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MITRE TECHNICAL REPORT

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A Frame of Reference for Public-Sector and Non-Profit Investment Selection Studies

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Kenneth P. Kuskey, Ph.D.

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MITRE
Washington C3 Center
McLean, Virginia

MITRE Department Approval

Michael Janiga

MITRE Project Approval:

Richard Tepel

Abstract

Investment selection studies are conducted to develop, analyze, recommend, and choose the investments an organization will make. This report offers a frame of reference for planning and organizing public-sector and non-profit investment studies. It is written in support of studies that The MITRE Corporation conducts for its sponsors (government agencies) and for itself (a non-profit organization operating in the public interest).

The report addresses those investment decision-making situations, common in public and non-profit enterprises, where the important reasons for investing are substantially non-financial and the anticipated returns from investment are not easily measurable in monetary terms. For instance, the desired returns from such investments may be to improve national defense or public-safety.

The frame of reference includes ideas, conditions, and assumptions for planning how such investment selection studies should be carried out. Its scope encompasses major inter-organizational studies, such as the Department of Defense's *C4ISR Mission Assessment* that MITRE led in 1997. It includes those aspects of organizational budgeting and source selection processes that are conducted to develop investment recommendations, as MITRE has done with the DoD, Federal Aviation Administration, and Internal Revenue Service. It also includes smaller studies, such as a DoD *Analysis of Alternatives.*

The frame of reference distinguishes two major types of investment selection study. First is simple selection, where one of several alternatives is selected. Second is complex selection, in which resources are allocated among many competing investment opportunities that are collectively unaffordable.

The report sketches a picture of all the activities an investment selection study might require. It distinguishes five major study activities: (1) Study initiation; (2) Searching for investment options; (3) Understanding the future; (4) Decision modeling; and (5) Developing investment recommendations. Not all activities will be appropriate for every investment study.

The report is based in part on E. S. Quade, *Analysis for Public Decisions,* 3rd ed., rev. by Grace M. Carter (Prentice Hall, 1989).

KEYWORDS: Study, investment analysis, investment selection, decision analysis, resource allocation, budgeting, selection, source selection, design, capital planning and investment control (CPIC)

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Section 1
Introduction

If we could first know where we are,
and whither we are tending,
we could better judge what to do,
and how to do it.

—Abraham Lincoln[1]

Purpose

This report offers a frame of reference for planning and organizing investment selection studies. It consists of ideas, conditions, and assumptions that suggest how selection studies should be approached by public and non-profit organizations for whom the important reasons for investing are mostly non-financial and the anticipated returns from investment are hard to measure in monetary terms. It is intended to help The MITRE Corporation's staff to plan such studies, providing them a basis for discussing a variety of important questions regarding any specific new study, such as

- How should we design and organize the study's activities?
- How well is our staff prepared to conduct the study?
- What analytical or business methodologies are appropriate for the study?
- What tools (software, facilities, etc.) are appropriate for the study?

The scope of the frame of reference encompasses major inter-organizational studies, such as the Department of Defense (DoD) *C4ISR Mission Assessment* that MITRE led in 1997. It includes those aspects of organizational budgeting and source selection processes that are conducted to develop investment recommendations. It also includes smaller studies, such as a DoD *Analysis of Alternatives.*[2] Not all aspects of the frame of reference will be appropriate for every investment selection study.

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1 Abraham Lincoln, "House Divided," a speech to the Republican convention at Springfield, Illinois, June 16, 1858.

2 DoD Instruction 5000.2-R, (Interim) *Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs*, Part 2; 2.4, Analysis of Alternatives.

The report's purpose is modest. It offers the frame of reference and some bibliographic citations. It does not offer best practices or tools for conducting a study.

Scope of the Report: What is an Investment Selection Study?

"Study"

A *study* is a careful analysis of a phenomenon, development, or question. The published report of such a study is also called a study.[3]

Because a study is a *careful analysis*, the term *analysis* is often a synonym for the term *study*. Economic analyses, decision analyses, portfolio analyses, systems analyses—all are studies.

"Decision Study"

One important kind of study, and the one emphasized here, analyzes decision and planning questions. The general outline of such a *decision study* is well reflected in Abraham Lincoln's words at the head of this section. In decision studies, one asks and answers several questions that cumulatively lead to a considered conclusion:

- What is the current situation?
- How will the situation change in the future if we do nothing?
- What would we like the situation to be in the future?
- What actions should we take to achieve the future situation we want?

"Investment Selection Study"

An *investment selection study*, as understood here, is a decision study in which the actions under consideration are potential future investments. Through systematic analysis, it develops a conclusion about which potential investments to make and which not to make.

In general, an *investment* is "the outlay of money, usually for income or profit."[4] For example, in an economics text we read, "Investment consists of the purchase of income-earning assets."[5]

In the government and non-profit sectors, however, an investment is the purchase of assets whose usual purpose is to generate *non-financial*, future, continuing, social benefits. The

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3 *Merriam-Webster's Collegiate Dictionary*, 10th ed. Springfield, Mass.: Merriam Webster Inc., 1994.

4 *Ibid.*

5 Edward Ames, *Income and Wealth* (New York: Holt, Rinehart and Winston, Inc., 1969), p. 35.

benefits may be increased military or police capabilities, expanded health care, or a better environment. Less often, the purpose of government investments is to generate financial social benefits, either as direct benefits or as cost savings or cost avoidance.

At MITRE, we chiefly study four kinds of investment question:

1. *Simple Selection (Source Selection)*—If we must select one investment to make, and only one, from a few *pre-specified* alternative investments, all addressing either the same basic objectives or competing objectives, which one investment should we select?
2. *Simple Selection (System Choice)*—If we must select one system to invest in, and only one, from an *infinite* variety of candidate systems, some of which are proposed by various stakeholders and others of which may be invented as compromises during the study, what one system should we select?
3. *Complex Selection (System Design)*—Considering that various aspects of a desired new system may be designed in a range of benefits or performance (from bare bones to gold plated) with a corresponding range of investment, what investment should we select for each aspect?
4. *Complex Selection (Budgeting)*—Among many competing pre-specified requests for investment, each satisfying its own unique objectives, which requests should we approve (select) and which ones should we disapprove?

Other investment questions are studied, but these four are the most common.[6]

Organization of the Report

Following E. S. Quade's recommended list of study activities, the report describes five major groups of investment study activities.[7] They apply to all four varieties of investment questions. The five groups are

1. *Study initiation*—Developing the study plan, organizing the study, and defining a baseline for analysis.
2. *Search*—Finding, understanding, validating, and organizing investment options for analysis.

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6 In the DoD, the first three questions are analyzed primarily within the Acquisition System, while budgeting questions are analyzed primarily within the Planning, Programming, and Budgeting System (PPBS).

7 E. S. Quade, *Analysis for Public Decisions*, 3rd ed., rev. by Grace M. Carter (Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1989), p. 49.

3. *Understanding the future*—Building an understanding of the future environment and operational context by developing probable scenarios.
4. *Decision modeling*—Developing mathematical models to represent the study's collective understanding of the effects that various investments may cause.
5. *Synthesis*—Evaluating investment options, performing decision analysis, developing investment recommendations or decisions, communicating study results.

While there is a logical sequence to the activities, in practice the activities occur *iteratively* or *in parallel*, and the results from any one activity may cause changes in the conduct of any other activity.

Sources

The report owes much to three books.[8] Quade's ideas, especially, are the basis for organizing the report. The report also draws upon interviews with senior Department of Defense managers and senior MITRE staff regarding their views on (1) the scope and priorities of C4ISR[9] investment studies that MITRE should conduct in the future; and (2) MITRE's strengths, weaknesses and opportunities for improvement with respect to conducting C4ISR investment studies. The interviews were collated in an unpublished working paper.[10]

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- E. S. Quade, *ibid.*
- Charles E. Lindblom, *The Policy-Making Process.* Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1968.
- M. Granger Morgan and Max Henrion, *Uncertainty; A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* New York: Cambridge University Press, 1990.

9 "C4ISR" stands for Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaisance.

10 Susan Parker and Ken Kuskey, "Collation of Interviews on C4ISR Investment Studies at MITRE," April 28, 1998.

Section 2

Study Initiation

Develop the Study Plan

Prepare an Issue Paper

To initiate a study, an issue paper is written for the potential sponsors of the study. However the need for the study may have arisen,[11] the paper identifies the problems at issue, describes what is known and unknown about the problems, suggests possible alternative solutions, suggests attributes for measuring success, and recommends whether a study should be done.[12] It identifies stakeholder organizations. It identifies resources that can be applied in the study. It includes a case for doing the study, including costs and benefits. It outlines the study plan.

According to MITRE's Peter Sharfman, who was a director of study managers for the Congress's Office of Technology Assessment, it is important to put in substantial time prior to the start of a study to figure out

- Who the end customer for the study is,
- The question(s) to work on for the customer,
- The form the answer should be in, and
- The form of logic and justification it will take to support the answer.

Without such a deliberate focus on the customer, the study team may be apt to focus on its own interests, which are not necessarily aligned with the interests of the customer.[13] The preparation of an issue paper provides the opportunity to develop this customer-focused information.

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11 For instance, the need may arise through an on-going mission analysis, a new vision, external challenges, a changing budget, or the personal interest of a decision maker.

12 Quade, *op cit.,* p. 73.

13 Peter Sharfman's comments are documented in Parker and Kuskey, *op cit.,* p. 25.

Quade recommends the elements of an issue paper, rephrased here for an investment study:[14]

- Source and background of the investment problem. (What seems to be the real problem?)
- Reasons for attention. (Why does the investment problem need attention in a study now?)
- Groups or institutions toward which corrective activity is directed by the study (i.e., for an investment study, the agencies that must implement the investments).
- Beneficiaries and losers (i.e., the stakeholders among DoD services and agencies, CINCs, and so forth, who will receive or lose the benefits of new investments)
- Related programs and activities.
- Goals and objectives for investments to satisfy.
- Criteria and effectiveness. (Measures related to the goals and objectives.)
- The framework for analysis (i.e., simple choice or budgeting; assumptions; constraints).
- Alternatives (i.e., the scope of options to be considered in the analysis).
- Recommendations (e.g. to do the study or not, or to take specific action without further study).

The preparation of an issue paper is itself a small study. Conceivably, as indicated in the last bullet above, the small study will uncover the solution to the problem.

The Study Plan

If the sponsors decide to proceed with the study, then a plan for conducting the study is prepared. The plan may be conceived usefully as a "contract" between those sponsoring the study and those conducting it. It may contain the typical "contract" sections: objective and scope, specifications, statement of work, schedule of deliverables, management plan, cost estimate, and any "sub-contracts" for outsourcing parts of the analysis. Its management plan should include a formal review process. The plan should include a realistic schedule of milestones and reviews to keep the study on track. The plan, in the form of a contract, is a basis for assigning authority and responsibility from the sponsors to the study leaders.

The study plan includes the tangible objective of the study, including the form of any recommendations. The objective may be a resource allocation among military systems, an

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14 Quade, *op cit.,* pp. 73-78.

“analysis of alternatives” for a single large system, an architecture and “road map” showing future desired systems and their timing, a resource allocation between different kinds of systems, or other analytical objective. The statement of the objective carefully delineates the scope of the study and any assumptions or constraints.

The study plan may include the organization of the study team, with roles and responsibilities, a work breakdown structure, a schedule of activities and milestones, and a budget showing sources and planned uses of resources. To the extent that the study involves the cooperation of various autonomous organizations, the study plan should provide ground rules for their participation. Such ground rules are necessary to assure each participant of fair treatment in the preparation and communication of study results.

The study plan may be comprised of plans for several sequential, parallel, or contingent studies that collectively achieve the main study objectives.

