "There is a 90% chance that sales will be 125 units per month, plus or minus 25." Then, by using probability theory the shape of the curve can be estimated.

In some cash flow models, it may be possible to express the project's NPV or IRR as a "linear" function of the input variables, such as in the equation:

NPV = A +B(Sales) + C(Labor Costs) + etc.

where A, B, C, D, etc., are numbers that usually can be derived from the sensitivity analysis. For example, in Figure 7, C could be the slope of the Labor Cost line. In such cases, if the input variables are distributed normally, simple mathematical techniques can be used to estimate the probability distribution for a project's NPV or IRR based on the distributions of the input variables.

The assumption that all the input variables are normally distributed reduces the rigor of the analysis but statistical theory states that the sum of independent random variables tends to be normally distributed, even if the individual variables are not. Consequently, the validity of the technique most likely would break down only if there are only a few uncertain variables, if they represent skewed probability distributions, or if one variable dominates most of the uncertainty.

The main problem with the normal approximation results from the fact that two drastic simplifying assumptions must be made. The first is the assumption of independence among the variables and among the cash flows. In other words, there can be no correlation between any of the variables in the calculation of the NPV

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or the IRR, nor can there be any correlation between the cash flows of any two years. This is clearly an extreme assumption, and is hardly ever the case in a real project. However, the calculations are much more simple if this assumption is made. Otherwise, if dependencies are assumed, it is necessary to calculate a correlation coefficient, which would make the technique very complex and unwieldy.

This analytical method, then, is at best only a crude estimate of the mean and standard deviation of the NPV or IRR for research and development projects. Nevertheless, it serves as a useful first approximation, and if the results of this analysis show that the project is obviously good or bad it may not be necessary to do further analysis. Generally, however, it is not advisable to make a go/no-go decision solely on this basis given the analytical limitations described above. If it appears that the project may be feasible, more detailed analysis using either risk-simulation methods or the decision tree approach, which follows, should be considered.

Again, it should be emphasized that regardless of which risk analysis approach is used, it is important to carry out a sensitivity analysis first in order to determine the relative importance of the different variables. It is a time-consuming process to estimate probability distributions for each variable; consequently, this analysis should be carried out for only those variables which have the greatest impact on the valuation of the project. Also, in preliminary analyses the simpler "Normal Approximation" may be used.

C. Decision Analysis and Decision Trees

Decision analysis is the term applied to the formal analysis of complex business decisions. The basic tool of decision analysis is the decision tree. Decision trees show the sequence of events in a project; they show when critical decisions must be made and what the possible outcomes of those decisions are. For example, Figure 8 shows the possible results of a single decision: the company decides whether or not to improve a current technology, with the possible eventualities that a competitor does or does not come out with its own improvement and that varying degrees of market share are subsequently lost or gained. Costs and probabilities are associated with each possible outcome, so that expected values can be determined for the decision.

Such decision trees, then, are useful primarily where decisions made in the later phases of a project are dependent upon the outcome of decisions made and events occurring in earlier phases. This is generally the case when evaluating research and development projects. For example, decision analysis techniques are especially useful in projects where it is necessary to calculate the value of additional information, such as in a sequential decision-making process where it might be necessary to determine whether more research is needed before committing further resources

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to the project (Recall the chemical company example at the beginning of this booklet.) In such a case, the decision analysis approach can be used to compare the costs and expected returns of the project with the additional research to those of the project without the additional research.

Major advantages of the decision analysis approach to R&D project selection are that it is easy to explain and that it clearly identifies the options. It is easy to see what decisions need to be made, in what order they need to be made, what the results depend on, and in which areas there is the greatest risk. The major disadvantage of the approach is that, even in moderate-size projects, the decision trees can become large and unwieldly. Various techniques have been developed to cope with these difficulties, but they are sufficiently specialized that a full-fledged decision analysis of a substantial R&D project probably will need to be supported by specialists in the field. Nonetheless, the principles and basic tools of decision analysis are useful at any stage of even small R&D projects and are readily available in several textbooks which require only a very basic knowledge of probability theory on the part of the reader.

In summary, sensitivity analysis, risk analysis and decision analysis are different but mutually supporting ways of looking at an R&D project. The emphasis of sensitivity analysis is to identify those factors which are most important to the bottom line. The focus of risk analysis is on estimating how much variability or uncertainty surrounds the bottom line. And the thrust of decision analysis is to dissect the project to identify natural leverage points. All three will be needed to a greater or lesser degree in order to properly assess the potential of a proposed project.

