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MEASURING BENEFITS OF MANPOWER, PERSONNEL, AND TRAINING (MPT) RESEARCH AND DEVELOPMENT

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The Air Force is constantly trying to develop new or improve existing tools to increase the efficiency in the way personnel life cycle resources are managed. One metric, commonly used, is based on utility. This research produced a utility assessment technology to aid decision makers. This technology involves the process of identifying, measuring, and combining attributes to create an explicit value structure to form a basis for evaluating MPT research projects and selecting the most beneficial and cost effective portfolio of MPT research efforts. Four different techniques were evaluated and compared, those being utility analysis, cost benefit analysis, production functions, and decision theory. The research identified cost benefit analysis and decision analysis as being most applicable to MPT research projects.

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PREFACE

The work documented in this report is a component of the Quality Force Models unit of the Manpower and Personnel Division's manpower and force management systems research and development program. It was accomplished as part of Project 7719, Force Acquisition and Distribution Systems and Task 771920, Manpower and Personnel Models. The tool will improve the conduct of manpower, personnel, and training research, and allow personnel managers and force planners to make more informed resource allocation decisions to achieve the Air Force's mission.

LIST OF ACRONYMS

AFHRL	Air Force Human Resources Laboratory
AFHPSP	Armed Forces Health Professions Scholarship Program
AFQT	Armed Forces Qualifying Test
AFROTC	Air Force Reserve Officer Training Corps
AFS	Air Force Specialty
AFSC	Air Force Specialty Code
AI	Artificial Intelligence
ANOVA	Analysis of Variance
ARPTT	Air Refueling Part Task Trainer
ASVAB	Armed Services Vocational Aptitude Battery
ATC	Air Training Command
BMT	Basic Military Training
CAT	Computerized Adaptive Testing
CBA	Cost Benefit Analysis
DoD	Department of Defense
ENJJPT	EURO-NATO Joint Jet Pilot Training
FAR	Fighter-Attack-Reconnaissance
IDMS	Integrated Decision Modeling System
IMIS	Integrated Maintenance Information System
JDI	Job Difficulty Index

MAC	Military Airlift Command
MPT	Manpower, Personnel and Training
OJT	On-The-Job Training
OTS	Officer Training School
PACE	Processing and Classification of Enlistees
PJM	Person Job Match
PROMIS	Procurement Management Information System
R&D	Research and Development
RPR	Request for Personnel Research
RRC	Research Review Council
SMART	Simple Multiattribute Rating Technique
SME	Subject Matter Expert
TAC	Tactical Air Command
TTB	Tanker-Transport-Bomber
UDB	Unified Data Base
VOICE	Vocational Occupational Interest Choice Examination
WAPS	Weighted Airman Promotion System

SUMMARY

To support the personnel life cycle it is imperative the Air Force improve existing tools and develop new ones to increase the efficiency with which human resources are managed. Defining and measuring the benefits of human-centered manpower, personnel, and training (MPT) research and research products are key to effective allocation of scarce research resources.

A commonly used metric for selecting among alternative actions is based on utility. It is through the use of the utility assessment process that the positive and negative attributes of a prospective alternative outcome are combined into a single assessed value. This research produced a utility assessment technology to aid decision makers. This technology involves the process of identifying, measuring, and combining attributes to create an explicit value structure to form a basis for evaluating MPT research projects and selecting the most beneficial and cost effective portfolio of MPT research efforts.

Four specific approaches offered potential for building assessment models: utility analysis, cost benefit analysis, production functions, and decision theory. Each of these techniques were evaluated and cost benefit analysis and decision analysis were found to be the most applicable to MPT research projects. A prototype model was developed incorporating these two techniques. The prototype is a three branch hierarchy with cost, benefit, and feasibility as the branches. The dollar values from the cost and benefit branches are combined with a standardized value from the feasibility branch to produce a final payoff dollar value. This dollar value can be used to help in the ranking of the projects but should not be used as a literal value. The research in this area, in light of budgetary constraints, will allow the MPT research community to make positive, supportable statements about the value of its research products.

I. INTRODUCTION

In light of ever-tightening budgetary constraints, it is imperative that the Manpower, Personnel, and Training (MPT) research community be able to make positive, supportable statements about the value of its research products. Moreover, the Manpower and Personnel Research Division of the Armstrong Laboratory's Human Resources Directorate (AL/HR) must decide the proper mix of its research efforts including selection and classification, job restructuring and determination, training, testing, and MPT decision aids and models. The decision rule in allocating scarce research dollars, given differences in fixed or accumulated intellectual capital in each of the research areas, should be such that the marginal benefit per dollar spent in each area be equal. However, it is difficult to direct the efforts toward the most potentially beneficial research areas when benefits are uncertain. This report discusses approaches for quantifying the benefits of Air Force research and development in MPT technology. The sections which follow provide information on methods of measuring benefits of MPT research and development. Section I continues with the technical approach and the background of utility assessment. Section II describes Evaluative Techniques addressed. Section III discusses application of techniques and Section IV presents analysis results and a discussion of possible problem areas with each technique. Section V presents the conclusions and recommendations.

Technical Approach

Commonly, the utility (or psychological value) approach is used in selecting among alternative actions. Utility is the concept used to differentiate between alternatives. It is through the use of the utility assessment process that the pros and cons of a prospective course of action are combined into a single assessment value. Intuition tempered with some analytical reasoning has often been used as one approach to utility assessment. This is reasonable, but experience shows that a systematic approach is generally more worthwhile. A technology of utility assessment which aids decision makers in making these kinds of decisions has been developed (Fast & Looper, 1988; Fast, Taylor, & Looper, 1991). The technology involves identifying, measuring, and combining attributes to create an explicit value structure and form a basis for evaluations and decisions.

Utility Assessment

Steps in the formal utility assessment process include:

1. Identify the perspective from which utility is to be assessed.
2. Determine the scope of the problem and identify the overall objective of the utility assessment.
3. Identify the set of alternatives to be evaluated.
4. Determine the attributes on which the alternatives are to be assessed.
5. Develop measures for each attribute.
6. Choose an assessment model.
7. Evaluate each alternative using this model.
8. Select the best alternative (or rank the alternatives).

The first three steps structure the assessment problem and answer the questions of whose utility, for what purpose, and for which alternatives. The next two steps define the value structure over which the alternatives are to be assessed. The last three steps concern the more mechanical steps of assessment of each attribute and synthesis into a decision criteria for selecting alternatives. This process has been used extensively by AL/HR in decision modeling and has been automated in the Integrated Decision Modeling System (IDMS) prototype (Fast, Taylor, & Looper, 1991). The steps are as follows:

Step 1. Identify the Perspective from Which Utility Is to be Assessed

This research effort involves assessing the benefit of MPT research and development (R&D). The perspective could take several forms, including that of a single decision maker such as the AL/HR director, a decision making body such as the Research Review Council (RRC), or a regulatory body such as the U.S. Congress. Choosing the RRC's perspective would narrow the scope of the problem. The RRC makes limited choices among MPT R&D alternatives and attempts to rank these alternatives to determine funding priority. An alternate perspective is that of the Air Force R&D funding issue. This perspective is useful in that we might be able to assess MPT projects along with hardware projects on a common metric. For purposes of the current project, the perspective used is the decision maker who makes alternative funding decision at the AL/HR level.

Step 2. Determine the Scope of the Problem and Identify the Overall Objective of the Utility Assessment Situation

A model developed using the AL\HR level perspective might be useful in defending MPT R&D allocations even at the congressional level. The overall objective of our assessment procedure is then the determination of the payoff to the Air Force of any MPT project expressed in monetary terms for comparison among projects. Thus, the AL\HR level perspective is used to develop the present model, but the user of the model will have the ability to narrow the perspective to that of the RRC without jeopardizing the credibility of the results.

Step 3. Identify the Set of Alternatives to be Evaluated

The set of alternatives in this assessment is all Air Force MPT R&D projects being considered for funding in a fiscal year. For assessment purposes, a subset of 30 hypothetical projects were used. Using this subset of 30 projects an actual assessment model was built following steps 6 and 7 above.

Step 4. Determine the Attributes on Which the Alternatives Are to be Assessed

The attributes for this assessment project depend on the technique used in the evaluation. Four alternative techniques for combining the attributes and their measures were considered: utility analysis, production functions, cost benefit analysis, and decision analysis. Each of these techniques including its corresponding attributes to be assessed, is briefly described in Step 5 and in more detail in Section II.

Step 5. Develop Measures for Each Attribute

In utility analysis measures are needed to estimate the returns and costs of undertaking a new R&D project. Expert judgment is often used to estimate both the utility(or value) of the project and its costs (though historical data on similar or related projects may be useful).

Production function analysis requires measures for such factors as labor and capital investment levels. Regression analysis is often being used to relate these factors to the output or benefit.

Step 6. Choose an Assessment Model

In this step, the analyst must choose an assessment model, which is used to combine the attributes selected in Step 4 and the measurement in Step 5 into a single measure of value. The models can take many forms, but this discussion is limited to the four techniques that were evaluated in Step 5. In this step, these four models are further developed so that each technique can be evaluated for use in the R&D project assessment context. We automated each of the four techniques to facilitate evaluation of the 30 sample projects. Software implementation of each technique is described in Section III.

Step 7. Evaluate Each Alternative Using the Assessment Model

The next step is to apply each model to 30 different R&D projects. Each of the 30 projects were evaluated using the four techniques. The results and conclusions from the evaluations are described in Section 4. After the evaluations, a single model (or combination of models) which best suits this context was developed. This prototype model could be automated and easily applied by subject matter experts (SMEs).

Step 8. Select the Best Alternative or Rank Order the Alternatives

In this step the automated process is used with a single project or a group of alternate projects. It produces a value for each project to determine the best project or a rank ordering of all the projects. The final value, and thus the rank ordering, depends on the technique used.

II. DESCRIPTION OF EVALUATIVE TECHNIQUES

Utility Analysis

Perhaps one of the most actively researched methods for assessing the utility of alternatives in psychological literature is the utility analysis model (Hunter & Schmidt, 1983). This method has most often been used to quantify the utility of selection tests or other organization interventions to improve worker productivity. The basic utility concept was first introduced by Taylor and Russell (1939). Refinements and elaborations to the basic model include work by Brodgen (1949) and Cronbach and Gleser (1965). More recently, economic variables have been incorporated into the Cronbach and Gleser formulation, (Boudreau, 1983). Matthews, Looper, & Engquist (1990) present an excellent annotated bibliography on work using utility models. The discussion that follows suggests how utility models may assist research managers in allocating scarce research budgets across competing projects.

Utility analysis is conceptually very similar to cost benefit analysis (CBA), although the application of the two techniques can be different in the measurement of benefits and costs, because of the difference in the perspective of the various disciplines. Benefits from an economic perspective encompass the monetary evaluation of consumer welfare, which psychologists view as ignoring many factors associated with the performance of the job and the work environment. Economists envision improvements in productivity as directly translatable into the competitive market wage which is presumed to encompass both monetary and nonmonetary aspects of the work. The psychology discipline emphasizes the impact of psychological manipulations such as selection tests and training which are often the focus of manpower research programs.