Organize the Study

Study Team

Quade suggests three roles for the analysts in a study: Project leader, project team member, and consultant.[15] These three can be somewhat generalized and extended to define all the roles of the study team as follows:

Leaders—The leaders are responsible, perhaps in a hierarchy or matrix, for coordinating the team members to fulfill the requirements of the study plan. More generally, they would be responsible to determine and direct the optimum application of all the resources of the sponsors to the requirements of the study plan. Preferably, the leaders themselves are experienced analysts.

Project Team Members—The project team members are the analysts responsible for directly performing the work defined in the study plan. They may be drawn from the sponsoring organizations, from the performing organizations, or from other organizations. They devote a large part of their time to the project.

Consultants—The consultants offer advice as requested by team members; they may be assigned special projects, such as model building or inventing investment options. The consultants devote a small amount of their time to the study.

Administration and Support—A large study may need security administrators, computer technicians, librarians, or other support specialists. Because visual materials are inherent to most stages of the study, it may be advisable to employ graphic artists to prepare visual material and to print or produce materials for briefings and reports.

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15 *Ibid.,* p. 79.

Project Management

In any study involving several teams, a project manager may be required. The project manager would develop a schedule of milestones, coordinate communications between teams, provide quality control for study products (coordinating a supportive peer review team to review study progress and products), provide financial management, and do whatever else may be necessary to optimize the application of all study resources.

Security

An investment study for the federal government will often involve classified government information. Consequently the study team will need to acquire, discuss, generate, process, store, and transmit classified information. For such activity to occur, a security plan and procedures will have to be prepared and implemented, covering all those topics. The plan and procedures will have to be coordinated with the study sponsors.

Several practical matters should be attended to, as follows:

- Security clearances for personnel will be necessary. Will there be enough personnel available with the needed clearances and accesses?
- In a large study, classified material needs to be organized systematically by a designated librarian for easy search and retrieval. Otherwise it may become practically "lost" even though it is being stored and accounted for formally.
- If the study needs connection to classified government data networks, this matter needs advance planning.
- The security plan will often need to provide for secure telephone and fax.
- The study will usually involve computer modeling with classified information. Suitable computers and a good, practical computer security plan and procedures are needed.
- A key element for efficient security administration is a collection of "classification guidelines." Such guidelines tell authors what information must be classified and what need not be classified. Without such guidelines, authors tend to mark every new document at the same level of classification as the sources they incorporate into the document. In fact, they might often be able to mark the new documents as unclassified, or classified at a lower level, if they knew the guidelines.

Equipment, Tools, and Facilities

Facilities may be needed for offices, conference rooms, and storage. Equipment may be needed for those facilities, including computers and copiers. Additionally, special tools may be needed, including application software and information services.

Define the Baseline for Analysis

In an investment selection study, it is important to define a baseline for analysis. The baseline answers the question: *Unless we make some change now, as a result of our study, what investments will we have in place to generate benefits in the future?* In other words, what systems and facilities will we either have in place or be putting into place, if we do not make some new decision now? In some cases, there will be a “zero base”: There will be no existing systems or facilities, nor will there be any commitments for future investments. More typically, many investments have already been made, and many are already planned for the future.

In general, the baseline is not a matter of black and white. It is seldom obvious, and it is often obscure. The sponsors and stakeholders of the study will need to work through a consensus process to define the baseline. They will look at various candidate existing systems and future investments and agree whether they are part of the baseline or not.

Once the baseline is agreed upon, optional changes to the baseline are the subject of analysis in the study. The final study recommendations will propose changes to the baseline.[16]

For the Department of Defense (DoD), the baseline often is defined as the plan for operating current systems and acquiring new systems that is in the DoD’s current Future Years Defense Plan (FYDP), or in recent proposed modifications to the FYDP. The FYDP has a six-year time horizon for programming and budgeting future expenditures. It has an extended planning annex covering up to 20 years of investments.

When the baseline is the FYDP, the study may require special budget expertise to determine exactly what is in the baseline. The best experts would have had career experience at DoD’s Program Analysis and Evaluation organization or similar offices.

The baseline is important in two ways. First, it shows the future planned investment costs. Second, it paints a picture of the future planned military capabilities. Both pictures are necessary to understand the costs and benefits of alternative future investments.

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16 Budgeting analyses sometimes use the terms “discretionary spending” and “non-discretionary spending.” These terms are roughly equivalent to “optional changes to the baseline” and “baseline,” respectively, in this paper. As with the baseline, negotiation and decision making typically will be needed to establish which spending is discretionary and which is non-discretionary.

Section 3

Search

It would seem that we cannot evaluate alternatives
unless we can first measure them, and we cannot measure them
without first identifying them.[17]

The investment selection study's search activities have the purpose of identifying, understanding, validating, and organizing the specific *investment options* that the study will analyze as potential changes to the baseline. Beyond that, the search activities also uncover important facts, estimates, and value judgments needed later to evaluate the potential investments.

In some cases, the investment options are defined external to the study. If so, the study team does not invent the options, but it still will investigate and validate them during the search activities. In a source selection, for example, firms submit proposals offering equipment requested by the government, and the government must choose which if any proposal(s) to accept. The proposals become the investment options. In the search activities, the proposals are investigated to verify that they are valid for the purposes of the source selection.

In other cases, some or all of the investment options must be invented as part of the study. Then the search is a matter of generating and screening options as well as clearly defining, understanding, and organizing the options. At one extreme, the goals for investments to satisfy are themselves unclear, so that the search for ideas begins by considering the purposes of investment and builds consensus about the specific goals that any investments should achieve. At other times, the goals for investment are clear, but it is not clear what can be done to achieve the goals. So studies are undertaken to learn what can be done. In yet other cases, many people may come forward advocating various solutions, and the invention becomes more of a screening and consolidation process than a pure invention process.

This section of the report

- Defines the term *investment option,*
- Describes various processes for inventing options,
- Describes methods for documenting and validating the options, and

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[17] Gene H. Fisher, *Cost Considerations in Systems Analysis* (New York: American Elsevier Publishing Company, Inc., 1971), p. 28.

- For complex selection, describes methods for organizing investment options in terms of *decision areas* and *decision variables.*

There can be no investment analysis, strictly speaking, unless and until the investment options have been agreed upon. This seems a simple truth, but some people seem reluctant to define the specific investment options. Perhaps they fear that the defined options will stop the search for better options. In practice, however, the analysis of specific options enables analysts and stakeholders to discover better options. We tend to do better thinking when we have specifics to think about.

Defining the Term "Investment Option"

For an investment selection study, we define investment opportunities formally in terms of composite *investment options.* The ultimate study recommendation or decision will consist of one selected investment option (simple selection) or a number of selected options (complex selection). For purposes of analysis in complex selection, the investment options themselves may be organized into *decision areas* and *decision variables,* to be defined later (p. 20).

The "Form" of Investment Options

We define an investment option to be a composite entity, whose elements may include one or more

- new investments,
- changes to existing investments, and
- changes to non-investment activities (e.g., operations and maintenance) that are linked to the new investments or to the changes to existing investments.

These elements, however many, are all considered collectively as a single discrete object of analysis and selection, the investment option.

Note that investment options are not being defined more broadly in terms of infinitely variable choices. There are no options with variable scope—no resizable options. Each option is a specific set of changes to the baseline. Every investment option is discrete.[18]

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[18] When desired, one may use a cumulative series of related discrete options to represent an otherwise infinitely variable option. Though analytical techniques exist to handle variable options, the use of discrete options facilitates many aspects of a study, such as defining composite options clearly, developing information about options, communicating clearly about options among study team members and study sponsors, and maintaining "configuration management" over the options.

The “Content” of Investment Options

An investment option, formally defined as just described, represents one or more real-life decisions to be considered in the study. Across a broad range of investment studies, the investment options may represent very different kinds of real-life decisions. In one study, the study question may be “What ideas for investment should we pursue to meet our needs in the far future?” In this case, the investment options may represent purely notional future concepts, useful for conducting high-level dialog and debate. In another investment study, the question may be “What performance specifications should we include in our Request for Proposals for the new system we want to purchase next year?” In this case, the investment options may represent concrete system capabilities easily demonstrated today.

Each study will need to deliberately establish its own standards for characterizing the content (i.e., meaning) of investment options, based on the study questions it intends to answer.

Invent Investment Options

If the search activities must invent some or all of the options, then even though the options must be discrete, the study must contemplate infinite possibilities to develop the options:

> “Reality allows an infinite set of options, and the hardest and most useful part of the study is often the identification of a limited set … that permit the decision-maker to actually maximize whatever is most important….”[19]

For this reason, it can be a difficult management task to get the options “pinned down” so that analysis may proceed. A deliberate and disciplined process may be needed to generate the definitions. The invention may proceed in many different ways, as discussed in the next sections.

Invent Options by Developing Goals

Our deliberate analysis of goals can help us to invent investment options:

> “Effective decision makers … thoroughly consider their goals and values relevant to a decision. Then they use that information to search carefully for a wide range of alternatives that have some promise of achieving these goals.”[20]

The study plan itself should include goals and objectives for new investments. Yet the plan’s stated goals and objectives may be too general to actually guide the generation of investment

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19 Peter Scharfman, private communication, January 18, 2001.

20 Daniel D. Wheeler, Irving L Janis, *A Practical Guide for Making Decisions* (New York: The Free Press, 1980), p. 7.

options. Accordingly, extensive study effort may be required to interpret, refine, or augment those preliminary goals and objectives to serve as a basis for generating options.

If goals are developed and prioritized by consensus in a study, this activity usually helps to "norm" the study team and study sponsors. That is, it helps them to align their expectations for the study before they begin to discuss investment options. This facilitates their work together because they can approach the investment options with a common mind.

A typical way to develop goals and objectives is to assess the baseline investment plan for strengths and weaknesses in light of future threats and opportunities.[21] By analyzing the strengths, weaknesses, opportunities, and threats (SWOT), the study can define its goals for change and prioritize the goals.

For SWOT methodologies, *goal-fabric* analysis and *scorecard* analysis may be used to develop the goals and objectives through expert judgment, often in a facilitated meeting.[22] The goals and objectives may be enhanced for military investment studies through *strategy-to-task planning*.[23] Modeling could be involved, in addition to expert judgment. Metrics may be defined for judging the success of new investments.

Another way to develop goals and objectives is through scenario planning.[24] In such planning, one imagines a variety of "histories" that may occur from the present forward. Goals may be generated by thinking through the imaginary histories and asking the question, "Given such histories might occur, what should we attempt to achieve, maintain, or avoid through our investments?"

The backward glance can also be a source of goals: What are we so proud of in the past that we want to perpetuate into the future? What are we ashamed of, and want to *not* perpetuate?

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21 The threats and opportunities may be defined as part of the scenario building of Section 4.

22 See Roy Gulick and Ken Kuskey, *The Goal Fabric; A Tool for Goal Setting and Action Planning* . McLean, Virginia: Decisions and Designs, Inc., 1992. For a description of scorecard methodology, see Ken Kuskey, "Naval Aviation Programs (OP-50) Analysis," in *Final Report; Analytical Support Services Contract MDA 904-87-C-2087* (Arlington, VA: Decisions and Designs, Inc., 1987), pp. 29-47.

23 Strategy-to-task planning is "the process of translating national military strategy to operational tasks. National military strategy is decomposed to theater military strategy and then to operational objectives. Once objectives are established, the associated tasks are articulated. This process ensures that actions at the operational level support the strategy of policy-makers." For analytical purposes, such thinking provides a hierarchy of tasks for which SWOT analysis can be performed. See Chairman of the Joint Chiefs of Staff Instruction 3170.01B, *Requirements Generation System* (15 April 2001), Encl. C, paragraph 1.a.(1).

24 See Section 4, "Understanding the Future," footnote 33.

For a new system, goal setting may profitably involve planned observations of "real people in real-life situations to find out … what confuses them, what they like, what they hate, and where they have latent needs not addressed by current products and services."[25] Human factors are at the heart of many systems.