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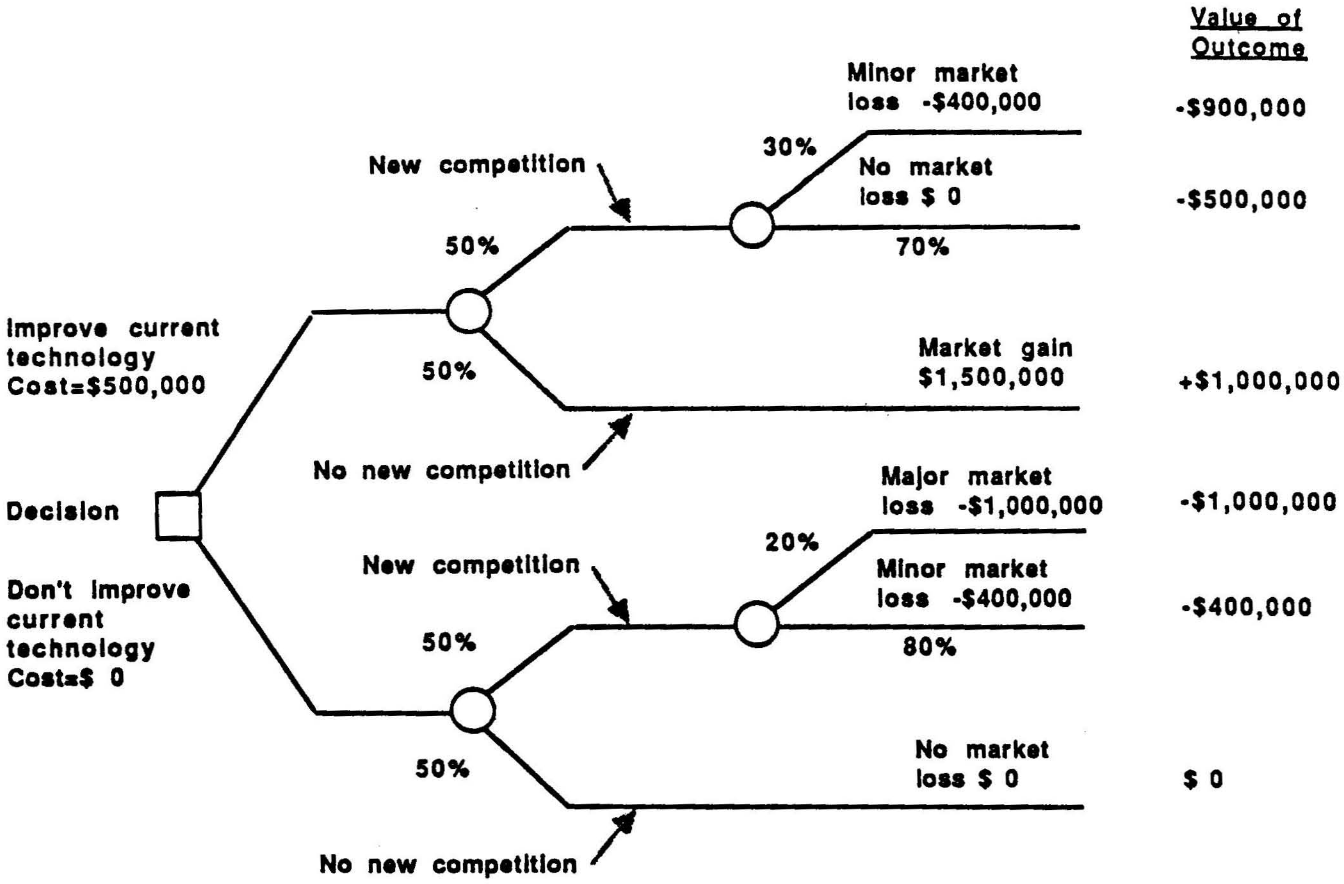
Figure 8. A Simple Decision Tree



Expected value of improving technology = [.3(-400,000)+.7(0)](.5)+(1,500,000)(.5)-500,000 = +$190,000

Expected value of not improving technology = [.2(-1,000,000)+.8(-400,000)](.5)+(0)(.5)-0 = -$260,000

D. Assessment of Probabilities

The preceding discussions were based on the assumption that probability distributions are available, and considered only how to apply them to a problem at hand, for example, how to combine the probability distribution of input variables in order to get the probability distribution of the NPV or IRR. It is now time to turn to what is probably the most difficult part of the risk or decision analysis processes, assessing the probabilities of the input distributions. There are two general methods for assessing probabilities, objective and subjective, that likely will be useful in the course of evaluating an R&D project.