The military provides one of the largest firm specific training programs of any public or private organization (Stone, Rettenmaier, Saving, & Looper, 1989). Because of large dollar investments for training, the Air Force is interested in any selection procedure that will improve productivity or the probability of worker success. Reduced training washout rates will decrease overall training costs. Utility analysis offers one method of evaluating the costs versus the benefits of a given selection test or post-selection organizational intervention in practical terms. See Matthews et al., (1990) for a complete description for the utility analysis technique. Matthews et al., (1990) also contains a mathematical description of the *utility analysis model* and examples of its use with pre- and post-enlistment intervention programs.

Production Function

The supply of goods and services fundamentally depends on the production function and the supply of factors of production, such as labor and capital. A production function defines a relationship between inputs and outputs while yielding the maximum output for a given level of inputs. Production functions have been estimated for numerous micro-level (DeVany, Gramm, Saving, & Smithson, 1983; Reinhardt, 1972) and macro-level analyses (Griliches, 1987; Mansfield, 1980). The standard production function can be expressed as:

$$Q = f(x_i) \tag{1}$$

where Q is the quantity produced and x_i are inputs, such as labor, capital, and R&D. R&D is usually a separate activity from the actual production of a firm's product. However, R&D generates improved technology which enhances the productive capacity of all combinations of labor and capital. R&D can also produce new products to be sold by the firm which increases revenues. For example, firms in the pharmaceutical industry direct their R&D efforts toward developing and testing new drugs. These drugs are then sold to the public, increasing the sales and revenues of the firm.

The Effect of R&D in the Production Function

The effect of R&D on production can be formalized to:

$$Q = ae^{gt}\, C^{b}\, L^{c}\, K^{d}\, e^{u} \tag{2}$$

or

$$\ln Q = (\ln a) + gt + b(\ln C) + c(\ln L) + d(\ln K) + u \tag{3}$$

where a represents other forces which affect output and change systematically, g is the rate of technical change, C is a measure of capital, L is a measure of labor, K is a measure of accumulated and still productive research capital, t is a measure of the growth rate, and u reflects all other random unsystematic fluctuations in output (Griliches, 1984). The coefficients are represented by b, c, and d. Equation (3) is a logarithmic transformation of equation (2), allowing estimation of the production function with ordinary least-squares regression (Kmenta, 1971). The production function in equation (2) is a Cobb-Douglas production function which assumes constant returns to scale, i.e., an increase in all inputs by a common percentage increases output by the same percentage (Zellner, Kmenta, & Dreze, 1966). Thus, percentage increases in the stock of research capital result in constant percentage increases in output regardless of the scale or overall productive capacity of the operation.

K is expressed as the summation of a weighted average of past gross investments in research. R&D is represented as a stock of research capital since products or services which result from research generally are not produced by a single research effort but represent the output of numerous research efforts as well as the change in the stock of human knowledge. Research activities often build on one another, taking advantage of past knowledge and discoveries. The approach taken to weight past investments in research depends on how important past research is to present R&D efforts. A geometric weight which assigns larger weights to more recent research investments could be applied to past investments in R&D (Griliches, 1984). The Cobb-Douglas production function has been used often to assess the contribution of R&D to aggregate and/or industry output (Griliches, 1986; Mansfield, 1980). Other, more complicated production functions may be suitable for MPT R&D (Henderson & Quandt, 1958) but past research efforts indicate that the form selected for the production function is not critical to obtaining consistent estimates of the relationship (Griliches, 1984).

Key Issues Identified in Past Research

Two key points have been made in past research concerning the contribution of R&D to output on the firm and/or national level (Griliches, 1986; Griliches, 1987):

(1) The stock of R&D capital contributes significantly to the explanation of cross-sectional differences in productivity.

(2) Firms which spend a larger portion on basic research rather than applied research are more productive.

The military MPT R&D is often categorized as applied rather than basic research although the benefits of each may not be easily differentiable. Mansfield (1980) used chemical and petroleum industry data to determine that the overall rate of return to R&D, basic and applied, is approximately 27%. Jaffe (1986) reported similar results, while Clark and Griliches (1984) reported an 18% to 20% return. Mansfield also found basic research to be far more beneficial to productivity than applied research. This may reflect a tendency for basic research findings to be exploited more fully or for applied R&D to be more effective in conjunction with some basic research.

Analysis of MPT R&D at the Aggregate Level

A times series analysis of aggregate expenditures for MPT R&D could provide the marginal contribution of research to the dollar cost of maintaining a fixed force size or a fixed pilot force or a fixed number of missions flown, etc. The characteristics of the force such as mental category, race, sex, education level, etc., must also be considered since these factors comprise the productive attributes of the fixed force. Aggregate studies use sales or value-added as Q in equation (3) (Griliches, 1986). The proxy for Q in an Air Force study could be the total dollars required to maintain a given force size.

The military production function equation to be estimated can be expressed as:

$$\ln Q_t = (\ln a_t) + b(\ln C_t) + c(\ln L_t) + d(\ln K_t) + e_i(\ln D_{it}) + u \qquad (4)$$

where D_{it} is the ith attribute of the force such as average Air Force Qualifying Test (AFQT) score, proportion of females, proportion of high school graduates, etc., in time period t. The estimated equation will provide input elasticities for each of the inputs, C, L, and K, directly from the estimated values of b, c, and d in equation (4). An input elasticity is defined as the percentage change in output due to a percentage change in an input. For example, if the value estimated for d in equation (4) was -0.1, then a 10% increase in the accumulated stock of research capital would result in a 1% decrease in the cost of maintaining a given level of output. If output was defined as the dollars required to maintain a constant attribute force level, the 10% increase in K would result in a 1% decrease in the cost to maintain the force. For an $8 billion personnel budget, a 1% decrease would equal $80 million.

The personnel budget figures used in equation (4) as Q_t should include the full investment cost (Stone et al., 1989) to train, compensate, and maintain the fixed attribute force for one time period. Since MPT R&D can affect accession and retention policy, training costs or effectiveness, and compensation policy or programs, the calculation of the full investment cost of the force will reflect cost savings or increases due to the implementation of MPT R&D technology. Thus, the $80 million savings projected in the previous example may be a reflection of reduced attrition, while the nominal cost of the personnel budget may remain constant.

An alternative approach to measuring the success of basic research projects was published in 1983 by Irvine and Martin. They proposed the use of citation evidence along with peer review to determine the productivity or efficiency of basic research performers. They analyze R&D as a separate production process instead of an ancillary activity to the production flow of goods. Although this methodology is intriguing and could be very useful in the future, it does not apply to this particular research effort.

Steps to Estimating the Production Function of MPT R&D

Several key steps must be taken to estimate a production function for MPT R&D in terms of the contribution to the production of national defense at the aggregate or project level.

(1) Determine an appropriate measure of output, Q, for national defense and/or a measure of total benefits.
(2) Determine appropriate measures of the inputs to the production of MPT R&D such as labor hours in total or by labor category (e.g., senior scientist), years of cumulative research experience, contribution to capital, computer hours, basic and applied research, technological change, etc.
(3) Identify potential surrogates which may be used for components of the production function.

Cost Benefit Analysis

Cost benefit analysis (CBA) is a way of deciding what society considers to be the most efficient allocation of resources (Casio, 1991; Stevenson, 1990). When only one option can be chosen from a series of options, CBA can inform decision makers as to which option is most preferred. For the analysis of MPT R&D, CBA is used as an analytical framework to evaluate whether a research project should be undertaken. With limited investment or research funds, CBA can provide insights into the combination of projects to be performed. The approach requires systematic enumeration of all benefits and costs that will accrue to society as a whole if a particular project is selected. This includes tangible and intangible benefits and costs, which may be either easily quantified or difficult to measure. The rationale for CBA is economic efficiency, ensuring that resources are put to their most valuable use.

In principle, the procedure followed in a CBA study consists of five steps.

1. Identify the project or projects to be analyzed.
2. Determine impacts, both favorable and unfavorable, present and future, on society.
3. Assign values, usually in dollars, to these impacts. Favorable impacts are registered as benefits, and unfavorable ones are registered as costs.
4. Calculate the net benefit (total benefit minus total cost).
5. Select the best (in terms of net benefit) project.

The mechanical elements of CBA are decision rules to determine whether a project or projects should be undertaken and, if so, at what level of effort.

The formal rules for CBA are just the beginning of the decision process. The decision maker must decide which rule is appropriate in any particular circumstance. For example, the net benefit approach of cost benefit analysis may be more or less appropriate for a specific instance than the benefit/cost ratio approach. Similarly, expected values may be more or less appropriate than actual values, depending on whether the environment is one of certainty or uncertainty. Removing a complex problem from its environment and placing it into a CBA framework helps to determine which aspects are relevant to the decision making process. The level of detail and sophistication on which an analysis is conducted is an essential element. For example, perhaps the costs and benefits of past and subsequent projects should be considered in addition to the complete analysis of the project at hand. The decision maker must also compute estimates of benefits and costs. This can be a very complex process, depending on the definition of benefits and costs as well as the level of sophistication of the analysis.

Valuation of Benefits and Costs for MPT Research and Development

Evaluation of research began with the analysis of rather small scale projects, mainly in medicine, experimental and social psychology, educational psychology, and economics. In economics, the basic approach was cost benefit analysis. The current practice of program evaluation research by economists is different from water resource projects and other previous evaluations which were the mainstay of traditional CBA. In more recent evaluations, the first priority is estimation of the quantitative effect of the program which logically precedes the determination of whether the benefits exceed the costs.

Consider the proposal of research to support the development of a new selection tool that would allow the Air Force to better allocate new recruits to Air Force career fields. Should this research be funded? How can the benefits to the Air Force be quantified? What is the end product of this new selection tool, more satisfied recruits or more productive recruits or both? Does the increased job satisfaction translate into decreased turnover which in turn means that the Air Force is providing a particular capability at a lower cost? Can the increased productivity of new recruits be directly measured as a result of better matching individuals to jobs? Can the reduced attrition, if any, be projected as a part of reduced costs to maintaining the force?

The application of cost benefit analysis to the development of a new selection tool begins to address these questions. The analysis requires information to assess the magnitude of the two basic components, benefits and costs. Once the costs and benefits have been identified and measured, the decision maker has numerous options provided in CBA literature from which to select a rule for acceptance or rejection of the project.

Enumeration of Project Benefits

First, the benefits of the project must be identified. The direct benefits are usually apparent but not always easily quantified. The new selection tool should more appropriately match the skills of the recruits to the requirements of the career field. Thus, given the mechanical, electronic, and other skill requirements of the career field, recruits are matched to their jobs. Better matching of individual skills and career field mental requirements could reduce attrition and washout during technical training. In addition, potentially fewer recruits could be required to begin the training since a higher ratio of success is expected due to the use of the selection tool. Training costs could decline at Basic Military Training (BMT) and technical training since fewer recruits may be needed to fulfill a given manning requirement.