Once goals and objectives have been identified, they may be used to stimulate ideas for investment options. See the subsection below on brainstorming and visualization (p. 15).

Invent Options by Conducting Supporting Studies

Quade has pointed out, "One cannot always decide what one wants to do until one has some idea of what one can do."[26] This means that scientific, legal, engineering, and economic studies may be needed to discover what might be done, how, and with what effect.[27] These studies may explore potential "alterabilities" in the baseline or in special scenarios, answering the question, "What can be changed?"

For military investment selection studies, it may be important, for instance, to conduct political studies related to potential options: What are NATO's plans and politics with respect to U.S. programs? Will European allies allow over-flight by U.S. airborne surveillance sensors?

Many if not most supporting studies may tap expert opinion. The study team may successfully plan, organize, and facilitate meetings of experts and authorities to discover what is possible, through enlightened structured conversation.

Supporting studies also may include computer modeling to explore the strengths of *cause-effect* relationships in the system under study. Such *exploratory modeling* is a powerful way to find investment possibilities. It is one of the two important uses of computer modeling during a study. The other use, *decision modeling*, is discussed below in Section 5. While the exploratory models need no real justification and little documentation, the decision models that help evaluate options must have substantial justification so that people can believe their results. The exploratory models may transition to become trusted decision models, but only with substantial documentation and traceability to authoritative sources.

Invent Options by Brainstorming and Visualization

Brainstorming is a group activity in which many ideas for solving a problem, either partially or completely, are quickly generated and then consolidated and ranked as potential solu-

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25 Tom Kelley with Jonathan Littman, *The Art of Innovation; Lessons in Creativity from IDEO, America's Leading Design Firm* (New York: Currency (Random House, Inc.), 2001), p. 6.

26 Quade, *op cit.,* p. 82

27 *Ibid.,* p. 54.

tions.[28] It is expected that each person's ideas will be a springboard for others' ideas. Brainstorming can be conducted in many ways and make use of a variety of technologies (e.g., electronic meeting systems, video teleconference).

If the study has developed goals or conducted supporting studies, as described above, the results may be used as a basis to brainstorm notional investment options. One can work through the goals in sequence, asking the brainstorming group, "If this is our goal, what new or changed investments would support it?" Either the goals or the "alterabilities" may be used this way as stimuli, but if both are available, they also may be used in "matrix" format (goal *vs.* alterability) as a framework for systematic brainstorming. Each cell of the matrix becomes the basis for new ideas: "If we want to observe activities in a region better, and if only NATO countries will allow airborne overflight by our military platforms, then what investment options should we consider?"

Other bases for brainstorming could be the current systems one is invested in, the current functions of the organization, or anticipated future threats:

- For each current system one asks the group, "When you think of this system, what different ideas do you think we could pursue?"
- For each current function of the organization, one asks, "When you think of our command communications, what different ideas do you think we should pursue?"
- For each anticipated future threats we might face, one asks, "Given what you know of country XYZ and the prospects for future conflict, what different investment ideas do you think we should pursue?"

Whatever the basis for the brainstorming, the resulting ideas for investment options are next screened, consolidated, and ranked. The top ideas are then elaborated and subject to further investigation, possibly through visualization.

Visualization means putting the ideas into some representation that can be better appreciated than simple words alone.[29] One can then see relationships and begin seeing how to improve the ideas. Drawings and physical models might help. Computer graphic renderings might help. Spreadsheets and graphs could be used. One might create a storyboard that shows how a system would be used. One might make a computer simulation that shows how the system might work through time. One might build a working prototype and put it to work. The point is to get a better view of the proposed investment and then use that view to improve the idea.

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28 A short history and description of the principles of brainstorming is provided by James L. Adams, *Conceptual Blockbusting; A Guide to Better Ideas,* 2nd ed. (New York: W. W. Norton & Company, 1979), pp. 134-137.

29 See Kelley, *op cit.*, for a discussion of how visualization contributes to innovation.

It is quite typical for organizations to use a committee to brainstorm and develop notional ideas, and then to advertise the ideas and ask for comments or for study proposals from a much broader group (e.g., through a private solicitation or through the federal government's *Commerce Business Daily)*. They then use the results they receive to refine the investment options. DoD has done this to explore ideas for building new military systems.

It is a useful strategy to iterate the search and synthesis phases of the study. One uses a sequence of brainstorming meetings (search) followed by evaluation meetings (synthesis). Through the sequence, one "boot straps" the study to generate and refine both its investment options and its decision criteria (evaluation factors).

Invent Options by Soliciting and Consolidating Options

In some studies, stakeholders may nominate investment options for implementation, either as complete solutions (for simple selection) or as partial solutions (for complex selection). The study may need to establish a formal process to solicit, receive, screen, and consolidate such options for inclusion in the analysis.

For simple selection, if different stakeholders propose different options, the study may proceed either to evaluate the options as is or to find additional *compromise* options to replace them in the study. The search for such compromise options may use the goal-development, supporting-studies, and brainstorming-visualization processes described above. Peter Sharfman suggests the following approach when various stakeholders may have worked out their preferred option in some detail, but the decision-maker wants to identify and choose an alternative that is not necessarily the first choice of any stakeholder but is acceptable to all:[30]

1. Review a set of clearly-defined, non-overlapping, and mutually exclusive options in order to get a feel for the "decision space," to identify the parameters to which the decision is most sensitive, and to allow key stakeholders to feel that their input has been given proper attention.
2. Create a set of alternatives to evaluate and present to the decision-maker that are all plausible choices (no "straw men" allowed), and that are likely to give the decision-maker an intuitive belief that if s/he knew and understood everything, then her/his first, second, and third choices would probably be among the alternatives listed. In this case the alternatives probably will overlap, and they should.
3. Feel free to invent alternatives that represent compromises among the options put forward by the stakeholders. Inventing an alternative that the decision-maker is really happy with is the greatest possible success for such a study.

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[30] Peter Sharfman, personal communication, Jan 18, 2001.

For complex selection, the options received may be redundant or synergistic to one another. The screening and review process may consolidate and reformulate options based on such interconnectedness. The options received may also show general trends (for instance, that everyone is beginning to run out of money to purchase new computers). In such cases, the study may formulate a new investment option suggested by the trend (for instance, to centralize the budgeting of new computers to achieve economies and to take the burden off the field organizations).

In the review and consolidation of options solicited for complex selection, it is important to identify any important *dependencies* among options. In practice, the most important dependencies are as follows:

- Two or more options are mutually exclusive—if you do one, you cannot or should not do the others.
- One option is not feasible to implement unless it is paired with some other option(s).
- One option will provide no value in use unless it is paired with some other option(s).
- One option will provide much more or less value when it is paired with some other option(s) than when not paired with the other(s).
- One option will cost considerably less or more when it is paired with some other option(s) than when not paired with the other(s).

Understand and Validate Investment Options

One person may invent an investment option, but generally many people will be involved in evaluating that option and deciding whether to include it in the study's final investment recommendation. These people need to understand the option in some depth before they can evaluate it or select it for recommendation: They need to know what the option is, what it will do, how it will benefit stakeholders, and how valuable that benefit may be. They need to believe that it is a valid option for inclusion in the study's analysis.

The essential steps to help study participants understand and validate the options are as follows:

- Prepare descriptions of the options.
- Communicate the descriptions to the study participants.
- Validate the options with the study participants.

Prepare Option Descriptions

Each investment option can be documented in a standardized format in a short paper or in briefing slides. Additional audio-visual or computer graphic material may help participants visualize the option. The essential information to prepare for study participants answers certain fundamental questions about an investment option:

- What activities will be done or changed? That is, what will happen if this investment is made? Who will do it? What is the project or program plan in brief?
- What will be delivered (quantity and quality) as a result of the activities? When? To whom? What is the risk of failure to deliver?
- How will the deliverables be used? Who will use them? When? For how long? What is the "concept of operations"? What logistics are involved? Is there a risk they *won't* be used?
- How will the use of the deliverables benefit stakeholders? Who benefits? Who loses? How sure are we that these benefits will happen? How can we measure the benefits?
- How do those benefits align with strategic goals and priorities?
- What is the life-cycle financial picture? When do we spend, and how much? When do we save, and how much?
- What does this investment option depend upon beside itself? Must anything else be done to make it successful? Are there any assumptions? Are there any upcoming policy or organizational changes that would place it at risk?
- What is the impact of *not* making this investment?

Communicate Investment Options to Study Participants

It is not enough merely to give the written descriptions of investment options to the study participants. To really communicate the options, invariably people must talk to people. Generally, the study must be deliberate in setting up a process for the authors and sponsors of options to communicate the options clearly to the study participants and stakeholders.

A typical process for communication involves a meeting to which the study's participants are invited. The written option descriptions are provided to the participants before the meeting for their study and investigation. At the meeting, the options are briefed to the participants in a uniform format for a standard period of time. The briefers answer questions from the participants. There is dialog among the participants, so that they are sure they have the same understanding of each option. Any clarifications agreed upon by the participants are documented.

For simple selection, there may be a separate communication meeting for each option. For complex selection, the separate options typically are briefed and discussed one after another.

Validate the Options

While anyone might propose an investment option, the study should not necessarily analyze and evaluate everything that is proposed. Some options may be incomplete, having insufficient information for evaluation. Other options may be outside the scope of the study's investment question. Others may be in the scope and fully documented, but they are so inconsequential or infeasible that further analysis is unwarranted. Others may lack support from any stakeholder.

A validation process screens out such options, so that only the most consequential, feasible, and well-sponsored options go forward into consideration for a place in the final study recommendation or decision. Otherwise the study's results are themselves at risk of appearing weak, infeasible, and unsupported.

A typical validation process is as follows:

- A validation sub-team reviews the options in depth and works with the authors and sponsors of options to make sure each option is as valid as possible;
- The validation sub-team nominates some options as invalid, providing reasons;
- During the meeting when options are briefed to study participants, the sub-team makes its recommendations; and
- The study participants discuss each option's validity and vote whether each option should go forward into further analysis or be declared invalid.

Identify Decision Variables and Decision Areas

Background

For complex-selection investment studies, the decision or recommendation is a *combination* of investment options, not a single unique investment option. Therefore, the study must analyze all the feasible combinations of options, not merely the individual options, as potential candidates to be the study's final recommendation. This can be a problem because there are typically many more feasible combinations than options. For instance, if there are ten investment options that may be combined in any way, then there are 1024 possible combinations.[31] So the study must evaluate 1024 combinations, not just the ten options. In principle, this would be an immense task, as compared to evaluating only ten options. Fortunately, there are analytical methods for simplifying this potentially immense task.

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31 In general, if there are *m* investment options, and if all combinations of the *m* are feasible, then the total number of possible combinations is 2^m.

The analytical methods to simplify complex selection are from the disciplines of decision analysis and operations research.[32] The methods involve decision variables, decision areas, decision models, preference models, and mathematical programming. Essentially, they make it possible to combine evaluations of individual investment options to obtain evaluations of all the feasible combinations of the options. This means that the evaluation of all feasible combinations is not much more difficult than evaluating all the individual options.

Usually, not all combinations of investment options are feasible. A set of decision variables and decision areas specify and organize the exact combinations of investment decisions that a study will analyze. They specify *what* is to be analyzed. The decision models, preference models, and mathematical programming specify *how* the decisions will be analyzed.

The decision variables and decision areas are discussed here as tools for organizing the investment options for analysis at the conclusion of a study's search activities. The other tools are discussed in Sections 5 and 6 of the report.

There is a large literature and a seemingly infinite variety of approaches for applying decision analysis and operations research methods to the analysis of investment options. The approach described in this frame of reference is one with a 20-year history of success in DoD system-design and budgeting applications. It is not the only possible approach, but it is a proven approach. It has been used with every Military Service and with many Defense Agencies. It was used once at the White House to shape the Foreign Assistance budget. It has been used continuously since 1977 to formulate the budget of the U.S. Marine Corps. It has recently been used several times to shape the U.S. Army's priorities for investment in information technology. It has been used for DoD C4ISR investment analysis.