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Objective probability assessment generally implies a historical basis for making an assessment. In other words, there is a record of past values for the variable that can be used to develop the probability distribution. Equipment reliability factors and market demographic factors are examples of the kinds of factors for which there may well be hard data available for probability assessment purposes. Even if full data are not available there might be a theoretical basis upon which a probability distribution could be estimated. For example, it might be known that certain variables are distributed in certain ways. More specifically, as was pointed out earlier, if the variability in a factor is the result of the accumulation of many relatively small disturbances, that factor likely will be well described by the normal distribution. While this sort of knowledge likely will not be sufficient to complete the probability assessment, it surely will reduce the difficulties involved.

Objective probability assessment rarely will be feasible for the most significant factors involved in high technology projects, since there is rarely a historical record or much research that has already been done for new technologies. So subjective probability assessments generally are required. The purpose of a subjective probability assessment is to quantify the judgment of an expert or group of experts on a particular variable. The distribution depends to a large extent upon the expert's range of information, how current the expert is in the field, and how carefully the questions have been specified. If very little is known about a subject, the distribution should be wide to cover all potential values. If much is known, the probability distribution assessed by an expert should be relatively narrow. Distributions should also change as additional information is obtained. As experts learn more, their distribution should either contract or shift on the basis of new information. Subjective probability assessment is directed toward eliciting these judgments in ways that will produce results which are reliable and accurate and which can be accumulated with similar results from other experts to give an overall picture of the risks involved in the project.

There is considerable disagreement among experts as to how best to elicit these judgments. All agree, however, that it is important, when using subjective probability assessments, to be as specific as possible about the variable in question. The more vague the question, the more likely it is that there will be misinterpretations. For example, rather than asking an expert, "What is the probability that sales will grow substantially?" it is better to ask, "What is the probability that sales will exceed $250,000 in the first twelve months of operation?"

To take a simple example, a novice's estimate of the likelihood that the number of spots on the upturned faces of two well-thrown dice will add up to two, three,..., twelve should eventually converge to the theoretical (objective assessment) distribution as he or she gains more and more experience in the game. If the dice are loaded, however, the observant novice's subjective

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distribution will tighten with experience, and make more and more reliable predictions, but will never converge to the theoretical distribution, which in this a case would not coincide with an objective probability assessment anyway. Indeed, with loaded dice an objective probability assessment would require extensive analysis which in the end would not produce more useful predictions of the next roll than those of the novice who patiently watched and recorded the results of many rolls until he or she became an expert on the behavior of that particular pair of dice.

Methods of subjective probability assessment include fixed interval methods, variable interval methods, and reference devices that can be used to estimate probabilities. In a fixed interval method the expert is asked to state the probability that a variable will be within a specific fixed interval. For example, the question would be phrased, "What is the likelihood that sales will be between 10 and 15 million?" The variable interval method is the reverse. The expert would be asked to state the value of a variable for a specific fractile of cumulative probability distribution, usually .01, .25, .5, .75, and .99. The question might be, "There's a 1% probability that sales will be above what level?"

In either case the analyst must be aware of certain biases commonly seen in people making probability assessments. These include "anchoring" on the first number given, i.e. the expert focuses on that number and subconsciously biases subsequent answers so he or she constructs a distribution that "fits" the first answer. To avoid this bias in estimating probabilities it is useful to use reference devices. One such reference device looks much like a roulette wheel except that there are no numbers and instead of alternating red and black spokes, sections of the wheel can be varied in color. Thus, to represent a decision with three to one odds, the spokes on one quadrant of the wheel might be red while those on the other three quadrants are black. With this method, the expert is generally offered many choices between unknown probabilities related to the project and various fictitious gambles where the odds are discernible by inspecting the wheel with various numbers of red & black spokes until the desired project probabilities are bracketed within acceptably narrow bands. Perhaps because the numbers involved need not be explicitly stated, this approach seems to alleviate the anchoring problem.

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CONCLUSION

Formal probability assessments are used only during the later stages of an R&D project. In moving through the development process, the simpler steps should be done first. A checklist approach will be appropriate at the idea stage. Later, at the preliminary assessment stage, qualitative scoring model approaches will be called for. A simple cash flow model to estimate the NPV of the project, for example, might be the first quantitative step in evaluating a research and development project. It would come into play no later than the concept stage. Next would come a sensitivity analysis to identify the most crucial variables. Once the variables are identified, it will be useful to structure some simple decision trees using two or three branches at each node to depict management choices, competitor choices and overall probabilities. This will more clearly illustrate the dependencies among the variables and provide a sense of whether the project is clearly acceptable or not. It also will be useful at this point to perform a second sensitivity analysis on the probabilities to see how much precision is required in estimating them. At this point, the probability distributions for the most important variables can be assessed, by a combination of objective, theoretical, and subjective assessments. From this analysis, more complex decision trees can be constructed as needed, and risk simulation can be used, based either on the project's financial model or directly on the decision tree, to generate a risk profile for the project.