If individuals are more appropriately matched to career fields, one might expect increased job satisfaction and, thus, a lower attrition rate at all decision points along the normal career path. Improved job satisfaction can offset opportunity costs which may exist for the individual as he/she attains more experience in a particular career field, contributing to reduced attrition. Improved job satisfaction could also contribute to a higher level of productivity; a happy worker is a productive worker. Higher productivity levels would increase the level of national defense produced for a given force size.

The estimation of the value of the improved productivity can be performed through the use of civilian occupationally-equivalent wages (Stone et al., 1989). The theory to support the use of the civilian wage as a proxy is based on the competitive demand for labor. The labor demand schedule is a derived demand; it is dependent upon the demand for the product that the labor produces. In the case of the Air Force, labor demand is dependent upon the demand for national defense. The demand schedule for labor in a particular industry is the value of the marginal product of different quantities of labor to that industry. This value is simply the price of the output times the marginal product of the particular unit of labor used in producing a given amount of output. In a competitive industry the wage rate is equal to the value of the marginal product. Theoretically, this model of labor demand establishes a relationship between market wages and productivity; the market wage is equal to the value of the marginal product of the airman in a competitive labor market.

At best, the use of civilian wages to estimate the value of the improved productivity will give a lower bound estimate of the benefits since the intangible benefits are not included in the calculation. Given data limitations, however, this approach will provide as good an estimate as possible. If an estimate of the percentage increase in productivity can be projected due to the implementation of the selection device, the value of the increased productivity can be obtained by multiplying the percent increase by the civilian wage.

The final step to estimating the benefit of the selection device would require accounting for the improvement in retention as reflected by an increase in the mean length of time an airman would remain in the Air Force, the mean length of stay. The increase in the mean length of stay would be multiplied by the average salary for comparable jobs in the private sector to obtain a gross estimate of the increased benefit to the Air Force due to the increased duration attributable to the implementation of the new selection device. The sum of the estimated value of increased retention and the estimate of the value of increased benefit due to increased productivity is the total benefit to the Air Force resulting from the introduction of the new selection device.

Enumeration of Project Costs

Besides the gross benefits, costs are an equally important consideration. Both economic cost and the accounting or financial cost of a project should be included in any cost benefit calculation. The accounting cost is the monetary value of the resources devoted to the project. Costs in this instance include the development costs associated with the project such as materials, salaries, and equipment, as well as administrative costs such as costs to administer and maintain the selection device. The economic or opportunity cost, however, is the benefit forgone by not developing the next best project. For example, this type of cost within the context of R&D project selection is the value or benefit associated with the highest valued project not chosen. This suggests that at the beginning of any CBA study for an R&D project it is necessary to identify all alternative research projects which involves assigning monetary benefits to all other possible projects. Although the work load is increased as a result of the need to capture all alternative benefits, the process forces decision makers to think through the entire portfolio of feasible projects and examine the various trade-offs before making a decision. Thus, the total cost of a project is then the actual development and administrative costs plus the opportunity cost.

Decision to Perform or Abandon the Project

The rules of choice are simple in a world of perfect certainty, independent alternatives, and unlimited resources. They become more complicated when uncertainty, complementary and substitutable alternatives, and budget constraints enter the picture. CBA assumes that a project is worthwhile if its benefits exceed its costs. Unfortunately, budget constraints often prohibit the funding of all worthwhile projects. Thus, a means or methodology for ranking worthwhile projects is necessary. Projects can be ranked on the basis of net benefit (benefits minus costs), ratio of benefits to costs, expected net present value, or internal rate of return, recognizing that potential inconsistencies can arise in the selection process between methodologies. In addition to using CBA as a means for selecting projects, additional weight can be given to those projects which decision makers deem essential to the maintenance or performance of the Air Force mission. Thus, a project which may exhibit a small net benefit could receive significant funding support because of the importance of the project as perceived by principle decision makers. CBA provides a tool with which to evaluate projects by a common unit of measurement, but should be tempered by the opinions of individuals who understand the overall picture in the performance and maintenance of MPT policy and programs.

Decision Analysis

Many different techniques not used in this paper can be included in the category called decision analysis. Decision theorists and analysts have developed a number of closely related decision modeling approaches such as multiattribute utility/value assessment and hierarchical analysis and have applied these techniques to a number of non-military problems. See Fast & Looper, 1988, for a complete description of the mathematical models used in decision analysis and examples of how they are applied to Air Force decision contexts.

III. APPLICATION OF TECHNIQUES

The four techniques were incorporated into a single software package for a comparative analysis of thirty R&D projects. Data for each of the techniques were entered, and a final value for utility was produced for all 30 projects using the four techniques, yielding a total of 120 final values. This section includes descriptions of the software implementation and application process.

Development of the Assessment Model

Upon initiation of the package, the user chooses utility analysis, production function analysis, decision theory analysis, or cost benefit analysis to evaluate the project at hand. Described below are the methods used to automate each of the techniques and evaluate the 30 projects.

Utility Analysis

As described in Section II, utility analysis provides an equation for the valuation of project utility. The software package allows the user to choose between a pre-selection and a post-selection intervention device.

Pre-selection. Upon opting to evaluate a pre-selection device, the user is asked to input values for:

N_s - the number of individuals given the selection test,
R_{xy} - the simple correlation between a selection test and work performance,
W50 - the dollar value of a worker at the 50th percentile,
W15 - the dollar value of a worker at the 15th percentile,
MN_x - the mean standard score for selectees, and
C_i - the cost per person of administering the test.

After the values for the variables have been entered, the user has the option to display the final statistics. Upon choosing that option, utility is calculated as:

$$U = (N_s)(R_{xy})(SD_y)(MN_x) - (N_s)(C_i), \text{ where } SD_y = (W50 - W15) \quad (5)$$

Post-selection. If the user chooses to evaluate a post-selection intervention device instead, values for N_s, SD_y, and C_i (defined above) must be input. In addition, the post-selection utility calculation requires values for:

MN_e - the mean performance of the group treated,
MN_c - the mean performance of the control group,
SD - the pooled variance, and
R_{yy} - the reliability of the criterion measure.

Again, the user can display the final statistics, in which case post-selection utility is calculated as

$$U = (N_s)(d_t)(SD_y) - (N_s)(C_i), \text{ where } d_t = (MN_e - MN_c)/(SD(R_{yy}))^{1/2} \quad (6)$$

In both pre- and post-selection cases, the project with the highest value receives the highest priority in funding.

Data Requirements. In order to accurately use the utility model for project selection, it is necessary to have values for each of the variables listed above. When the values are not available, expert estimation can suffice. Proxies were used for some of the variables. For example, if salary incorporates worth, then W50 and W15 can be estimated by the salary at that percentile level of proficiency. Assuming they are normally distributed, we can estimate SD_y as W50 minus W15. Or it may be more appropriate to estimate SD_y by using the "salary percentage technique." Here, SD_y is estimated as 40 percent of the mean annual salary of the workers used to accomplish a job (Matthews et al., 1990). The data used in the analysis of the 30 projects can be found in Appendix A.

Model Specifications. For utility analysis, the model to be used is already defined as the equations above. Thus, no user input is required to determine the specifications of the model. The data requirements are incorporated in this pre-defined model to yield a value of utility for each project.

Production Function

Similar to utility analysis, the production function approach uses a mathematical equation to quantify benefits of MPT R&D. The software for this technique requires the user to input values for the variables:

a - other forces which affect output and change systematically
C - the measure of capital
L - the measure of labor
K - the measure of accumulated and still productive research capital
b_1, b_2, b_3 - coefficients, or weights, of C, L, and K, respectively.

Upon request for the final statistics, utility is calculated by the production function:

$$\ln Q = (\ln a) + b_1(\ln C) + b_2(\ln L) + b_3(\ln K). \tag{7}$$

In this case, utility is measured by Q, which is the quantity produced of some output, such as the total dollars required to maintain a given force size.

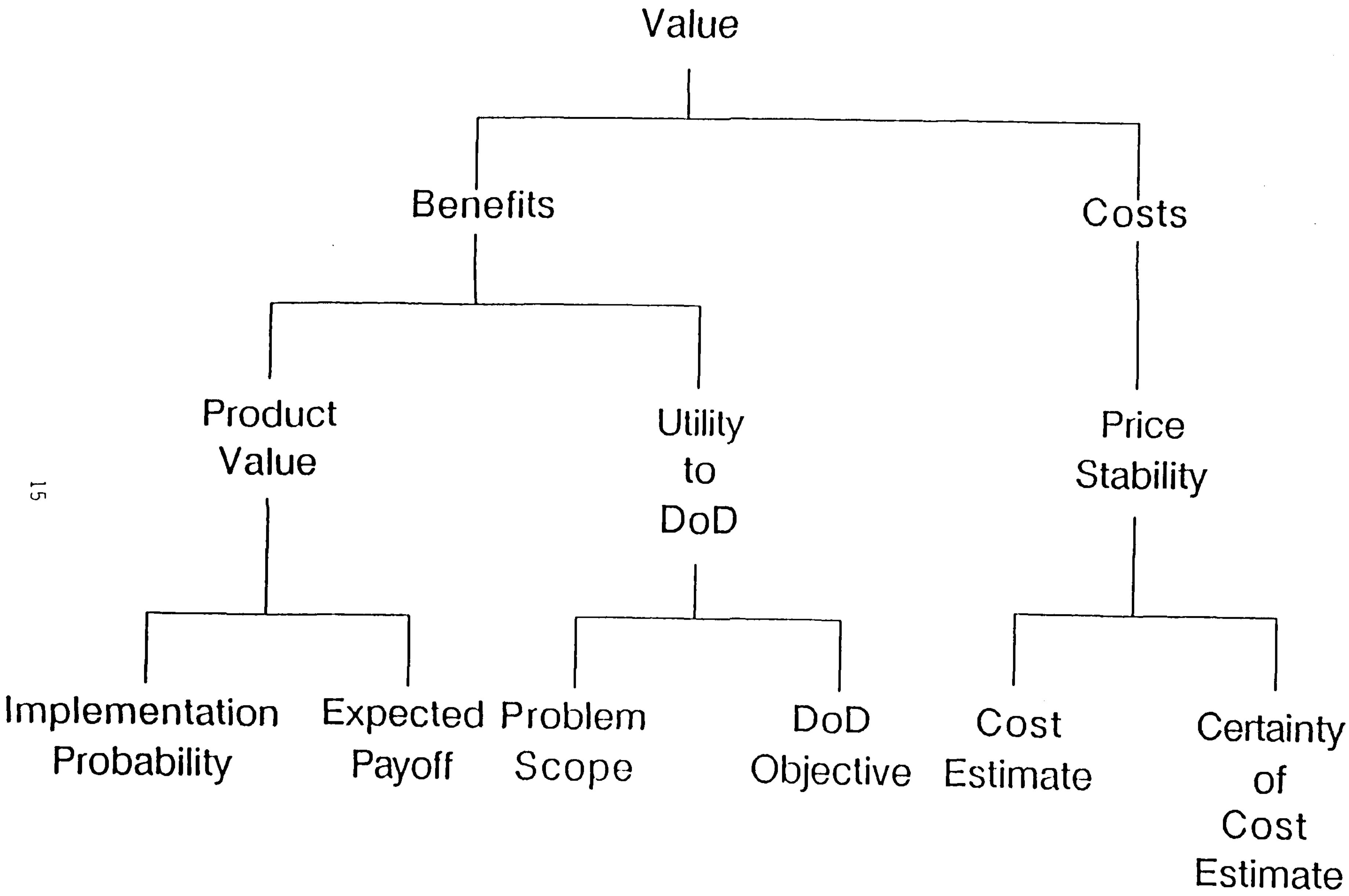
Data Requirements. For proper execution of the production function, values for each of the variables above must be available. The values for a, C, L, and K should each be measured in a common unit such as dollars. If data are available such as the number of machine or man hours necessary to complete the research project, dollar values can typically be estimated. Data for the 30 projects can be found in Appendix A.