Decision Variables

The purpose of *decision variables* is to account for strong dependencies among the investment options (see the list of dependencies on p. 18). If there are no strong dependencies between options, then decision variables are *not* needed. A decision variable is essentially a list of all the feasible, worthwhile combinations of a small group of the investment options that interact strongly among themselves but interact only weakly with options outside the group. A study will need to define as many decision variables as it finds such groups of tightly interacting options.

A decision variable is analogous to a multi-position switch: Each possible switch setting represents one feasible, appropriate combination of the options, and the switch can be set to only one of its positions at a time. The decision variable consolidates options into feasible combinations of options, and those combinations—instead of the options

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32 See for example, Frederick S. Hillier and Gerald J. Lieberman, *Operations Research,* 2nd ed. San Francisco: Holden-Day, Inc., 1974.

themselves—become the objects of evaluation and selection. To set a switch to a particular position is analogous to selecting the combination of investment options at that position for inclusion in the study's final investment recommendations.

In a simple-selection study, we might say there is just one switch, and its positions correspond to the mutually exclusive investment options under evaluation. For complex-selection studies, there may be several switches. Moreover, each switch position will correspond to a combination of several investment options, not just a single option. And furthermore, unlike simple selection, the combinations at each setting may share options in common. In other words, the feasible combinations of the options will generally overlap to some extent.

The table below shows a hypothetical decision variable. The columns correspond to four investment options, labeled A, B, C, and D. The rows correspond to six alternative decisions, of which one and only one must be selected. Each decision is a different combination of the four options. The Xs on each row show the options included in the decision. In this hypothetical case, Decision #1 has no Xs, so it is the *null decision*—none of the options is selected with this decision. Note that of a possible total of 16 combinations of the four options, the hypothetical study team has judged that only the six combinations shown in the table are both suitable and feasible for consideration. The other ten have been judged unsuitable or infeasible.

Table 1. Hypothetical Decision Variable

Decision	*Option A*	*Option B*	*Option C*	*Option D*
1				
2	X			
3	X	X		
4		X	X	
5	X	X	X	
6	X			X

In the simplest case of complex selection, there are no strong dependencies among any of the investment options. Each of the options can be considered as a two-decision decision variable (a two-position switch). The decisions are (1) "Include this option in the budget" and (2) "Exclude this option from the budget." If there are 300 such options, as there are in some budgeting studies, then there will be 300 of these two-position decision variables.

In a more complicated budgeting case, where both Option A and Option B are possible to include in the budget, but where Option B cannot be accomplished without Option A, a decision variable could be built with three positions. The positions would be (1) "Exclude both A and B from the budget," (2) "Include A but not B," and (3) "Include both A and B." Note that there is no position for the decision "Include B but not A."

The decision variables will consolidate a study's investment options into tailored combinations based on their redundancies, similarities, and dependencies. This is a matter of judgment. In general, investment options may depend upon each other—for decision making purposes—through the means by which they are implemented, through the joint benefits they provide, or through the subjective value attached to their joint benefits. All these considerations are taken into account in constructing a set of decision variables as feasible, logically coherent combinations of the possible options.

Procedurally, the study team will review the options, looking for strong dependencies. The team will identify groups of options that have strong dependencies among themselves but only weak dependencies with options outside their group. For each such group, the team will make a list (the decision variable) of all the feasible and potentially appropriate combinations of its options. The team may add a "zero base" combination to this list, signifying a potential study decision to recommend not investing in any of the options. After being constructed this way, one and only one of the listed combinations will end up in the study's investment recommendation (assuming there is a recommended investment).

As formulated in the decision variables, each separate decision (combination of options) requires estimates of life-cycle cost and financial benefits, expressed as changes from the baseline and typically specified for a multi-year planning horizon. Each decision also requires descriptions of the objective non-financial benefits its options will provide and the reasons that those benefits are important. The financial and benefit aspects of a decision will come from the descriptions of the investment options it includes, and from consideration of synergies and redundancies among those options.

Decision Areas

If there are many independent investment options (i.e., options not part of a decision variable), and if they represent diverse spheres of interest (such as communications, intelligence, and information assurance), it is generally useful to partition the independent options and decision variables according to the different interests. We call the partitions *decision areas*. The purpose of decision areas is to organize the work of evaluating the investment options and decision variables. The options and variables in each area can be analyzed separately, and then the collective analyses merged together to form a grand analysis.

In general, we can use a *hierarchy* of decision areas to represent a top-down partitioning of the options and decision variables into narrower and narrower spheres of interest. The top level of the hierarchy includes all the investment options of the study. The lowest level of the hierarchy is a decision area that includes a few investment options and/or decision variables corresponding to a narrow interest. Investment analysis proceeds by analyzing lower level decision areas and then merging these analyses together into the higher-level decision areas.

Various teams may do the analytical work for lower-level decision areas, and then *integrating* teams may blend the lower level analyses together. For instance, in preparing the U.S. Marine Corps' program budget (called Program Objective Memorandum, or POM), integrating teams are used to blend the analytical result of sub-teams. The integrating teams are called *program evaluation groups* (PEGs). The following figure illustrates the hierarchy of decision areas recently in use by the Marine Corps. The "program requests" at the left correspond (mostly) to investment options. They filter through "Functional PEGs" up to "Integration PEGs" and finally to the POM Working Group."

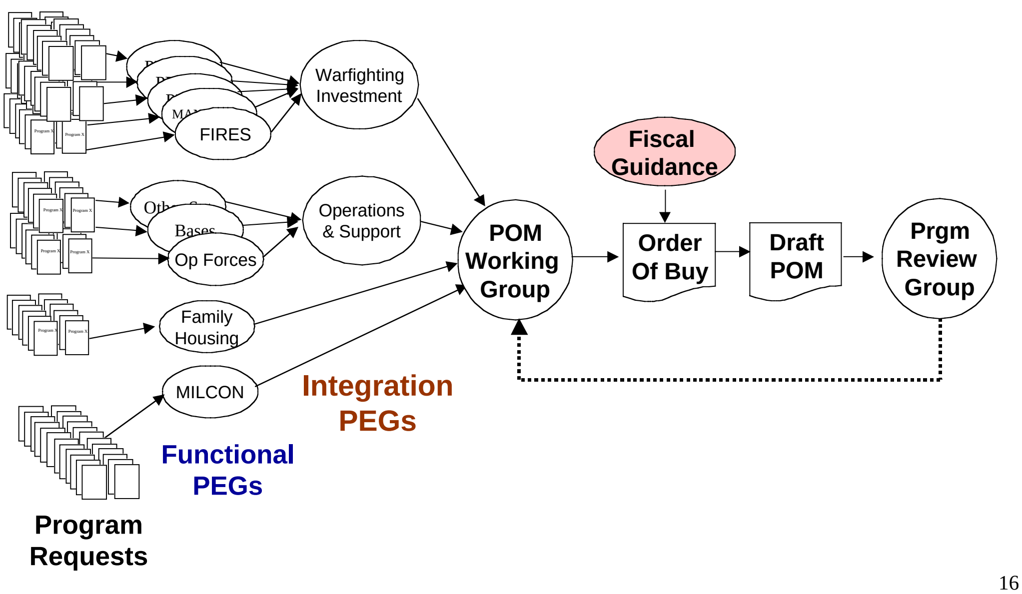

Figure 1. Decision Areas for USMC Budgeting

Unlike decision variables, decision areas do not correspond to a complete list of feasible, appropriate combinations of options. There are no switch positions. Instead, there is a list of switches (decision variables) and investment options. Usually, these switches and options will be independent. So they may be selected in any combination. In principle, but seldom in practice, a decision area may also have a list of dependencies, specifying interactions among the otherwise independent variables and options in the decision area or across decision areas.

Decision areas are part of the analytical process of breaking a problem down into parts, analyzing the parts, and then synthesizing an integrated answer to the problem. While some may complain that such a process creates "stove pipes" or "silos" of isolated thinking, such need not be the case. One can look for interdependencies across the decision areas.

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In organizing investment options for a complex selection, we use decision variables to represent "tight coupling" among the investment options. We use decision areas to organize the options and decision variables into subsets to be analyzed separately before being integrated into an overall analysis. If there is some "weak coupling" among options, such dependencies can be accounted for as dependencies within and across decision areas.

It would be a formal milestone of the study to have the decision variables and decision areas reviewed and accepted by the sponsors as a basis for further analysis.

Section 4

Anticipating the Future

We should all be concerned
about the future because
we will have to spend
the rest of our lives there.

—Charles F. Kettering

This brief section of the report may be considered a high-level summary and a placeholder for further development.

While there may be no facts about the future, all rational investment analysis involves a mental projection of new and planned investments into the future. In the projection, one imagines what the future will be like, what one's goals should be, and how well the investments will perform to satisfy one's goals.

Scenarios are an aid to thinking about the future.[33] They provide the analytical mechanism to describe potential stories of the future, much as a screenwriter prepares a storyboard and fills in details. In another form, they provide a mechanism to analyze the future itself, breaking it up into potential features that may occur in various combinations with different probabilities. If so, then *scenario variables* define the future possibilities, and the study proceeds to analyze investment decisions in light of the scenario variables and their probabilities.[34]

Besides being aids for thinking about what might happen in the future, scenarios may serve to limit the scope of a study to certain kinds of future, as follows: A policy maker says, "These six are the kinds of scenarios I think we should be prepared for. We do not need to get involved in the other ten scenarios. Let's find investments that will help us do the first six scenarios." Thus the same study question might receive different answers during different political administrations because of different policies about the appropriate use of the armed forces.

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33 The seminal paper is by Pierre Wack, "Scenarios: Shooting the Rapids," *Harvard Business Review*, Nov-Dec 1985, pp. 139-150. For a textbook discussion, see Appendix B, "Scenario Planning for Decision Making," in Craig W. Kirkwood, *Strategic Decision Making; Multiobjective Decision Analysis with Spreadsheets* (New York: Duxbury Press, 1997). See on the web, Kees van der Heijden, ed., *Scenario Planning; Select Bibliography*, http://www.gbn.org/public/gbnstory/ex_bibliography.htm

34 Michael F. O'Connor and Ward Edwards, *On Using Scenarios in the Evaluation of Complex Alternatives,* Technical Report 76-17. McLean, VA: Decisions and Designs, Inc., 1976.

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In military investment selection studies, an analysis of the future often involves three key aspects: the threat, our own technology, and the operational situation. Many other aspects may be involved as well, such as industrial capacity, logistics, or politics.

Develop Threat Scenarios

What military capabilities will our adversaries possess in the future? For instance, will they be able to conduct field operations at night? Will they be able to detect our aircraft? Will they be able to deny our data communications? The range of potential questions is limitless. Generally, the investment options the study is considering will suggest the kinds of adversary capabilities to consider.

Develop Technology Scenarios

What new technologies will shape our capabilities and our adversaries' capabilities in the future?[35] What will those capabilities be? What is our technology road map to the future?[36] It has been said that today's smart investment decision is tomorrow's legacy problem. Will our investments serve as stepping-stones to the future, or will they lead us astray?

Develop Operational Scenarios

Typical variables here are the geographic location of a conflict, intensity of conflict, red/blue concepts of operations and tactics, and phases of the war.

Organize Scenario Variables

The synthesis of scenario information into scenario variables supports the subsequent analysis of investment options. The form of synthesis will depend on the form of analysis, and vice versa.

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35 See Stephen M. Millett and Edward J. Honton, *A Manager's Guide to Technology Forecasting and Strategy Analysis Methods.* Columbus, Ohio: Battelle Press, 1991.

36 For the Department of Defense, the Director of Defense Research and Engineering coordinates the development of the *Defense Science and Technology Strategy*, which is a place to start investigating technology scenarios.