Analyses should be performed early in the development stage and repeated at appropriate points throughout development, testing, and trials as more and more information becomes available.

Some summary points deserve to be emphasized in conclusion:

- Information is required to effectively match resources to technology projects; as a project progresses and more resources are needed, the value of information increases. While the emphasis in this booklet has been on analytical tools for R&D project selection, the fundamental point that information is critical needs to be kept at the forefront. As old test pilot put it, "My fundamental job is to ensure that we all are operating from the same set of facts."

- While decision makers must ultimately rely on their own judgment, they should be aware of the analytical tools available to help them determine what information they need and how that information can be organized.

- Some analytical tools are simple and can be used effectively by most people at the beginning stages of the innovation process; other techniques are more complex and costly, requiring special exper-

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tise and data, and are more appropriate to the later stages of the innovation process.

- No matter what the analytical tools, the input information must be reliable and accurate for the decision to be well made; "garbage in, garbage out" is not the watchword of computer modelers for no reason. In particular, as a project progresses and more and more powerful quantitative analytical tools are brought to bear on the decision process, care is required to avoid infatuation with the quantitative to the neglect of the qualitative factors. Maintenance and updating of some variant of a scoring model throughout development, test, and trials is a healthy discipline.

- Ultimately, as U.S. industry (entrepreneurs, companies, investors, and financial intermediaries) takes maximum advantage of its unparalleled opportunities and resources and makes sound decisions about selecting and developing technologically innovative projects, the U.S. will be able to compete more effectively and maintain its dominant position in world markets.

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FOOTNOTE

The approaches to research project selection recommended in this booklet are not universally accepted by experienced R&D managers. For example,

> "In recent years formal business planning has stressed the risk weighted, discounted rate of return on R&D projects. The professional literature bulges with methodologies for R&D project evaluation that focus on estimates of potential markets, project costs, and probabilities of success. For slow-growing and protected industries, these methods have been successful. For fast-moving and worldwide industries they have been a disaster. The Japanese and Western entrepreneurs have outflanked and overwhelmed companies relying on such hands-off analytic models."7/

In the authors' judgment, the fault in such arguments is that they pose a specious "judgment versus analysis" dichotomy. They tend to support the idea that R&D evaluation is solely an exercise in intuition. Unfortunately, such rejections of rational approaches are far too common in the current U.S. business environment.

The damage done by purely intuitive approaches to project selection fall into two broad categories. The first can be characterized as "hip shooting." Too many projects have been funded in America and then failed miserably for lack of adequate analyses of the kind described in this booklet. The number has been great enough to contribute to a tangible, although unquantifiable, discrediting of technology innovation in the U.S. 1984 and 1985 capital markets. The authors' plea, therefore, is, "No matter how impatient you may be with formalities, force yourself to go through at least a checklist before throwing money at a proposed R&D project."

The second kind of damage is what we call "conservative paralysis." That is, if a project fails to fit into a familiar and predictable mode, it simply receives no support. There is, of course, an analytical version of "conservative paralysis." Indeed, many of the innovators who (like the author quoted above) reject formal analytical approaches, do so because of wrenching experiences with absolutely unimaginative drones who, to borrow a phrase, "knew the cost of everything and the value of nothing." Calculating an IRR by rote using only "conservative" assumptions at each step is a formula for rejecting innovation. It is sure to

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7/ Schmitt, R.W., "Successful Corporate R&D," pp. 124 -128, Harvard Business Review, Vol. 63, No. 3, May-June 1985

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cast a bad light on innovation. But, as should be clear from the earlier discussion, such an approach is no more than using numbers to mask a fear of the unknown. The scoring model approach to project selection tends to force these intuitive fears out of hiding into the light where they can be assessed and placed in context.

In summary, the authors recommend an orderly disciplined approach to project selection which incorporates both analysis and judgment. At minimum some sort of checklist approach should be used in R&D project selection. Indeed, this is the most appropriate approach at the very early stages of a project. Moreover, at later stages the authors recommend using a scoring approach -- based largely on intuitive inputs early on, but increasingly based on analysis and research later. At no point, however, should the decision process degenerate into an exercise in numerical calculations; judgment will always be crucial. The discipline of the scoring model approach -- supported by quantitative analysis and probability assessments to a greater or lesser extent depending on whether a large or small investment decision is at issue -- will be valuable in helping entrepreneurs, investors, and financial intermediaries involved in technology innovation to avoid the Scylla of "conservative paralysis" and the Charybdis of "hip shooting."

We firmly believe that a substantial increase in the application of these approaches, even imperfectly, will produce a significant improvement in the employment of our national resources.

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