Model Specifications. The production function format is based on the production function used by Griliches, 1987. He used a similar model to quantify the effects of basic and applied research in various industries. Based on Griliches' model, we have defined a as \$200,000, b_1 as .291, b_2 as .611, and b_3 as .089. The analysis is limited to the effect of MPT R&D on productivity in the military. The relationships among the variables are determined by user input. In order to input the coefficient values, the relative contribution to output (Q) of each of the inputs must be available or estimated. These coefficients may be defined once and saved for use in all the projects.

Cost Benefit Analysis

The software development and calculation procedure for cost benefit analysis is quite different from that of both the utility and production function analyses. To begin, we developed a hierarchy (Figure 1) with fixed attributes on the bottom level. These attributes represent the different components of benefits and costs to MPT R&D. Through user input, a functional relationship is defined between each pair of attributes which determines the composition of the factor on the next higher level using the policy specifying techniques described in Fast & Looper, 1988. For example, product value is some function of implementation probability and expected payoff.

Definition of equations continues all the way up the hierarchy to determine the final value for utility. That is, benefits are some function of product value and utility to DoD, and costs are some function of (equal to) price stability. This allows expert opinion to determine the relative importance of the components to overall utility. Recall that the



<u>FIGURE 1</u>. COST BENEFIT ANALYSIS

definition of utility in cost benefit analysis is benefits minus costs. Therefore, the functional relationship for the final value is simply benefits minus costs.

After defining the relationships among the different components of benefits and costs, the values for each of the attributes are defined. From there, the equations are calculated throughout the hierarchy to determine the utility of each project. The project with the highest value receives the highest priority in funding.

Data Requirements. For cost benefit analysis, the decision maker must be able to supply values for each of the six bottom level attributes:

1. Implementation Probability - Once personnel research is completed, a final product exists. This product may have a variety of forms, such as a final report with policy recommendations, a new selection test, or a computer software package to be used in training. The implementation probability is the likelihood that the final product will actually be implemented in the Air Force. The scale for this attribute is a continuous probability:

0 - No chance for project implementation

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1 - Definite project implementation

2. Expected Payoff - Every research and development effort is originally conceived in hopes of producing some monetary benefit in the future. To estimate the expected payoff, assume the project is implemented in the Air Force as intended by the research. That is, assume the implementation probability is 1. The value for expected payoff is a function of various inputs. Ideally, it is the expected net present value of the dollar return to the Air Force due to the project. This requires the user to know the dollar benefit that the project could yield, the probability of realizing that yield, the discount rate, the flows of income, and the number of years of the flows. If all this information is not available, it could suffice for the user to know the dollar benefit the project could yield and the certainty that the estimate is accurate. This certainty could be measured as a probability (e.g., 85 percent certain) or on a scale such as 1 to 8 where 1 is extremely uncertain and 8 is extremely certain. Only the final value for expected payoff is input in the software package.

Many personnel projects have intangible effects which are monetarily beneficial but difficult to quantify. Such benefits may include reduced training costs, instructor manpower savings, reduced training or maintenance time, or enhanced retention. For these benefits, expected payoff may be determined by using the valuation of Air Force experience (Stone et al., 1989). In this case, the user must know the magnitude or sensitivity of the effect, the benefit (or reduced cost) per individual of the effect, and the number of individuals or Air Force Specialties (AFSs) affected. Utility analysis may also be a useful methodology to arrive at a value for expected payoff. The scale for this attribute is from $0 to $6M. Any project with an expected payoff greater than this limit is recorded at $6M.

3. Problem Scope - Some research and development projects influence other projects, policies, and decisions throughout MPT, the Air Force, or the DoD in general. The extent of this influence is referred to here as the problem scope. Each project addresses a problem. The larger the number of personnel, organizations, or issues affected by that problem, the wider the scope. The scale for this attribute is:

1 - Extremely Narrow
2 - Very Narrow
3 - Moderately Narrow
4 - Slightly Narrow
5 - Slightly Wide
6 - Moderately Wide
7 - Very Wide
8 - Extremely Wide.

4. Department of Defense (DoD) Objective - Theoretically, each personnel research project is conceived with an ultimate goal in mind. This attribute is a measure of *how important* that goal is to the Department of Defense. Measurement is a discrete scale from 1 to 8. The more the project serves an important DoD objective, the higher the value of this attribute. The scale for this attribute is:

1 - Extremely unimportant to the DoD
2 - Very unimportant to the DoD
3 - Moderately unimportant to the DoD
4 - Slightly unimportant to the DoD
5 - Slightly important to the DoD
6 - Moderately important to the DoD
7 - Very important to the DoD
8 - Extremely important to the DoD.

5. Cost Estimate - This attribute is an estimate of the total cost of the project. It includes all costs from the start date through the implementation of the final product. Ideally, the cost estimate is a net present value in dollars. To estimate the cost, the user must know the amounts of the payments, the number of years over which the payments span, and the discount rate. Typically, the cost estimate is a fairly straightforward calculation. The scale for this attribute ranges from $0 to $6M. If the cost estimate is greater than this limit, it is recorded as $6M.

6. Certainty of Cost Estimate - In some personnel research and development projects, the estimated cost is more or less than the actual cost once the project is undertaken. Certainty of the cost estimate measures the likelihood that actual costs will deviate from estimated costs. The more uncertain is the cost estimate, the more likely actual costs will deviate. The scale for this attribute is:

1 - Extremely uncertain of cost estimate
2 - Moderately uncertain of cost estimate
3 - Slightly uncertain of cost estimate
4 - Slightly certain of cost estimate
5 - Moderately certain of cost estimate
6 - Extremely certain of cost estimate.

These attributes represent the different components of benefits and costs to MPT R&D. Next, the software package allows the user to define a functional relationship between each pair of attributes which determines the composition of the factor on the next higher level. For example, product value is some function of implementation probability and expected payoff. Again, the supply of other data may lead to estimations of these variables. For example, problem scope may be represented by the number and type of users of the product. Expected payoff may be determined by using the valuation of Air Force experience (Stone et al., 1989). Data for the 30 projects can be found in Appendix A.

Model Specifications. For cost benefit analysis, the model solely depends on input from the user. The user must be able to define the functional relationships among the attributes, as well as among the factors at upper levels of the hierarchy.

A total of four equations must be formed for completion of the cost benefit hierarchy. The fifth equation is benefits minus costs. To define an equation, the software provides options to input each of the required values. The skeletal equation in the program is

$$\begin{aligned} a &+ b_1x_1 + b_2x_1^2 + \ldots + b_nx_1^n \\ &+ c_1x_2 + c_2x_2^2 + \ldots + c_nx_2^n \\ &+ d_1(x_1x_2) + d_2(x_1x_2)^2 + \ldots + d_3(x_1x_2)^n \end{aligned}$$

In this equation, the x's are the values selected by the user for each attribute. The user provides values for n for x_1, x_2, and (x_1x_2). For evaluation of the 30 projects, we used the curve fitting feature of policy specifying to construct the equations (Fast & Looper, 1988). Then, values must be input for the coefficients. All four equations are specified in this manner. Having entered values for each of these variables throughout the hierarchy, the model is defined. The values for the attributes are incorporated into this model, and utility can be calculated. For consistency, these specifications may be saved and used for all projects which are ranked against each other. The model specifications used for evaluation can be found in Appendix B.

Decision Analysis

The software development process for decision analysis is similar to that of cost benefit analysis. We built a hierarchy containing attributes relevant to the calculation of total project utility (Figure 2). In addition to the six attributes used in cost benefit analysis (implementation probability, expected payoff, problem scope, DoD objective, cost estimate, and certainty of cost estimate), the other six attributes to be considered in decision analysis are: state of the art, expertise availability, time to complete, certainty of time schedule, personnel availability, and funds availability.

Notice that the right hand side of the hierarchy is exactly the same as the cost benefit hierarchy. For decision analysis, another branch called feasibility is added. Now utility is some combination of benefits, costs, and feasibility.

In response to software prompts, a functional relationship is defined between each pair of attributes on the bottom, or twig, level. These functions determine the value for the factors on the next higher level. The factors at this level consist of technical capability, timeliness, resources, product value, utility to DoD, and price stability. Technical capability, then, is some function of state of the art and expertise availability.

Rather than continuing to define equations up the hierarchy as in cost benefit analysis, a swing weighting version of Simple Multiattribute Rating Technique (SMART) (Von Winterfeldt & Edwards, 1986) is used to describe the relative importance of each of the middle level factors to the value of its respective branch. A value of 100 is attached to the most important factor, against which the other factors on the branch are weighted. The assigned values are then standardized to sum to one. Technical capability, timeliness, and resources are each a proportion of feasibility. Likewise, product value and utility to DoD are each some proportion of benefits. Since there is only one factor for costs, price stability accounts for 100 percent of costs. Similarly, the three major branches are weighted against each other and then standardized to define their relative importance to the total value of utility. In essence, we have formed a probability tree with each probability representing the weight of importance to the next higher level (Fast & Looper, 1988). However, the bottom level is composed of functions rather than weights, allowing for interaction between the attributes.

To calculate total project utility, we multiplied down the hierarchy and summed across all pairs of attributes at the bottom level. Thus, total utility is essentially a weighted average of each of the six pairs of attributes. The weights assigned to each phase of the hierarchy should be considered very carefully because they have a strong impact on the final weight of each of the 12 attributes. For example, suppose the subject matter experts decide that feasibility is irrelevant to a particular context. Consequently, the final utility value for that set of projects would be comprised of only those attributes also used in cost benefit analysis. This may or may not be appropriate, depending on expert opinion for that particular context.