Section 5
Decision Modeling

"A decision is always only a guess."[37]

"Theories [models] are necessary because life is such a mess."[38]

"We construct and run models because we want to understand the consequences of taking one decision or another."[39]

"A model decoupled from its reality—the passions and politics it can arouse—is little more than an intellectual exercise."[40]

The Role of Decision Models

The decision model's most essential function, at its best, is to serve as a platform for productive dialog, debate, and negotiation among a study's stakeholders about complex interdependent issues and concerns. It represents their shared understanding not only of what will result to them (benefits and losses) from various investments, but their own mutual roles in implementing and making use of the investments. At its worst, the decision model can become "a battlefield on which power relationships are enacted,"[41] a destructive vehicle for the dishonesty and flaws of human nature.[42]

A model is "a set of propositions or equations describing in simplified form some aspects of our experience."[43] We use decision models to describe, to varying levels of detail, the

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37 Andrea Williams, *Making Decisions* (New York: Kensington Publishing Corp., 1985), p. 13.

38 Ames, *op cit.*, p. 15

39 Herbert A. Simon, *Prediction and Prescription in Decision Modeling,* Technical Report AIP-44, Department of Psychology, Carnegie Mellon University (June 1988), p. 7.

40 Michael Schrage, *Serious Play; How the World's Best Companies Simulate to Innovate* (Boston: Harvard Business School Press, 2000), p. 136.

41 *Ibid.,* p. 158.

42 *Ibid.,* p. 131.

43 *Web Dictionary of Cybernetics and Systems.* (See http://pespmc1.vub.ac.be/ASC/INdexASC.html.)

different effects one may anticipate from making various decisions in the presence of various scenarios. Decision models are tools for making informed, logically consistent guesses (estimates) about the important effects of decisions.

At their simplest, decision models may be only diagrams that portray how the decisions (investment options) and scenarios will produce various effects. They embody "propositions" of a very simple form, e.g., "Decision *X* will increase effect *Y*." More complex models may use equations that calculate *how much* the effect *Y* will increase if *X* is decided.

The decision model takes as its inputs the independent investment options, decision variables, and scenario variables. As outputs, when the model is quantitative, the decision model provides estimates (or a probability distribution) of the important tangible joint effects of the decision and scenario variables. The effects are typically described in terms of financial results (quantified in money terms) and non-financial results. The non-financial results often are differentiated and quantified as measures of effectiveness (end results of decisions) and measures of performance (intermediate results). The decision-modeling task develops information or computer algorithms that describe the study's mutual understanding of causality among the inputs and outputs. We may call the decision models *causal models* because we use them to describe or estimate the cause-effect relationships between the inputs and the outputs.

Some decisions are too complex to model well. For instance, a nation-wide network of computers operated by Caltech in the late 1960s was not adequate to predict the results of sending various guidance decisions to the Mars Mariner spacecraft. Instead, a duplicate spacecraft on earth was sent the decisions, and its behavior was observed before the decisions were sent to the true spacecraft.

Yet some studies may not need decision models at all. Expert or stakeholder estimates may substitute adequately for cause-effect models. This may happen in two ways:

1. Experts directly estimate the costs, measures of performance, and measures of effectiveness that will result from various combinations of decision and scenario variables; or

2. Expert stakeholders directly judge the value of the non-financial results of various combinations of decision and scenario variables, only implicitly estimating the measures of performance and effectiveness.

In developing models for military investment studies, we may find, as Peter Sharfman has put it, that wars are much too complex to model well, but also too complex to comprehend intuitively. Then what do we do? We can strive to do a better job of modeling the performance of military systems in combat, and we can strive to do a better job of eliciting and organizing expert and stakeholder estimates. Both approaches can add value.

A decision model may evolve during a study. Specifically, it may evolve from a purely conceptual, non-quantitative model to become a quantitative deterministic model, and finally to become a fully probabilistic model.

Non-Quantitative Models

A decision model may be useful and adequate even though it is not in any sense quantitative or "calculating." As described above, the purpose of a model is to serve as a platform for productive dialog, debate, and negotiation among a study's stakeholders about complex issues. A diagram on a whiteboard may achieve that purpose if it represents a consensus among stakeholders about how the world works and how their decisions will have an impact. It may well be that a quantitative model is *usually* not required to serve this purpose.

Every decision model, whether ultimately quantitative or not, begins as a set of related concepts representing decisions, outcomes, uncertainties, constraints, and cause-effect relationships. One may use schematic diagrams to develop, represent, and refine the connections among the concepts in a stakeholder group. The author knows of two formal methods for automating such representations. First is "Strategic Options Development and Analysis" (SODA), originated by Colin Eden and Fran Ackermann, and supported by software known as *Decision Explorer*.[44] The second is "Visual Image Mapping System" (VIMS), supported by the software *QuestMap,* originated by Jeff Conklin of the company Group Decision Support Systems.[45]

Deterministic Models

To move to a quantitative model, which calculates outputs from inputs, one usually begins with a *deterministic* model. In the purely deterministic model, the inputs, outputs, and intervening calculations do not involve random variables. No probabilities are used. Such a model produces output in the form of point estimates. The output is a single number for each measure. Typical tools for deterministic modeling are *Mathematica* (Wolfram Research, Inc.), *Analytica* (Lumina Decision Systems, Inc.), *ithink* (High Performance Systemc, Inc.) for systems dynamics models, and even *Visual Basic* (Microsoft Corp.).

Deterministic models are used to test the sensitivity of the output to various parameters of the model, especially the decisions and scenarios. Sensitivity studies done with a deterministic model will suggest which variables should be treated probabilistically, if any.

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44 See Colin Eden and Fran Ackermann, *Making Strategy; The Journey of Strategic Management.* Sage Publications, 1998. Pp. 528. Further information on the book and the Decision Explorer software may be found on the web at www.banxia.co.uk/demain.html. Eden and Ackermann are professors at the University of Strathclyde Graduate Business School, Glasgow, Scotland.

45 See the website www.gdss.com for further information.

Probabilistic Models

When the same new investment may produce a wide range of outputs, quantitative probabilistic models are used to develop the probabilities of the possible outputs. Analysis with such models helps us hedge our decisions against outcomes that may be quite unlikely but would be very *unfortunate.* Such analysis also lets us direct our decisions to best achieve outcomes that may be quite unlikely but would be very *fortunate.*

Normally, we might prefer to avoid investment options whose future benefits may vary greatly as a result of presently unknown, future, contingent factors. Such avoidance is probably the norm in U.S. government decision making. However, avoidance is not always possible, even for the government. Probabilistic models provide the means to analyze our decisions when we believe we must consider investment options whose results are uncertain.

In a fully probabilistic model, the scenarios are random variables specified with probabilities, many of the intervening causal relationships are also specified probabilistically, and the output of the model is a probability distribution for each measure, not just a point estimate or average.[46] The probability distribution(s) describe ranges of uncertainty for the output measures. The software tool *DPL* may be used for many cases of simple and complex selection with fully probabilistic models.[47] *DPL* calculates its results analytically and recommends the best option(s) to select. Other tools, such as *Analytica* and *Extend* (Imagine That, Inc.) use repeated random number generation and statistical analysis to calculate the results of alternative selections, but they do not have optimization techniques to find the best selections.

Between the fully deterministic and fully probabilistic models, we may distinguish intermediate forms. For instance, one may specify scenarios and intermediate calculations probabilistically but specify the outputs as averages. The outputs are calculated as expectations from the intervening probabilities. This is the form of output in MITRE's C4ISR Analytic Performance Evaluation (CAPE) analyses.[48] Such models can generate a common understanding of the "main effects" of probabilistic phenomena, though they fall short of developing understanding about the range of effects. When a broad range of possible effects is not an issue, such models may be sufficient for establishing the study's recommendations.

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46 In general, the output is a joint probability distribution for all measures.

47 *DPL* is a product of Applied Decision Analysis, Inc., a subsidiary of PriceWaterhouseCoopers. See on the web http://www.adainc.com.

48 Kenneth P. Kuskey and Susan K. Parker, *The Architecture of CAPE Models,* MTR 98W00153. McLean, VA: The MITRE Corporation, 2000.

In light of the foregoing, the process of decision modeling may include developing the decision model, collecting the information to perform deterministic analyses, and collecting the information to perform probabilistic analyses.

Develop the Decision Model

Because of the decision model's role as platform for debate and negotiation, the first consideration in designing the model should be "Who benefits from this model?"[49] The shape and content of the model can disadvantage some stakeholders to the advantage of others. What form of model can best represent all their mutual interests effectively? Build that model.

The literature of decision analysis is a rich source of concepts for developing non-quantitative and quantitative decision models.[50] The process for developing the model is evolutionary and open-ended. There are continuous modifications of the model in response to past modifications, a bootstrap process that ends only when it appears there is nothing else to learn. Larry Phillips of the London School of Economics has defined the result of this learning process to be a *requisite* decision model:

> "A model can be considered requisite only when no new intuitions emerge about the problem."[51]

Generally, it will take longer to obtain a requisite model when the problem being modeled is complex, when there is much information about the problem, and when many stakeholders need to be convinced of the final model's veracity. A simple model may be more practical than a complex model, even if not as precise, merely because it is understandable and acceptable to a broader audience.[52]

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49 Schrage, *op. cit.*, p. 160.

50 For instance, Robert T. Clemen, *Making Hard Decisions; An Introduction to Decision Analysis.* Boston: PWS-Kent Publishing Company, 1991. For specific guidance on modeling investment decisions, see Chapter 8 "Resource Allocation" and Chapter 9 "Multiattribute Preference Theory" in Kirkwood, *op cit.* Another excellent book, which introduces the *Analytica* software for modeling complex decisions, is M. Granger Morgan and Max Henrion, *Uncertainty; A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (see note 8). For modeling the financial aspects of investment decisions, consider Gene H. Fisher, *Cost Considerations in Systems Analysis* (see note 17). Also see Eden and Ackermann, *op. cit.*

51 Larry D. Phillips, "A Theory of Requisite Decision Models," *Acta Psychologica*, 56 (1984), pp. 29-48, quoted by Clemen, *op cit.*, pp. 11-12.

52 The simpler model may also be more accurate than the complex model. See the paper by MITRE authors Paul E. Lehner and Christopher Elsaesser, "On the Value of Detailed Modeling," an unpublished paper presented at INFORMS in 1996.

For purposes of building insights about an investment problem, some *exploratory* modeling may incorporate ambiguous parameters not easily understood or reliably measured. However, a quantitative decision model—which serves as an agreed consensus among stakeholders about the extent to which investment options may add value—should not normally incorporate such ambiguous parameters. It should incorporate them only if they have little effect on the estimated benefits of investment options. Otherwise consensus may never be achieved.

To take the study results forward persuasively, it is essential to document any decision models well and to have legitimate authorities validate them. It will also be useful to the study if the modeling tools include visualization of relationships, architectures, networks, and outcomes.

Collect Deterministic Information

As the quantitative decision model evolves, its parameters must be collected. Since the results of modeling depend on the parameters used, one must develop a clear basis for the parameters, including traceability to authoritative sources. Generally, point estimates and statistical averages may suffice as parameters for deterministic analysis.

For both deterministic and probabilistic information, a great asset for organizations would be a continuing authoritative database of information to serve various studies as they arise.

Collect Probabilistic Information

For probabilistic analysis, it will be necessary to collect at least some probabilistic parameters, not merely point estimates. This requires considerably more effort than collecting the deterministic information. Whole probability distributions may be elicited from experts, or merely statistical parameters such as fractiles, the mean, the variance, covariances, and related parameters. There is a decision-analysis literature on practices for eliciting probability distributions from experts.[53]

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53 For instance, Miley Merkhofer, "Quantifying Judgmental Uncertainty; Methodology, Experiences, and Insights," *IEEE Transactions on Systems, Man, and Cybernetics,* Vol. SMC-17, No. 5, Sept/Oct 1987, pp. 741-752. Also see R. L. Keeney and D. von Winterfeldt, "Eliciting Probabilities from Experts in Complex Technical Problems," *IEEE Transactions on Engineering Management,* Vol. 38, No. 3, August 1991, pp. 191-201. Also see G. G. Shephard and C. W. Kirkwood, "Managing the Judgmental Probability Elicitation Process: A Case Study of Analyst/Manager Interaction," *IEEE Transactions on Engineering Management,* Vol. 41, No. 4, pp. 414-425.