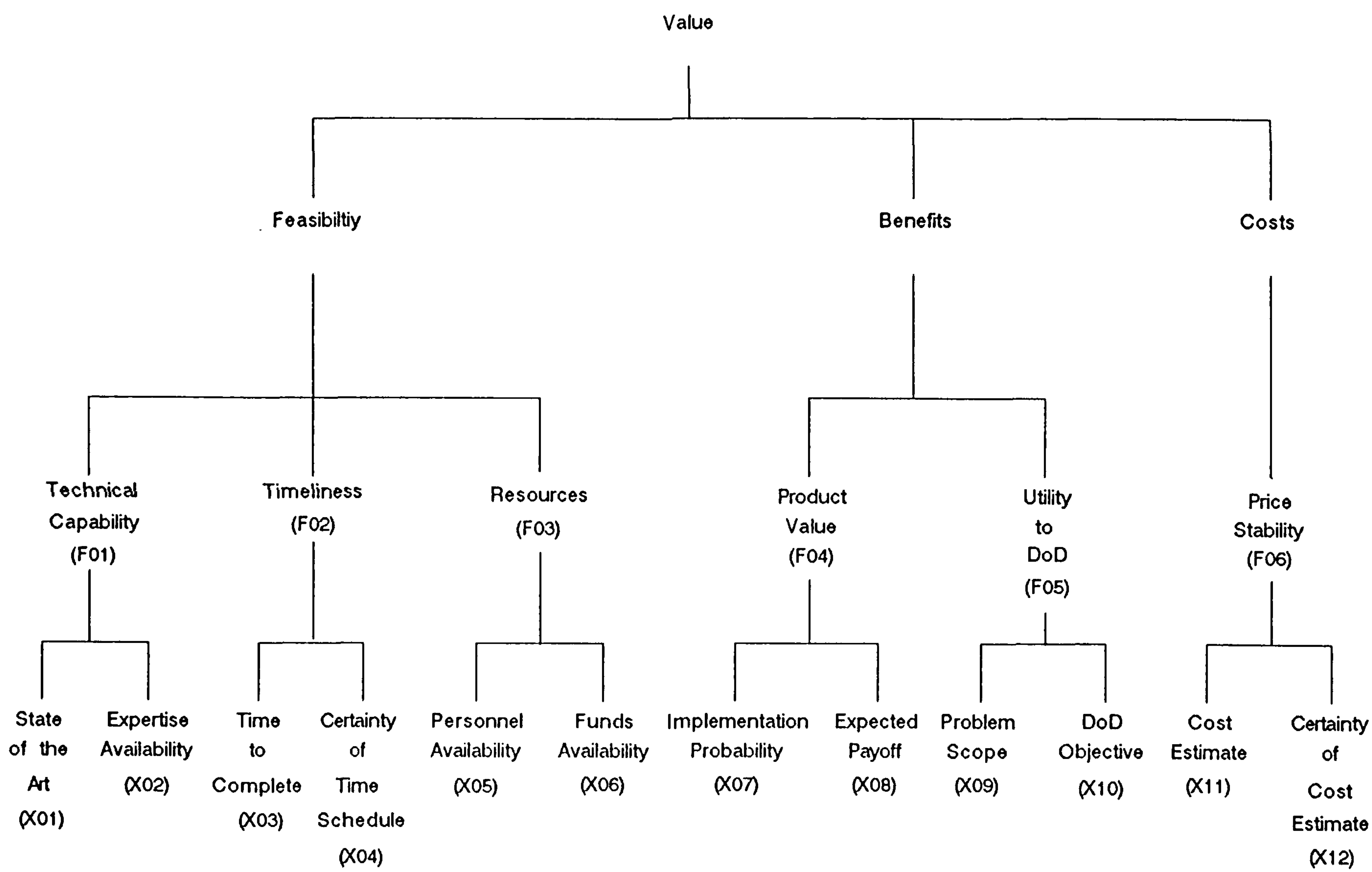

Figure 2. DECISION THEORY ANALYSIS

Data Requirements. In decision theory, the decision maker must supply data for all twelve attributes. Six are defined as in cost benefit analysis. The other six attributes are defined as:

1. State of the Art - Research and development projects encompass many levels of technical and analytical difficulty. Those projects which remain within the boundaries set by previous research are said to be within the state of the art. Those projects which expand the limits constraining related research are not within the state of the art. These go beyond the accepted horizon to open doors for innovative research and development.

The scale for this attribute is:

1 - Project is within the state of the art
0 - Project is not within the state of the art.

2. Expertise Availability - For some research and development projects, deliverability may depend on whether the necessary expertise has been developed. Expertise is an individual or a group of individuals with the technical capability necessary for completion of the project. In order for technical expertise to be available, the project must be within the state of the art. Expertise is distinguishable from personnel availability in that the former is concerned only with the existence of expertise as opposed to its accessibility. The scale for this attribute is:

1 - Expertise is available
0 - Expertise is not available.

3. Time to Complete - The time to complete a research and development effort is the estimated number of months (0 to 60) from start to finish of the project. All time from the allocation of funds to completion of the end product, such as a final report, should be included in this time. For a stream of research, the entire stream should be considered from 6.1 through 6.3 funding. Any time span greater than 60 months is recorded as 60 months.

4. Certainty of Time Schedule - In some personnel research projects, the estimated time for completion is longer or shorter than the actual duration once the project is undertaken. Certainty of the time schedule measures the likelihood that the actual time frame will deviate from the estimated schedule. The less likely the actual time will deviate, the more certain is the time schedule. The scale for this attribute is:

1 - Extremely uncertain of time schedule
2 - Very uncertain of time schedule
3 - Moderately uncertain of time schedule

4 - Slightly uncertain of time schedule
5 - Slightly certain of time schedule
6 - Moderately certain of time schedule
7 - Very certain of time schedule
8 - Extremely certain of time schedule.

5. Personnel Availability - For many research and development projects, deliverability depends on the availability of personnel. Each project requires a certain number of man hours. If enough personnel can be acquired to complete the required man hours, then personnel are available. If there are not enough personnel within the organization and it is inappropriate or too costly to hire outside labor, then personnel are not available. The scale for this attribute is:

1 - Sufficient personnel are available for completion of project
0 - Sufficient personnel are not available for completion of project.

6. Funds Availability - Funds are available if they can presently be budgeted for implementation of the project. The decision of availability of funds should be independent of the probability of funding any other projects being ranked against the project at hand. The scale for this attribute is:

1 - Sufficient funds are available for completion of project
0 - Sufficient funds are not available for completion of project.

Model Specifications. The effectiveness of the decision analysis model depends on the specifications input by the user. In addition to supplying values for each of the attributes, the user must be able to rank and weight each branch of factors in the hierarchy. This requires knowledge about the relative importance of the factors to the next higher level. Decision theory is distinguished from cost benefit analysis in that the latter requires the user to provide equations rather than ranks and weights.

On the bottom level of the hierarchy, equations must be defined in the same manner as described in cost benefit analysis above. That is, a skeletal equation is provided in which the user must input values for the attributes, exponents, and coefficients. Again, functional relationships are defined at the attribute level to allow for interaction between the attributes. To specify the model for the upper levels of the hierarchy, the software provides prompts to elicit ranks and weights for each branch. For consistency, these specifications must be saved and used for all projects which are ranked against each other. The model specifications used for evaluation of the 30 projects can be found in Appendix B.

IV. ANALYSIS RESULTS AND DISCUSSION

A sensitivity analysis was performed on each technique to determine the importance of each variable to overall utility measurement. The most common problem tends to be difficulty in gathering accurate data; although, the extent of this difficulty depends on the technique. This section presents the results of analysis using the four techniques as well as their compatibility with an MPT R&D application. In addition, this section presents a discussion of the ease of use and potential problem areas associated with each technique.

Sensitivity Analysis

A sensitivity analysis was accomplished to determine which variables were most important in determining the utility value using the four techniques. The sensitivity analyses reported here examined the effects of input variables on output variables for three of the four methodologies used to analyze R&D in MPT. A sensitivity analysis was not performed for the production function since the functional form and the contribution of the input variables to the variation in the dependent variable are well defined. The analyses were performed to determine the importance of inputs to the variation in the output variables. Input values were systematically increased and decreased for each input.

Utility Analysis

An analysis was performed for utility analysis using the following input variables and respective values for the pre-selection utility analysis:

- v1: Number of subjects given the test: 500; 5,000; 50,000; and 500,000
- v2: Simple correlation between the selection test and work performance:0.1, 0.3, 0.5, 0.7, and 0.9
- v3: Standard deviation of job performance in dollars: 1,000; 3,000; 5,000; 7,000; and 9,000
- v4: Mean standard score for selectees: 0.1, 0.3, 0.5, 0.7, and 0.9
- v5: Cost per person for administering the test: 5; 50; 500; 5,000; and 50,000.

The post-selection utility analysis involved the following input variables and values:

- v1: Number of subjects given the test: 500; 50,000; and 1,000,000
- v2: Standard deviation of job performance in dollars: 1,000; 5,000; and 10,000
- v3: Mean standard score for selectees: 0.1, 0.5, and 0.9
- v4: Mean standard score for control group: 0.1, 0.5, and 0.9
- v5: Pooled variance of job performance: 0.01, 0.25, and 0.50
- v6: Reliability of the criterion measure: 0.1, 0.5, and 0.9
- v7: Cost per person for administering the test: 5, 500, and 10,000.

The values assigned to each of the variable inputs, five for pre-selection utility analysis and seven for post-selection utility analysis, produced 2500 and 2187 combinations of values, respectively. These combination of values resulted in the following distribution of utility analysis index values:

Pre-Selection Utility Analysis Index

Percentiles	Index Values
1%	-2.49e+10
5%	-1.19e+10
10%	-2.40e+09
25%	-1.38e+08
50%	22500
75%	1.12e+07
90%	1.73e+08
95%	6.11e+08
99%	1.96e+08

Post-Selection Utility Analysis Index

Percentiles	Index Values
1%	-6.33e+11
5%	-4.53e+10
10%	-1.25e+10
25%	-5.66e+08
50%	-5000000
75%	1.13e+07
90%	7.93e+09
95%	4.17e+10
99%	6.32e+11

The analysis of variance (ANOVA) of the pre-selection utility analysis index, shown in Table 1, indicated that three of the variables were not statistically significant at explaining the variation in the index: simple correlation between the selection test and work performance, standard deviation of job performance in dollars, and minimum standard score for selectees. Thus, the cost per person for administering the test and the number of subjects were the primary factors affecting the variation. The results for the post-selection utility analysis, shown in Table 2, differ but are not necessarily inconsistent. Only two of the seven input factors for the post-utility analysis index are statistically significant: mean performance measure for the group receiving the experimental treatment and mean performance measure for the control group which does not receive the experimental treatment. In the calculation of the post-utility analysis index, these two factors form the net benefit accruing to the test group from the experimental treatment.

Table 1. ANOVA Results for Pre-selection Utility Analysis Index

Number of obs = 2500   R-square = 0.4091   Root MSE = 4.1e+09

Source	Partial SS	df	MS	F	Prob > F
Model	2.91e+22	19	1.53e+21	90.36	0.00
v1	1.07e+22	3	3.55e+21	209.41	0.00
v2	2.41e+19	4	6.03e+18	0.36	0.84
v3	2.41e+19	4	6.03e+18	0.36	0.84
v4	2.41e+19	4	6.03e+18	0.36	0.84
v5	1.84e+22	4	4.60e+21	271.1[illegible]	0.00
Resid	4.21e+22	2480	1.70e+19		
Total	7.12e+22	2499	2.85e+19		

Table 2. ANOVA Results for Post-selection Utility Analysis Index

Number of obs=2187   R-square=0.0750   Root MSE=2.0e+11

Source	Partial SS	df	MS	F	Prob>F
Model	7.17e+24	14	5.12e+23	12.57	0.00
v1	5.67e+21	2	2.84e+21	0.07	0.93
v2	312048862	2	156024431	0.00	1.00
v3	3.58e+24	2	1.79e+24	43.94	0.00
v4	3.58e+24	2	1.79e+24	43.94	0.00
v5	208665437	2	104332719	0.00	1.00
v6	162257580	2	81128790.2	0.00	1.00
v7	5.67e+21	2	2.84e+21	0.07	0.93
Resid	8.84e+25	2172	4.07e+22		
Total	9.56e+25	2186	4.37e+22		

Cost Benefit Analysis

An analysis was also performed for cost/benefit analysis using the following input variables and respective values:

v1: Probability of implementation: 0.1, 0.4, 0.7, and 1.0
v2: Potential payoff of the project: 5, 25, 50, and 75 (in thousands of dollars)
v3: Scope of the problem: 1, 3, 6, and 8
v4: DoD objective: 1, 3, 6, and 8
v5: Cost estimate: 5, 25, 50, and 75 (in thousands of dollars)
v6: Certainty of cost estimate: 1, 4, and 6.

The values assigned to each of the 6 variable inputs produced 3072 combinations of the 6 values. Thus, 3076 runs of the cost/benefit analysis model were made in order to evaluate the effect of the six input values. These combinations of values resulted in the following distribution of the cost/benefit analysis index values:

Percentiles	Index Values
1%	781
5%	5169
10%	16629.4
25%	82774.3
50%	707216.5
75%	3917390
90%	7964566
95%	9726622
99%	1.41e+07

The ANOVA of the cost/benefit analysis index, shown in Table 3, indicated that three of the six input variables were statistically significant at explaining the variation in the index: potential payoff, DoD objective, and cost estimate.

Table 3. ANOVA Results for Cost/Benefit Analysis Index

Number of obs = 3072 R-square = 0.6867 Root MSE = 1.9e+06

Source	Partial SS	df	MS	F	Prob > F
Model	2.4347e+16	17	1.4322e+15	393.84	0.0000
v1	1.5108e+10	3	5.0361e+09	000.00	0.9986
v2	6.4201e+15	3	2.1400e+15	588.49	0.0000
v3	8.6859e+10	3	2.8953e+10	000.01	0.9962
v4	9.7697e+15	3	3.2566e+15	895.54	0.0000
v5	8.1450e+15	3	2.7150e+15	746.61	0.0000
v6	1.2421e+13	2	6.2104e+12	001.71	0.1814
Resid	1.1106e+16	3054	3.6364e+12		
Total	3.5453e+16	3071	1.1544e+13		

Decision Analysis

For the computation of the decision analysis index, 12 input variables were used:

v1: State of the art: 0 and 1
v2: Expert availability: 0 and 1
v3: Time to complete: 20 and 60
v4: Time certainty: 3 and 7
v5: Persons availability: 0 and 1
v6: Funds availability: 0 and 1
v7: Implementation probability: 0.3 and 0.8
v8: Potential payoff: 20 and 60
v9: Problem scope: 3 and 7
v10: DoD objective: 3 and 7
v11: Cost estimate: 20 and 60
v12: Cost certainty: 2 and 5

Two values were assigned to each of the 12 variable inputs, thus producing 2^{12} or 4096 combinations of the 12 values. Thus, 4096 runs of the decision analysis model were made in order to evaluate the effect of the input values. These combination of values resulted in the following distribution of decision analysis index values:

Percentiles	Index Values
1%	13.3
5%	16.7
10%	18.9
25%	27.3
50%	33.6
75%	54.2
90%	65.81
95%	74.26
99%	79.21

The ANOVA of the decision analysis index, shown in Table 4, indicated that eight of the 12 input variables were statistically significant at explaining the variation in the index. The four factors which were not statistically significant were state of the art, expert availability, persons availability, and funds availability.

Table 4. ANOVA Results for Decision Analysis Index

Number of obs = 4096 R-square = 0.9106 Root MSE = 5.30166

Source	Partial SS	df	MS	F	Prob > F
Model	1169031.49	12	97419.29	3465.94	0.00
v1	4.78	1	4.78	0.17	0.68
v2	4.78	1	4.78	0.17	0.68
v3	624298.51	1	624298.51	22211.00	0.00
v4	399537.38	1	399537.38	14214.55	0.00
v5	3.09	1	3.09	0.11	0.74
v6	3.09	1	3.09	0.11	0.74
v7	1135.45	1	1135.45	40.40	0.00
v8	1373.54	1	1373.54	48.87	0.00
v9	10210.47	1	10210.47	363.26	0.00
v10	10210.47	1	10210.47	363.26	0.00
v11	70475.65	1	70475.65	2507.35	0.00
v12	51774.31	1	51774.31	1842.00	0.00
Resid	114763.45	4083	28.11		
Total	1283794.94	4095	313.50		

Comparison of Output of Each Technique

In addition to the sensitivity analysis, a comparison of the output of each technique was performed. The question being examined in this comparison was how similar were the results from using each of the four techniques across the 30 simulated projects? Rank order correlations were used because the values for the input variables were subjectively selected from a range of possible values; thus, the actual utility or payoff from undertaking any given simulated project should not be directly compared with that of any other project. The rank orders from the 30 projects are also shown in Appendix C.

Table 5 shows the rank order correlations for the four techniques. Only the rank ordered outputs from utility analysis and production functions and from cost/benefit analysis and decision analysis were statistically different from 0.0 at the .01 level of significance.

The latter is readily understandable since a significant portion of the decision analysis hierarchy is composed of the entire cost/benefit decision hierarchy. An explanation for the relationship between utility analysis and production functions may be the fact that both techniques have estimates of the productivity of labor in each project.

Table 5. Rank Order Correlations

	UA	PF	CBA	DA
Utility Analysis (UD)	1.00			
Production Functions (PF)	.52*	1.00		
Cost/Benefit Analysis (CBA)	-.02	.18	1.00	
Decision Analysis (DA)	-.09	-.12	.61*	1.00

* Significant at .01 level

Although this comparison was done on simulated projects, with data on real projects, using each technique to estimate the value and costs of conducting each project and comparing the output from each technique could be very valuable. An MPT R&D resource allocation decision maker could average across the four techniques as well as investigate through further sensitivity analysis why similarities or differences might exist. Such analysis should provide greater insight into the MPT R&D decision process and result in more effective use of limited R&D resources.

Discussion

Utility Analysis

The ease in using utility analysis comes in its pre-defined equations. The model is already specified regardless of the type of application. However, utility analysis was developed specifically for selection tests, or for intervention devices in which productivity can be measured before and after the intervention.

For even the purest selection test, several problems arise in applying utility analysis. Although the variables fit neatly into an equation, the values assigned to those variables are difficult to obtain. Matthews et al., (1990) discuss some of the major problems with utility analysis. Several essential elements are necessary for the estimation of utility (U). First, the value for standard deviation (SD_y) is approximated using an approach suggested by Schmidt, Hunter, McKenzie, & Muldrow (1979). The estimation of SD_y presumes a defensible method for approximating the dollar value of productivity. The measurement of job performance in the Air Force is an ongoing area of research in which any selected measure requires caution in its application to a utility analysis. The calculation of SD_y, given a sound methodology for measuring job performance, is still an approximation to be used with caution. The value for d_t suffers from the same problems.

Second, the validity coefficient is not only dependent on the measurement of performance but also on the credibility of the coefficient. The correlation between performance and the device, (r_{xy}), involves direct measurements of performance. To the extent that measures of performance are invalid, utility analysis based on them is questionable. In the case of the 30 projects, performance measures were unavailable, so utility analysis suffers greatly. Moreover, there are other factors that explain the individual variation in salary that, when left out of the benefit algorithm, leave biased estimates of the worth of a selection or intervention device. This is illustrated even assuming that performance can be reflected in dollars. Third, additional factors such as personnel turnover and probability of program success should also become an integral part of the utility analysis.

One major problem with the utility benefit formulation is the strong possibility of an omitted variable bias. For example, economic research has suggested that other variables such as experience and education are important in explaining the salary variation across individuals. In this context, if a test score is positively correlated with factors such as experience, and education, and these variables are excluded from the estimating equation, the coefficient on test score is overestimated by capturing the effects of some of the omitted variables.

It is necessary to clarify the relationship between utility analysis and cost benefit analysis. Whereas cost benefit analysis is an approach to looking at a utility as some net benefit, utility analysis specifically defines the benefits and costs with an equation. Utility analysis, then, is really a specific example, or subset, of cost benefit analysis.

Utility analysis could potentially be very useful to decisions concerning pre- and post-selection tests. However, more research must be conducted on the data that is required to estimate values for the variables. Estimations by subject matter experts are a possible solution for some of the variables, such as the number of individuals tested or the cost to administer the test to an individual. The final values for utility can be found in Appendix C.

Production Function

Like utility analysis, the ease in using the production function comes in its structured model specifications. However, several problems surface in the attempt to measure the benefits (output) of MPT R&D at the project level. Quantifying the output of MPT R&D projects is not obvious, even though surrogates are available at the aggregate level and each project has assigned deliverables. Literature tends to use measures such as value-added and total revenues which are not available for MPT R&D. Total expenditures do not measure benefits, because all projects are not successful; and an expensive project may or may not be as beneficia' to the military as a less expensive project. The dollar size of the research budget for an individual project may have little bearing on the extent of benefit to the Air Force. Measuring the inputs also presents a challenging problem, although factors such as man-hours, contribution to capital, profit, and travel costs may be available from the proposed project budgets.

The key issue is deriving an unbiased measure of output for each project. In addition, a particular MPT R&D project is not independent of previous research, so the problem of determining a methodology to capture the contribution of past research to the present project may not be trivial. Also, MPT R&D performed by the Air Force is not independent of research performed by other branches of the military. In fact, several joint research committees exist to take advantage of research performed across the branches of service.

Research in MPT does not always lead to the generation of a useful product, especially with respect to basic research. Projects can often be assigned probabilities of success, though numerous factors such as the level of funding, number of participating specialists, and level of previous pertinent research can affect the outcome of a project beyond the feasibility of the statement of work. The failure of a project does not imply that research in the particular area of interest is not beneficial or useful to the Air Force mission of national defense. The research attempts which seemingly fail to achieve their initial objectives are often necessary learning stages and/or adaptations to changing technology in the process of producing a useful end product. Thus, the key issues are the direction of basic and applied MPT R&D given the short and long term needs of the Air Force and the expected return from the allocation of these funds in selected areas of MPT research.