Section 6

Synthesis—Developing Study Recommendations

Our age is characterized by the perfection of means and
the confusion of goals.[54]

Ultimately all policies are made … on the basis of judgments.
There is no other way, and there never will be…. In the end,
analysis is but an aid to judgment…. Judgment is supreme.[55]

Reason is a pole that may keep the plant of intuitive thought
from growing crooked, but it is not itself either a plant or
a valid substitute for a plant.[56]

Synthesis is the "end game" of an investment study, bringing closure to the study's activities. In synthesis, the investment options are analyzed in the light of authoritative value judgment to develop, assess, and communicate the study's investment recommendations or decisions.[57]

Synthesis has five steps:

1. Determine specifically how the study team will evaluate the investment options in terms of both financial and non-financial considerations, using value judgment, expert estimates, and other information.
2. Evaluate the non-financial aspects of the options directly, using value judgment, or develop the parameters of a *preference model* that will be used with a decision model to evaluate the non-financial aspects of the options indirectly.
3. Estimate the financial costs and benefits of the investment options.

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54 Attributed to Albert Einstein, source unknown.

55 Alain C. Enthoven, former U.S. Assistant Secretary of Defense (Systems Analysis), quoted by Fisher, *op cit.*, p. 7, from an article in *Business Week* (Nov 13, 1965), p. 189.

56 Bruno de Finetti, Professor of the Theory of Probability at the University of Rome, *Probability, Induction, and Statistics; The art of guessing* (New York: John Wiley & Sons, 1972), p. 148.

57 Throughout this section, the term "investment option" or simply "option" denotes both the decision variables and the independent investment options defined in Section 3.

4. Perform a decision analysis to illuminate the best investment option(s) to recommend in light of the judgmental evaluations, financial estimates, and constraints.
5. Choose, assess, and communicate the study's recommendations or decisions.

This section describes ideas, methods, and processes related to the five steps, as follows:

- *Evaluating the non-financial benefits of investment options*—the role of value judgment, approaches for incorporating value judgment in synthesis, and practical methods for evaluating options.
- *Performing decision analysis*—basic concepts, the role of models, the use of models.
- *Developing recommendations or decisions*—selecting investment recommendations or decisions, assessing them, and communicating the study's results

Evaluate Investment Options

Investment decision making means choosing goals for investments to satisfy, not merely choosing investments that will satisfy goals. As James March has written, "Human choice behavior is at least as much a process of discovering goals as of acting on them."[58] Likewise Quade writes, "Preferences are pliable, not fixed. … Every new fact or experience remolds our policy preferences."[59]

Many goals and priorities for investment will have been developed during the study's search phase and decision modeling phase. The synthesis phase brings together the study's goals and priorities to formally evaluate the investment options.

Typically some goals will be more important than others in selecting an investment recommendation, in the sense that we will try to meet some goals completely but may leave others only partially met, if met at all. An important function of the synthesis phase is to analyze the options in light of the relative importance of the goals, seeking investments that emphasize the most important goals.

The Role of Value Judgment

Let us consider an important philosophical and practical issue: Should we organize the evaluation of investment options in light of goals as if evaluation were a purely objective process, or should we consider it properly a subjective process? In other words, should our evaluations of investment options be based on objective information only, or should it be based on human preferences as well?

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58 James G. March, *Ambiguity and Choice in Organizations* (1976).

59 Quade, *op. cit.*, p. 102.

Engineers, with their analytical training and reliance on science, might tend to think that evaluation should be a purely objective process. In fact, some people may consider that the relative importance of goals should be an objective calculation, much as one calculates measures of effectiveness. For instance, one eminent American has written,

> "I have in mind an ultimate dependence upon science because it is finally for science to determine, so far as it can, the relative worth of our different social ends…."[60]

The opposite view taken here is that goals and the relative importance of different goals are inherently subjective matters, not objective. They concern human purposes and preferences. They reside fundamentally *inside* the stakeholders and decision-makers, not outside. Hence it is not rational or practical to determine the relative value of optional investments simply by objectively studying the investments and their expected results. Instead, one must also ask the stakeholders how much they value those results.[61] Theory and methods for such elicitation are core topics of the discipline of decision analysis.[62]

In this preference-oriented view, evaluating investments is something like conducting an art contest. It requires judges who evaluate, develop preferences, and select a winner using some subjective basis (i.e., their "best professional judgment"). Likewise, stakeholders and their best judgment are necessary for evaluating investment options. Extending a proverb, as beauty is in the eye of the beholder, so value is in the eye of the stakeholder. The stakeholders evaluate investment options based on what they perceive to be best for them and for the enterprise as a whole. One may conjecture that public-sector organizations become strong and productive to the extent that they create an environment conducive to collecting and applying such stakeholder evaluations to their planning and decision making.

In government decision making, the stakeholders or their authorized representatives exercise their best judgment to decide which goals to pursue and how much importance to give to each goal. Ideally, they do not act as private individuals, but as stewards for their enterprises

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60 Justice Oliver Wendell Holmes, quoted in Charles E. Lindblom, *The Policy-Making Process* (Prentice-Hall Inc., 1968), p. 79

61 Holmes's view might be considered an extreme Enlightenment perspective, hoping against hope that science and rationality can be depended upon to decide what is best for mankind, not merely what is true. The different view taken in this paper has been fundamental to the development of decision science in engineering, psychology, and business schools from the latter half of the 20th century on.

62 See Ralph L. Keeney, *Value-Focused Thinking; A Path to Creative Decisionmaking.* Cambridge, Mass.: Harvard University Press, 1992. This book won the 1994 Decision Analysis Publication Award from the Institute for Operations Research and Management Science.

who serve the public interest. Likewise, in a government *study* that is chartered to recommend investments, the stakeholders act as such good stewards.

If value is in the eye of the stakeholder, then an important corollary is that evaluation must always involve the stakeholders. No independently developed measures of effectiveness or performance may substitute for their judgment. *No systems engineer can calculate how valuable some investment is apart from carefully elicited direct knowledge of the preferences of officially designated stewards of the public interest.*

Contrary to the view that an investment study should be a "purely scientific" analysis based on objective facts, excluding subjectivity, we may quote James Schlesinger, eminent analyst, government official, and MITRE Chairman:

> "…analysis is not a scientific procedure for reaching decisions which avoid intuitive elements, but rather a mechanism for sharpening the intuitions of the decisionmaker. ...the role of the subjective preferences of the decisionmaker remains imposing. Analysis is, in the end, a method of investigating rather than solving problems. The highest strategic objectives, the statement of preferences or utility, must in large part be imposed from outside. … good analysis by itself cannot insure correct decisions."[63]

Approaches for Incorporating Value Judgment in Synthesis

To ensure the validity and acceptance of its results, the study team usually must develop an authoritative basis for evaluating the investment options with or on behalf of the stakeholders (beneficiaries and losers identified in the study plan).[64] This involves several activities:

- Working with stakeholders, establish a set of attributes covering the interests that stakeholders hold in the results of investment decisions. These attributes correspond to benefits, costs, measures of effectiveness, measures of performance, and so forth.
- Decide whether the attributes are to be simply kept in mind when assessing preferences, or whether they are to be individually represented in a preference model.
- Working with stakeholders, either

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63 James R. Schlesinger, "Uses and Abuses of Analysis," a memorandum prepared for the U.S. Senate, in Harley H. Hinrichs and Graeme M. Taylor, ed.s, *Program Budgeting and Benefit-Cost Analysis; Cases, Text, and Readings* (Pacific Palisades, CA: Goodyear Publishing Co., Inc., 1969), p. 348.

64 Without such a basis, the study risks giving the appearance that a group of self-appointed experts is behind its recommendations, a sure recipe for controversy, opposition, and unnecessary failure. The exception is when the study team itself includes a "blue ribbon panel" of authorities and experts.

– Measure their preferences for investment options directly, or

– Develop parameters for a preference model, so that the model measures the stakeholders' preferences for different levels of the attributes.

In such activities, the team may develop complex value or utility functions;[65] it may develop formulas describing the public's "willingness to pay" for the benefits of government investments,[66] or it may simply enumerate and rank key goals to be considered in setting priorities over investment options.

Value functions, utility functions, and willingness-to-pay (WTP) functions all quantify subjective preferences for the diverse outcomes that may result when one makes an investment.[67] We will call them all *preference models.* Value functions and WTP functions are useful for deterministic analysis. Utility functions are useful for probabilistic analysis. All three kinds of function evaluate the outputs of a decision model. The functions turn the decision model's several measures of effectiveness and performance into one or two measures of preference. Because they combine several measures into one or two measures, they encompass and represent all the value tradeoffs among the several measures.

When used, the preference model is the place where the study's analysts establish tradeoffs between various levels of various measures of effectiveness. The tradeoffs are a matter of value judgment, not of technical judgment. It would often be a formal milestone of the study for the study sponsors to review and accept the preference model, or other results of this activity, as a basis for continuing with further analysis.

We may distinguish two approaches to preference modeling. First, the preference model may be developed before the investment options are defined. In this case, one anticipates all the important attributes of value that will discriminate appropriately among the options. Second, the preference model may be developed after the investment options are defined. One compares the actual options, looks for attributes that discriminate among the options, builds a

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65 Ralph L. Keeney and Howard Raiffa, *Decisions with Multiple Objectives; Preferences and Value Tradeoffs.* New York: John Wiley & Sons, 1976.

66 Robert Dorfman, ed., *Measuring Benefits of Government Investments.* Washington, D.C.: The Brookings Institution, 1965. Also see Samuel B. Chase, Jr., ed., *Problems in Public Expenditure Analysis.* Washington, D.C.: The Brookings Institution, 1968.

67 A recent handbook written by economists and decision analysts discusses these various kinds of preference function and their use with financial measures. See John Dodgson, Michael Spackman, Alan Pearman, and Larry Phillips, *Multi-Criteria Analysis; A Manual.* London: Department of Environment, Transport and the Regions, Dec. 2000. It is on the web at www.defra.gov.uk/environment/multicriteria/index.htm.

quantitative preference model based on the attributes, and evaluates the options by providing scores for the options and weights for the attributes.

Yet a third approach might be called “un-modeling.” In this approach, one does not use a model. Instead, a stakeholder group ranks and measures the options directly, through discussions. The group, working by consensus, documents the strengths, weaknesses, risks, and costs of the options in light of broad goals, which are the attributes previously agreed.

Generally, the third approach provides the most authoritative results. It is the approach most often relied upon in source selections, where protests must be defended against by conducting a demonstrably systematic, unbiased, non-arbitrary analysis.[68] It is also used in budgeting.[69] The third approach has a special advantage for budgeting studies. In a budgeting study, it is not unusual for each investment options to have its own unique attributes, not shared with other options. The third approach does not require a model of all possible attributes of value. It would be a great burden to have to build a model that included each attribute.

The first and second approaches both develop preference models based on measurable attributes of the options. This has the advantage over the third approach of making it much easier to explore new investment options and evaluate them without reconvening a stakeholder group. The second approach has the advantage over the first of being informed by the investment options, so that the preference model can be focused to discriminate among the options. It is possible to carry out the first approach and then to find that the preference model does not discriminate appropriately among the actual investment options. On the other hand, the first approach creates a preference model that may assist those who generate the investment options, informing them of the most important attributes to emphasize in their options.[70] So all three approaches have their place in studies.

Methods for Evaluating Options

A large variety of methods is available for assessing the non-financial value of investment options, ranging from simple to extremely complex. Practical, non-controversial methods in use for many years are identified and summarized here. The methods involve different modes of evaluation and different bases for evaluation.

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68 See Michael F. O’Connor, Janine L. Faris, and Joan S. Lovelace, “A Decision Support Procedure for Best Value Source Selections,” *Acquisition Review Quarterly,* Vol. 4, No. 2 (Spring 1997), pp. 135-160.

69 See Ken Kuskey, Debbie Dickins, Albert Macias, *The Program Prioritization System; USMC Handbook for Resource Allocation.* McLean, VA: Decisions and Designs, Inc., 1994.

70 For an example of the first approach see Terry A. Bresnick *et al.,* “Airborne and Space-Borne Reconnaissance Force Mixes; A Decision Analysis Approach,” *Military Operations Research,* Vol. 3, No. 4 (1997), pp. 65-78.

We differentiate three *modes* of evaluation:

1. *Non-quantitative*—evaluation is done by putting options into categories, by assessing strengths and weaknesses of options, by ranking options. Quantitative measures of value are not used at all. Source-selection evaluations are typically non-quantitative.

2. *Quantitative with implicit outcomes*—evaluation is done by asking stakeholders to score the value of the options directly, mentally (implicitly) taking into account both the effects the outcomes will cause and the value of those effects. For instance, budgeting decisions are often quantitative with implicit outcomes.

3. *Quantitative with explicit outcomes*—evaluation is done by estimating the outcomes of investment options (estimates may be made by experts or by a decision model) and using a preference model to calculate a score from the estimates. For instance, some DoD Analysis of Alternatives studies have been quantitative with explicit outcomes.

In addition, we differentiate two *bases* for evaluation:

1. *Individual evaluation*—each option is evaluated on its own merits, without comparison to any other option. This is typical in source-selection evaluation.

2. *Comparative evaluation*—each option is evaluated solely in comparison to other options, not on its own merits. The evaluation is done in terms of differences between the options or in terms of differences between various combinations of the options.

Table 2 summarizes practical methods of evaluation in the three modes with the two bases, for both simple and complex selection. Nine different methods (numbered 1-9) are listed. Tables 3 and 4 expand Table 2 to provide a summary of each method's process. Unfortunately, it is beyond the scope of this report to offer more detail. A technical report or book chapter could be written on each method, and has been written in some cases.

None of the methods below treat uncertainty explicitly. In government analyses, it is expected that stakeholders "discount" the value of options when the benefits are uncertain. If such uncertainty needs explicit modeling, advanced methods are available.[71]

The methods listed here have proven to be practical. Those that are quantitative are based on simple linear additive multiattribute value analysis, or on simple extensive measurement (the balance beam process). There are forms of preference model that are not linear or additive. It is suggested that the study team should attempt to use the methods listed here first, and then move to other forms only if necessary.

Human purposes and goals are not necessarily measurable in financial terms. Most of the methods listed below do not require financial measures of value. The exception, when it is

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[71] Keeney and Raiffa, *op. cit.*

possible, is the best-value analysis phase of the Federal source selection process. In that process, it is important to attempt to quantify in financial terms (i.e., units of money) the differences in non-financial value among the options. That is, one attempts to find a basis for saying that the difference in value between two options is worth the difference in cost.

Table 2. Practical Methods for Evaluating the Non-Financial Aspects of Investment Options

	Mode of Evaluation		
Basis of Evaluation	**Non-Quantitative**	**Quantitative — Implicit Outcomes**	**Quantitative — Explicit Outcomes**
		Simple Selection	
Individual Evaluation	❶*Source-selection evaluation,* highlighting strengths and weaknesses of each option.	❷*Linear additive multi-attribute value analysis,* with value scales anchored independent of the options.	❸*Linear additive multi-attribute value analysis with value functions.*
Comparative Evaluation	❹*Best-value analysis* for source selection, emphasizing major differences between options.	*Scheme #1* ❺*Best-value analysis* for source selection, emphasizing major differences between options, *using quantitative measures of the differences.* *Scheme #2* ❻*Linear additive multi-attribute value analysis,* anchoring each value scale with the options themselves.	*Not Applicable.* Use the approach for individual evaluation when explicit outcomes are available.
		Complex Selection	
Individual Evaluation	❼*"Project categorization,"* assigns options to different categories differing in urgency or importance.	②*Linear additive multi-attribute value analysis,* with value scales anchored independent of the options.	③*Linear additive multi-attribute value analysis with value functions.*
Comparative Evaluation	❽*Direct ranking of options* against one another, creating a "1 to N" list of options.	❾*Balance-beam measurement process.*	*Not Applicable.* Use the approach for individual evaluation when explicit outcomes are available.

Table 3. Evaluation Processes for Simple Selection

	Mode of Evaluation		
Basis of Evaluation	**Non-Quantitative**	**Quantitative — Implicit Outcomes**	**Quantitative — Explicit Outcomes**
Individual Evaluation	Define attributes of value. Define strengths and weaknesses for each option, considering all attributes. For each option separately, 1. Rank its strengths. 2. Rank its weaknesses.	Define attributes of value. For each attribute, define a range of value, providing exemplars of value to serve as anchors for the top and bottom of the scale. Define swing weights that measure the importance of moving from the bottom to the top of each scale. Score each option on each attribute. Calculate a weighted average score for each option, using the weights.	Define the outcomes that will be valued. Define value functions, one for each outcome, showing how value increases or decreases with the level of the outcome. Define swing weights that measure the importance of moving from the lowest to the highest value for each value function. Estimate the valued outcomes for each option. From these estimates and the value functions, determine the value measures for each option. Calculate a weighted average value for each option, using its value measures and the swing weights.

	Mode of Evaluation		
Basis of Evaluation	**Non-Quantitative**	**Quantitative — Implicit Outcomes**	**Quantitative — Explicit Outcomes**
Comparative Evaluation	Define discriminator areas. For each pair of options, 1. Determine differences in performance for each discriminator area. 2. Rank the differences.	*Scheme #1* Continuing the discriminator analysis at left, 1. Use the balance beam process to measure the value of all discriminator performance differences. 2. For each pair of options, add up the value of each option's positive differences, and show which member of the pair has the greatest total. *Scheme #2* Define attributes of value. For each attribute, 1. Rank the options. 2. Assign scores of 0 and 100 to the worst and best options. 3. Assign intermediate scores to the other options. Define swing weights that measure the importance of moving from the worst to the best value for each attribute. Calculate a weighted average score for each option, using the weights.	*Not Applicable*

Table 4. Evaluation Processes for Complex Selection

	Mode of Evaluation		
Basis of Evaluation	**Non-Quantitative**	**Quantitative — Implicit Outcomes**	**Quantitative — Explicit Outcomes**
Individual Evaluation	Define categories of value (e.g., Must Buy, Critical, High Value, Nice to Have). Assign each option to one category.	*Scheme #1* Use the same process as that for individual evaluation with simple selection (not repeated here). *Scheme #2* *Often used but has a poor theoretical basis.* Define attributes of value. Assign weights to the attributes. Rate each option from 1 to 5 on each attribute, using only whole numbers (sometimes it is 1 to 10). Calculate a weighted average rating for each option.	Use the same process as that for individual evaluation with simple selection (not repeated here).
Comparative Evaluation	Organize options into one or more *decision areas* (see p. 23). For each decision area, 1. Define goals. 2. Describe benefits and drawbacks of each option in light of the goals. 3. Rank options against one another, producing a complete order of the options, either doing this once or doing it once for each of several goals.	Continuing the comparative analysis at left, 1. For each decision area separately, use the balance beam process to measure the value of its options. 2. Use the balance beam to measure "sample" options that represent all the decision areas. 3. Using results of steps (1) and (2), develop one scale of value for all options. 4. If step (3) has been done separately for each of several goals, then develop weights for the goals and apply the weights to develop a single scale of value for all options.	*Not Applicable*

Perform Decision Analysis

In the *decision analysis* activity, one uses the results of all prior tasks to find—insofar as possible through analysis—the best investment decision(s). The decision analysis bridges the logical gap between problem and solution, question and answer, needs and recommendation. It creates a more disciplined or objective basis for the recommendation than a simple reliance on otherwise unsubstantiated expert opinion to discern the best course of action.

In the case of simple choice, the ideal decision analysis would generate a best-value ranking of the investment options, where the ranking balanced both non-financial and financial factors. In the case of complex choice (budgeting), the decision analysis would generate the best investment portfolio fitting the budget constraints. Or, in cases without budget constraints, the decision analysis would generate the best-value investment portfolio, considering both financial and non-financial factors.

Practically, the decision analysis may not identify the best investment decisions. Instead its chief value is to narrow the range of possible investment recommendations to something manageable by policy makers through judgment alone. For instance, it may generate a subset of investment options for budgeting, ranked in order of buy, though it does not identify any one best portfolio of those options. Or for simple selection, it may quantify the non-financial and financial aspects of the options, rule out dominated options, but not rank the options.

This task may include the classic phases of decision analysis—deterministic, probabilistic, and informational.[72] The deterministic analysis uses no probability distributions as inputs or outputs. Through sensitivity analysis, one finds whether a probabilistic phase is needed.

For complex selection, the decision analysis will usually apply integer or dynamic programming techniques or tools to find the best selections of options.[73] In doing so, one may rank options by benefit-to-cost ratio, a very practical method used to select options for the U.S. Marine Corps' budget.[74] Or one may use much more complex approaches.[75]

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72 Professor Ronald A. Howard of Stanford University described these phases in the late 1960s. For an introduction to his ideas, see Ronald A. Howard, "The Foundations of Decision Analysis," *IEEE Transactions on Systems Science and Cybernetics*, Vol. SSC-4 (1968), pp. 211-219.

73 For instance, G. Hadley, *Nonlinear and Dynamic Programming.* Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1964.

74 Kuskey, Dickens, and Macias, *op. cit.* A classic technical paper underlying this approach is H. Everett, "Generalized Lagrange Multiplier Method for Solving Problems of Optimum Allocation of Resource," *Operations Research*, 11, 399-417 (1963).

Decision analysis may include computer-based analysis, utilizing the models and information developed in other tasks. The following subsections provide concepts regarding modeling and its appropriate use in decision analysis.

The Role of Models in Decision Analysis

In the most general case, synthesis employs both decision models and preference models. Their combined use is illustrated in Figure 2.

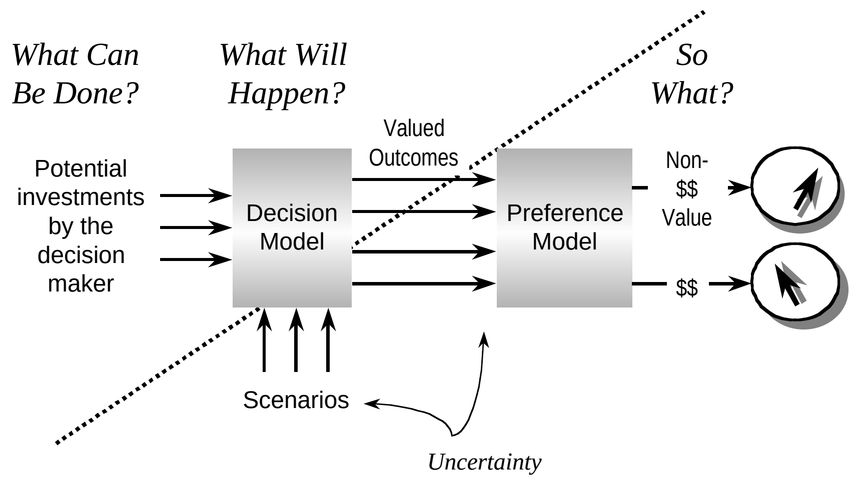

Figure 2. Decision Analysis with Decision and Preference Models

At the left are the investment options. At the bottom are the scenarios. For any specific combination of investment options and scenario variables, the decision model calculates *valued outcomes* as measures of effectiveness or measures of performance.[76] Then the preference model takes as inputs the valued outcomes (or the probability distributions over them) and turns them into evaluations. The preference model represents the study's considered judgment about the value of alternative levels of the valued outcomes.