Due to the problems discussed above, it is difficult to actually quantify the contribution to output of the capital, labor, and R&D stock; however, given the data for the variables, the production function does yield a ranking of the projects. The final values for utility can be found in Appendix C.

Cost Benefit Analysis

Applying cost benefit analysis to the 30 MPT research projects proved to be an effective methodology for this type of analysis. By expanding the general idea of benefits minus costs to incorporate the relationships among the attributes in MPT projects, a seemingly reliable ranking of the projects was achieved. The final values for utility can be found in Appendix C.

The resulting figure for overall utility is a dollar amount. This number seemingly places an actual dollar value on a project. However, the resulting dollar figure is only as valid as the dollar figures input in the equations. Therefore, the value for final utility must not be taken too literally. The value does provide a valid means for ranking a set of projects against each other.

There are, however, several issues which complicate the CBA procedure. These include the selection of the appropriate decision rule for selecting the most beneficial project, uncertainty associated with outcomes or costs, and evaluation of future benefit and cost flows. The central issue in applying CBA to research and development is the difficulty in the identification and valuation of benefits and costs.

Net Benefits Versus the Benefit to Cost Ratio. In the literature on project selection, it is sometimes the case that a variant of the CBA methodology, the benefit to cost ratio method, is proposed (Paolini & Glaser, 1977). In this method, a project is recommended because its benefit to cost ratio (total benefits divided by total cost) is greater than one, or it is rejected because the ratio is less than one. It may also be adopted because the project has the largest benefit to cost ratio among competing projects. In many circumstances the benefit to cost ratio criterion leads to the same choice as maximization of net benefits. However, when a choice must be made among mutually exclusive projects or when resources are constrained, the two criteria may lead to inconsistent choices. To understand how the benefit to cost ratio can be misleading, suppose a policy maker is considering two alternative research and development projects. CBA produces estimates as follows:

Project	Benefits	Costs	Net Benefits	Benefit/ Cost Ratio
I	$ 10,000	$ 1,000	$ 9,000	10.0
II	$100,000	$25,000	$75,000	4.0

In this situation, Project I has a higher benefit to cost ratio, while Project II has larger net benefits. In the example, if the decision maker is maximizing net benefits on a project by project basis, Project II is preferred; but, if the decision rule is to maximize the benefit per unit of cost, then Project I is the clear choice. If the level of effort could be increased in Project I to $25,000 with the benefit to cost ratio constant, then the apparent ambiguity between the decision rules would disappear.

Uncertainty in the Environment. In striving for more accurate estimates of benefits and costs, complications are introduced into the analysis. For example, there may be uncertainty about the exact magnitude of the benefits but relative confidence in the probability of their occurrence. In this instance, the benefits can be multiplied by their respective probabilities and summed to produce a value for benefits which is a weighted average based on their expected probability of occurrence. Suppose there are three estimates of the benefits of a particular project: \$100,000, \$80,000 and \$60,000 with estimates of the probability that each will occur of, respectively, 20%, 50%, and 30%. The project would have an expected benefit of

$$(0.2 \bullet \$100{,}000) + (0.5 \bullet \$80{,}000) + (0.3 \bullet \$60{,}000) = \$78{,}000,$$

which would be used as the total benefits in the analysis. In this example, only three discrete amounts are estimated. More likely, the analyst will have a continuous range within which the benefits are expected to fall and as estimate of the frequency distribution of the benefits over this range. Thus, CBA employing expected values has a more complicated computation of the expected benefits than CBA in a certain environment.

Evaluating the Flow of Future Returns and Costs. Another important modification is the recognition that both benefits and costs may occur overtime. Using standard discounting techniques to establish equivalent present values, the relative attractiveness of different projects can be compared. The results, however, are sensitive to the discounting procedure. For example, a cash flow of \$1,000 in one year, \$3,000 in two years, and \$5,000 in three years, using an interest rate of 10%, would have a present value of

$$[\$1{,}000/1.1] + [\$3{,}000/(1.1)^2] + [\$5{,}000/(1.1)^3] = \$7{,}144.$$

Hodder and Riggs (1985) illustrate how discounting techniques tend to favor near-term, incremental contributions over longer-term, but presumably larger advances. In particular, the discount rate should consist of three components: a risk-free time value of money, a premium for expected inflation, and a premium for the risk of project failure. Instead, applications typically apply a single, undifferentiated discount rate for all three components and thus heavily penalize the future on the grounds that it is inherently less certain. In addition, the level of uncertainty associated with a typical R&D program should decrease as progress is made, and therefore the program risk premium should vary from one stage to the next. If the future cash flows are adjusted for their changing risk premium, the final result may be quite different from an unadjusted estimation. Thus, the need to separate time discount and risk adjustment factors and to vary the latter for different stages of the program is recognized in the literature. Unfortunately, according to Hodder and Riggs (1985), this need is generally ignored in practice.

The choice of an appropriate discount rate is essential in reference to MPT R&D. The funds expended for a government project are not funds that would otherwise stand idle. They are obtained by the government from the private sector, either by taxation or borrowing. If these funds were left in the private sector, they would be put to use there and would earn a rate of return that measures the value that society places on that use of the funds. If the funds are diverted to government use, the true cost of the diversion is the return that would otherwise have been earned. This opportunity cost is the correct discount rate to use in calculating the present value of a proposed project. Most economists who are concerned with determining the appropriate discount rate for public projects use a figure of about 10 percent.

Valuation of Benefits and Costs. By far the most difficult issue in CBA is how to actually place a value on benefits and costs. The methodology used for the valuation of costs and benefits is not standardized across studies but is adjusted depending on the characteristics or attributes of the program or venture being reviewed. Some benefits, and especially some costs, are straightforward and easily calculated. In MPT research, though, there are far more intangible benefits and costs. One way to calculate benefits is the valuation of Air Force experience (Stone et al., 1989). This methodology incorporates human capital and human resource accounting techniques to quantify such benefits as reduced attrition, increased retention, and improved training effectiveness. The valuation of Air Force experience could be incorporated into a computer simulation model, and allow the benefit calculation to be done by aging the manpower force through several years, accounting for some change in retention or attrition due to the impact of a personnel policy change. This policy change would be attributable to the benefit of an MPT R&D project.

Decision Analysis

Decision analysis is a systematic and structured methodology for the purpose of aiding in the decision-making process. It is not designed to be an exact model of the decision-making process, but a consistent method with which to attack all decisions of a particular type. Keeping this in mind, decision analysis proves to offer consistency and validity to MPT R&D decisions. As with each of the above methodologies, there are pros and cons to applying decision analysis in the research context.

The final value for utility in decision analysis is a standardized number. In this case, it is a number from 1 to 100. Therefore, this final utility does not place an actual value on a particular project. The single number tells the decision-maker nothing about the value of the project. However, in the context of competing projects, the final value describes the relative worth of the projects. Therefore, decision theory is useful in ranking the projects against each other. The final values for utility can be found in Appendix C.

Another issue involved in decision theory is the attributes to be evaluated. There are several more variables than in any of the other methodologies we have explored. In general, the attributes are also considerably more subjective. On one hand, this makes the data much easier to attain. Decision makers need only to fill in their estimates on many of the attributes. In addition, the number of attributes tends to remove some of the emphasis off the cost and benefit estimates which are often uncertain. On the other hand, this makes the data far less reliable. It may be difficult to reach a consensus among several individuals on how so many attributes should be rated and weighted.

Accumulation of Data. Ideally, the decision maker should have all the data necessary to rank the projects available. Although much of the data can be difficult to attain, the resource allocation manager can increase the accuracy of the evaluation of the project by supplying useful as well as descriptive information to the decision makers. Considering the variables necessary for the techniques described above, that data can be summarized in this proposed format for a request for personnel research. Of course, the more quantified is the data supplied, the more useful it will be to the decision maker.

V. CONCLUSIONS AND RECOMMENDATIONS

This report compared four techniques for their usability in the measurement of benefits of MPT research and development. Utility analysis was most useful in measuring the benefits of selection tests or other intervention devices in which productivity of the worker can be measured before and after the intervention. In other MPT R&D efforts, utility analysis has limited practical applicability. Production function methodologies were not applicable to the individual R&D project problem. It was difficult to quantify the contribution to output of the various input variables.

Cost benefit analysis was found to have practical application to the R&D project problem. The family of techniques was specifically developed for the problem of comparing alternative plans, for which the cost and benefit of each plan could be measured. The problem with cost benefit analysis was that the user must decide on a way in which to measure the costs and benefits associated with an individual R&D project. For test devices, utility analysis was a useful tool for determining the costs and benefits associated with developing the test. For other types of MPT R&D projects a computer simulation model incorporating human capital, human resource accounting, and productivity measurement tools would be an extremely useful tool for developing estimates of costs and benefits.

Decision analysis was also found to have practical applications to the MPT R&D selection context. In general, however, the results were more subjective than the cost benefit approach, since the data collection effort was primarily concerned with expert judgments rather than costs and benefits. Decision analysis was found most useful in rank ordering R&D projects, rather than in measuring the benefit of R&D projects.

The ANOVA indicated that not all of the respective input factors were equally important in explaining the variation in the three output variables. In many cases input variables were difficult, if not impossible, to measure or obtain. However, if such variables were statistically unimportant, then the use of the technique was not significantly hampered by the lack of accuracy in the estimation of the input variable. Conversely, if a difficult-to-obtain input variable was statistically important to the use of the technique, then the use of the technique was severely limited for lack of creditable input data.

Based on these results and conclusions a prototype functional software package was developed. This package incorporated the best points of the techniques, forming a model suitable for the MPT R&D context.

There are many ways in which this prototype model is flexible to change, but one particular flexibility would be most beneficial. In addition to the user having the option to choose data, model specifications, and benefit calculations, the option to change the structure of the basic hierarchy would open new doors for such a package. If this characteristic was developed, the package could be applied to a much wider range of research topics. Continued research in this area, then, could potentially be quite beneficial.

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APPENDIX A

SIMULATED DATA FOR FOUR TECHNIQUES

Utility Analysis Data - Pre-Selection

	N_s	R_{xy}	W85/W50/W15	MN_x	C_i
Project 1:	55,000	.12	10,000/8,000/3,000	.62	100
Project 2:	25,000	.3	12,000/8,000/4,000	.55	150
Project 3:	10,000	.4	5,000/2,000/1,000	.4	200
Project 4:	25,000	.53	8,000/6,000/2,000	.63	150
Project 5:	55,000	.4	12,000/8,000/6,000	.88	500
Project 6:	5,000	.09	6,000/4,000/1,500	.72	100
Project 7:	40,000	.15	18,000/12,000/2,000	.81	200
Project 8:	15,000	.77	15,000/10,000/5,000	.88	250
Project 9:	40,000	.9	19,500/12,000/4,000	.77	25
Project 10:	20,000	.75	18,000/12,000/6,000	.75	120
Project 11:	See post-selection				
Project 12:	30,000	.35	17,500/13,500/11,500	.70	130
Project 13:	See post-selection				
Project 14:	50,000	.25	10,000/6,000/2,000	.6	75
Project 15:	See post-selection				
Project 16:	50,000	.19	8,200/5,100/4,300	.81	55
Project 17:	15,000	.78	22,000/17,000/15,000	.9	485
Project 18:	55,000	.66	12,000/6,000/3,200	.7	25
Project 19:	2,000	.85	25,000/17,000/5,000	.8	55
Project 20:	15,000	.25	25,000/17,000/5,000	.8	50
Project 21:	12,000	.38	12,000/8,000/6,000	.78	20
Project 22:	2,000	.4	12,000/8,000/6,000	.64	100
Project 23:	48,000	.45	18,000/17,290/15,480	.42	75
Project 24:	55,000	.67	20,000/16,000/8,000	.75	35
Project 25:	10,000	.33	10,000/5,000/2,000	.6	25
Project 26:	See post-selection				
Project 27:	20,000	.55	40,000/31,000/22,000	.8	120
Project 28:	8,000	.21	9,000/6,000/3,000	.84	28
Project 29:	20,000	.64	40,000/31,000/22,000	.8	150
Project 30:	50,000	.78	8,000/6,000/4,000	.78	80

Utility Analysis Data - Post Selection

	N_s	MN_e	MN_c	$_sD$	Ry_y	C_i
Project 11:	45,000	.7	.4	.03	.21	100
Project 13:	35,000	.89	.51	.023	.3	400
Project 15:	55,000	.85	.35	.04	.45	70
Project 26:	20,000	.72	.5	.03	.75	1,000

Production Function Data

	Capital (M)	Labor (M)	R&D Stock (M)
Project 1:	2	1	.250
Project 2:	3	2	5
Project 3:	1	1	1
Project 4:	1	1	1
Project 5:	.5	1.5	1
Project 6:	5	5	0
Project 7:	3	2	0
Project 8:	2	1	2
Project 9:	2	4	5
Project 10:	10	10	20
Project 11:	15	15	1
Project 12:	1	3	5
Project 13:	3	7	2
Project 14:	3	5	3
Project 15:	4	6	10
Project 16:	2	2	3
Project 17:	1	1	0
Project 18:	.5	1.5	15
Project 19:	2	8	4
Project 20:	2	3	5
Project 21:	2.5	2	0
Project 22:	2	8	5
Project 23:	2	3	1
Project 24:	5	10	20
Project 25:	.5	1.5	3
Project 26:	10	20	1
Project 27:	3	4	3
Project 28:	5	5	10
Project 29:	5	15	10
Project 30:	1	2	15

Decision Analysis Data

	State of Art	Expert Avail	Time to Compl	Time Cert	Person Avail	Funds Avail
Project 1:	1	1	24	5	1	1
Project 2:	1	1	60	6	1	1
Project 3:	1	1	24	6	1	1
Project 4:	1	1	36	7	1	1
Project 5:	1	1	20	3	1	1
Project 6:	1	0	36	2	1	1
Project 7:	1	0	30	4	1	1
Project 8:	1	1	48	3	1	1
Project 9:	1	1	24	5	1	1
Project 10:	1	1	36	7	1	1
Project 11:	0	0	48	8	0	0
Project 12:	1	1	18	6	1	1
Project 13:	1	1	50	5	1	1
Project 14:	1	1	60	8	1	1
Project 15:	1	1	60	8	1	1
Project 16:	1	1	42	6	1	1
Project 17:	1	1	42	7	1	1
Project 18:	1	1	24	5	1	1
Project 19:	1	1	42	7	1	1
Project 20:	1	1	27	6	1	1
Project 21:	1	1	9	6	1	1
Project 22:	1	1	36	6	1	1
Project 23:	1	1	60	7	1	1
Project 24:	1	1	24	4	1	1
Project 25:	1	1	12	6	1	1
Project 26:	1	1	45	5	1	0
Project 27:	1	1	24	3	1	1
Project 28:	1	1	52	5	1	1
Project 29:	1	1	42	6	1	1
Project 30:	1	1	30	7	1	1

Decision Analysis Data: Part 2 (Also CBA)

	Impl Prob	Pot Pay	Prob Scope	DoD Objec	Cost Estim	Cost Cert
Project 1:	.8	10	4	6	5	6
Project 2:	.9	20	5	5	10	6
Project 3:	.85	25	3	5	3	7
Project 4:	.8	15	4	5	3	7
Project 5:	.75	15	6	7	2	3
Project 6:	.3	30	4	5	10	3
Project 7:	.4	20	2	6	5	4
Project 8:	.6	30	3	6	3	5
Project 9:	.5	18	4	3	4	2
Project 10:	.85	40	5	7	20	4
Project 11:	.6	60	3	5	30	6
Project 12:	.95	20	6	6	4	3
Project 13:	.7	35	4	6	10	2
Project 14:	.93	40	7	7	8	3
Project 15:	.98	30	7	7	10	3
Project 16:	.8	10	6	5	4	2
Project 17:	.6	40	2	8	2	2
Project 18:	.92	30	7	7	2	7
Project 19:	.75	50	4	7	10	3
Project 20:	.35	40	4	5	5	4
Project 21:	.5	15	5	5	3	5
Project 22:	.95	50	8	7	10	4
Project 23:	.4	25	6	6	5	2
Project 24:	.85	30	7	5	15	3
Project 25:	.8	20	3	3	2	3
Project 26:	.65	60	2	6	30	5
Project 27:	.78	35	4	6	7	4
Project 28:	.4	40	4	5	10	2
Project 29:	.35	45	2	7	20	4
Project 30:	.45	30	7	7	15	3

APPENDIX B

MODEL SPECIFICATIONS

Decision Analysis

$F1 = 40x_1 + 60x_2$; Technical Capability

$F2 = 31.429 - .64292x_3 + 8.571x_4 - .0238x_3x_4$; Timeliness

$F3 = 20x_5 + 30x_6 + 50x_5x_6$; Resources

$F4 = 10x_7 + .5x_8 + x_7x_8$; Product Value

$F5 = -14.286 + 4.286x_9 + 10x_{10}$; Utility to DoD

$F6 = 54.2870 - .9524x_{11} + 5.713x_{12} - .0476x_{11}x_{12}$; Price Stability

x_1 = State of the Art

x_2 = Expertise Availability

x_3 = Time to Complete

x_4 = Certainty of Time Schedule

x_5 = Personnel Availability

x_6 = Funds Availability

x_7 = Implementation Probability

x_8 = Expected Payoff

x_9 = Problem Scope

x_{10} = DoD Objective

x_{11} = Cost Estimate

x_{12} = Certainty of Cost Estimate

Ranks and Weights for Decision Analysis:

Rank	Weight (1-100)	
Technical Capability	1	100
Timeliness	3	75
Resources	2	80

	Rank	Weight (1-100)
Product Value	1	100
Utility to DoD		290

	Rank	Weight (1-100)
Feasibility	2	80
Benefits	1	100
Costs	3	75

Cost Benefit Analysis

$F7 = 10x_{13} + .5x_{14} + .333x_{13}x_{14}$; Product Value

$F8 = -9.388 + 2.9592x_{15} + 6.5306x_{16} - .1x_{15}x_{16}$; Utility to DoD

$F9 = -2.143 + .6548x_{17} + 2.143x_{18} + .012x_{17}x_{18}$; Price Stability

$F10 = .5F7 + .333F8 + .003F7F8$; Benefits

$F11 = F10 - F9$; Value of Utility

x_{13} = Implementation Probability

x_{14} = Expected Payoff

x_{15} = Problem Scope

x_{16} = DoD Objective

x_{17} = Cost Estimate

x_{18} = Certainty of Cost Estimate

APPENDIX C

FINAL VALUES FOR UTILITY

	Utility Analysis	Production Functions	Cost Benefit Analysis	Decision Analysis
Project 1:	14,960,000(18)	955,028(24)	839,000(28)	67.55(12)
Project 2:	12,750,000(20)	2,142,791(15)	902,000(27)	66.10(18)
Project 3:	- 400,000(30)	883,079(26)	1,175,000(22)	72.39(5)
Project 4:	29,640,000(15)	883,079(27)	763,000(29)	69.98(9)
Project 5:	11,220,000(22)	924,681(25)	2,312,000(9)	67.01(15)
Project 6:	310,000(29)	1,102,734(22)	1,241,000(21)	45.21(29)
Project 7:	40,600,000(13)	542,964(28)	1,161,000(24)	49.49(28)
Project 8:	47,070,000(12)	1,149,188(21)	1,805,000(16)	66.50(16)
Project 9:	220,760,000(4)	3,499,859(12)	1,164,000(23)	56.26(26)
Project 10:	65,100,000(10)	9,200,081(3)	2,097,000(12)	71.09(7)
Project 11:	1,959,461,012(2)*	10,158,610(2)	609,000(30)	44.54(30)
Project 12:	10,800,000(23)	1,994,019(17)	2,391,000(8)	69.42(10)
Project 13:	1,886,359,134(3)*	4,246,086(10)	2,431,000(7)	63.52(20)
Project 14:	28,750,000(16)	3,584,072(11)	3,492,000(2)	74.84(3)
Project 15:	2,045,878,979(1)*	4,848,974(6)	2,887,000(5)	71.65(6)
Project 16:	3,406,000(27)	1,819,670(18)	1,742,000(18)	60.59(24)
Project 17:	13,785,000(19)	258,226(30)	3,402,000(3)	70.27(8)
Project 18:	69,773,000(9)	1,176,695(20)	2,495,000(6)	80.90(1)
Project 19:	16,210,000(17)	4,354,828(9)	3,253,000(4)	73.21(4)
Project 20:	35,250,000(14)	2,439,659(14)	1,796,000(17)	66.40(17)
Project 21:	6,873,600(24)	514,908(29)	1,022,000(26)	67.20(14)
Project 22:	824,000(28)	4,442,178(8)	3,803,000(1)	80.15(2)
Project 23:	12,038,400(21)	2,114,077(16)	2,163,000(11)	62.62(22)
Project 24:	219,175,000(5)	7,519,551(5)	1,871,000(14)	65.07(19)
Project 25:	5,690,000(25)	1,019,661(23)	1,332,000(19)	61.61(23)
Project 26:	200,162,903(6)*	10,762,900(1)	1,134,000(25)	55.53(27)
Project 27:	76,800,000(8)	3,127,265(13)	2,296,000(10)	68.70(11)
Project 28:	4,009,600(26)	4,628,826(7)	1,967,000(13)	59.66(25)
Project 29:	89,160,000(7)	9,057,159(4)	1,257,000(20)	63.27(21)
Project 30:	56,840,000(11)	1,716,332(19)	1,847,000(15)	67.25(13)

* Post-selection intervention device
( ) Denotes rank order based on final value