As shown in the figure, the preference model typically has two evaluation measures as its outputs: One measure represents the non-financial, judgment-based benefits and costs of the

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75 See a survey of 33 methods in Zachary F. Lansdowne and Bruce W. Lamar, *A Survey of Portfolio Selection Methodologies*, MITRE Technical Report 01B0000015, May 2001.

76 Generally, the scenarios or cause-effect results may be uncertain, so that the valued outcomes are also uncertain and must be represented probabilistically instead of with deterministic estimates.

decision, and the other represents the estimated financial benefits and costs of the decision.[77] In this two-measure format, the decision analysis centers on calculating the non-financial value and the net financial cost (or benefit) for potential investment decisions.

For simple selection, both measures are merely calculated and displayed for each option. For complex selection, mathematical programming techniques are used with the measures to find "efficient" combinations of options, which are those combinations providing the most value for any given cost.

For both simple and complex selection, the two measures are typically not used directly to choose investment recommendations. Instead, the selection of investment recommendations is typically left to human judgment at a later stage of analysis, using the two measures as data. (By exception, the two measures may be combined in the preference model if the study has determined a general relationship between the financial and non-financial measures, i.e., a *willingness to pay* for non-financial benefits or value.)

The diagonal line across the figure signifies the division of "objective" and "subjective" aspects during decision analysis. The objective aspects—potential investments and cause-effect relationships—are above the line. The subjective aspects, below the line, are the uncertain cause-effect relationships (if any), the scenarios, and the judgmental preferences. Some of the valued outcomes may be objective, but many may be affected by subjective uncertainties. The financial benefits and costs will typically be based on professional judgment and cost models, which may be uncertain. They are shown with the subjective aspects of the study.

The Extent of Modeling in Decision Analysis

Each study team must decide how much modeling it needs for synthesis. Some studies will use many models, and other studies will use none. There is no norm.

A simple direct conversation among stakeholders about preferences among investment options may generate more mutual understanding and consensus than any model. On the other hand, a few facts and a simple cause-effect model may clear up longstanding disagreements and hostilities. More is not necessarily better. Less may be better.

In some cases, neither decision nor preference models are used. Synthesis occurs through the direct judgmental evaluation of options without intervening models involving causality, valued outcomes, or preferences for outcomes. This is the norm in source selection evalua-

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[77] The financial output from the preference model will typically be the net cost of the investment option, and so it could properly be considered an output of the decision model, not the decision model. However, in a more general case, some benefits may be "dollarized" through willingness-to-pay functions or other method and added to or subtracted from the net cost. Hence it is appropriate to consider the financial output as something generated with the preference model.

tions and organizational budgeting. Judgment and conversation among stakeholders—without models—take account of causality, uncertainty, valued outcomes, and preferences to rank or measure the investment options directly. As long as the final rankings or measures can be explained convincingly to the study sponsors, it does not matter whether a model was used.

If one may use the *acceptability* of study recommendations as the basis to judge that models were *not* necessary, this suggests a more general strategy for using models during synthesis:

- First attempt to do the synthesis without models.
- If this first attempt succeeds, so that it gains acceptance for study recommendations, the study is over.
- If it does not succeed, use it to illuminate key aspects of the study for which deeper understanding or more explicit preferences need modeling. In other words, use it to point the direction and to give focus to modeling efforts.
- Modeling can proceed iteratively from this initial focus. Proceed to build the minimum set of models that might be sufficient (or *requisite*, see p. 33); attempt synthesis again; either gain acceptance for results or launch into more modeling; and so forth.

Generally, two questions will determine how much modeling is needed:

- Can stakeholders directly estimate the end effects of each investment option and their combinations? Or can they estimate the end effects only through some chain of interdependent intermediate causes and effects?
- Can stakeholders directly evaluate the end effects of the investment options? Or must they break their evaluation down into different attributes of value or into non-linear combinations of value?

If the answers to both questions are yes, then no decision or preference models are needed. If the first answer is yes, then a decision model is needed. If the second answer is yes, then a preference model is needed.

Tools for Investment-Selection Decision Analysis

Many software tools are available to assist with the decision-analysis task for investment selection analysis. The journal *OR/MS Today* publishes an annual survey of decision analysis tools (see on the web http://lionhrtpub.com/software-surveys.shtml). Some tools employed by or known to MITRE investment-selection analysts are listed below.

HiView (simple selection, implicit outcomes) provides for direct judgmental evaluation of options without preference functions. It provides for a hierarchy of value attributes to which weights are assigned at each level. It has been in use in various versions for over 20 years. It is available from the London School of Economics, which holds the copyright. (See http://www.decision-conferencing.com/tools.htm.) It is also available from Krysalis Ltd. (see *High Priority* below).

Logical Decisions (simple selection, explicit outcomes) supports simple selection. It enables (1) direct judgmental input of estimated outcomes of options, and (2) the use of preference functions to measure the value of the outcomes. (Logical Decisions, 1014 Wood Lily Dr., Boulder, CO 80401. See http://www.logicaldecisions.com/.)

Equity is specifically designed for use in complex selection. In use in various versions for over 20 years, it has been used for resource allocation at the White House, every military Service, Westinghouse Corporation, and many other organizations. It enables the user to divide investment options into decision areas, to account for mutually exclusive options, and to account for options that build on one another cumulatively. It finds, displays, and makes available for analysis the "most" efficient combinations of options (i.e., those combinations that are extreme points of the convex hull of all efficient combinations). These are often about a third of all the efficient combinations, usually enough to guide decision-makers. *Equity* is available from the London School of Economics, which holds the copyright. (See http://www.decision-conferencing.com/tools.htm.) It is also available from Krysalis Ltd. (see *High Priority* next).

High Priority (complex selection) enables (1) direct judgmental input of estimated outcomes of options, and (2) the use of preference functions to measure the value of the outcomes. It enables one to freely specify and display three types of dependencies among options:

- Selection of one option may be ruled out unless other options are selected, too;
- The selection of one option may rule out the selection of others; and
- The combined value or cost of any two options may differ from the sums of their separate values and costs.

High Priority finds, displays, and makes available for analysis the "most" efficient combinations of options. Given sufficient time, *High Priority* also finds, displays, and makes available for analysis all efficient combinations of options. It is available from Krysalis Ltd. (See the web site http://www.krysalis.co.uk/; the mailing address is 28 Derwent Drive, Maidenhead, Berkshire SL6 6LB UK).

Program Prioritization System (PPS) was developed for the U.S. Marine Corps by Decisions and Designs, Inc. It is licensed for unlimited use and duplication within the U.S. government. PPS has been used and refined continuously since 1977 to aid the Marine Corps' resource allocation. Last updated in 1994, PPS is currently a DOS application for use on IBM-compatible personal computers. PPS provides data bases, decision aids, and production tools for developing a multi-year, multi-appropriation program budget such as the Commandant of the Marine Corps' Program Objective Memorandum (POM). Each PPS data base, of which there may be several, can maintain information on up to 500 competing program initiatives in 99 categories. PPS's decision aids include spreadsheet-like displays to project on a screen for group use in facilitated discussion and decision making about the priorities of initiatives and the selection of initiatives to include in the POM. PPS's functions provide the means for comparing benefits across diverse categories of initiatives, for sorting initiatives into a cost-efficient "order of buy," and for preparing various pre-formatted reports useful for analysis. PPS's production tools include a special program for importing cost information and reports for listing the controlling budgets for various appropriations based on final program decisions. In addition, PPS provides a worksheet for group display that can be used independently of budgeting to set priorities for goals, requirements, problems, and actions. The document *The Program Prioritization System; USMC Handbook for Resource Allocation* (Vienna, VA: Decisions and Designs, Inc., 1994) is a complete guide to program budgeting and to the use of PPS. The document is licensed for unlimited use and duplication within the U.S. government.

Balanced Scorecard—Decision Analytic Model (complex selection) is a recently developed MITRE tool that integrates constrained optimization techniques with the balanced scorecard. It provides for a hierarchical multiattribute preference model, direct judgmental estimation of explicit outcomes, and for a wide variety of dependencies among options. Within its dependencies, it allows for the time phasing of options. For any resource constraints the user provides, it finds the most efficient combination of options.[78]

Expert Choice (simple selection) provides for (1) direct judgmental input of estimated outcomes of options, and (2) the use of preference functions to measure the value of the outcomes. It provides for a hierarchy of value attributes to which weights are assigned at each level. It has been in use in various versions for many years. While the evaluations of options can be developed with any measurement method and then input to *Expert Choice*, the software also provides a value measurement method called the Analytic Hierarchy Process (AHP). AHP itself, not the *Expert Choice* software's general capability, is controversial because it is not consistent with the axiomatic frameworks of measurement theory and decision analysis taught in the major schools of decision science and mathematical psychology. Nonetheless, *Expert Choice* is very widely used with AHP and accepted by many in practice. (It is not in use at MITRE by the author.) Though it is fundamentally a simple-selection tool,

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78 Lansdowne and Lamar, *op. cit.*, pp. 4-31 to 4-36. Also see B. W. Lamar, D. Dornbusch, and H. Callihan, *Integrating the Balanced Scorecard and Decision Analytic Methodologies for IT Investment Decision-Making: A Proof of Concept Case Study with NAVSEA Fleet Logistics*, MITRE Technical Report MTR01B0000011, March 2001.

it may be extended with a spreadsheet add-in for use with complex selection. It is available from Expert Choice, Inc. (http://www.expertchoice.com).[79]

FedSelect® (simple selection) is Windows-based proposal evaluation software, available on GSA schedule. While this product is not currently used by the MITRE Economic and Decision Analysis Center, it is representative of the type of analytical tool useful for a non-quantitative decision analysis. To quote the DoD Acquisition Deskbook, "*FedSelect*® is designed to assist a source selection process by automating evaluations of competing proposals that uses evaluation factors/areas with criteria/thresholds. It provides fully traceable and automatically documented proposal evaluations focused on capturing rating and risk rationale behind the business decision, and supported by linkage to proposal strengths and weaknesses. In addition, there are pre-formatted interim and final reports used to brief to decision making officials." MITRE staff frequently use similar software installed at various government source-selection evaluation offices.[80]

Microsoft *Excel* (simple or complex selection) is a useful spreadsheet tool for both simple and complex selection when the number of options is relatively small. Guidance for using spreadsheets for such analysis can be found in Craig Kirkwood's text, *Strategic Decision Making* (see footnote 33).

Develop Recommendations or Decisions

Make Selection Recommendations or Decisions

Based on the information developed in all prior tasks, including the decision analysis, the study team chooses the recommendations it will make. Or, if the team is so empowered, it decides which investment options to select. In both cases, the choice is an exercise of judgment alone, not the result of any computer model. That is, people exercise professional judgment to decide what they will recommend or decide as a result of the study. The recommendation or decision should include plans for adjusting the selection to future contingencies.

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79 For a comparison of *Expert Choice* and *Equity* as tools for complex selection, see D. Dornbusch, A. Elmer, K. Kuskey, B. Lamar, T. Shimi, *A Comparison of Two Project Selection Tools: Expert Choice and Equity*, MITRE Working Note WN01B0000062, September 2001. In an appendix, it contains a short case study comparing the results of the AHP "ratings method" of value measurement (supported in *Expert Choice*) with the results of the "balance-beam" method often used with *Equity*.

80 See http://www.deskbook.osd.mil/valhtml/1/13/132/1322/1322S01.htm for the DoD Acquisition Deskbook's description of *FedSelect*.

Assess Selection Recommendations or Decisions

The essence of this task is to review the decision or recommendation in detail to test it for suitability, feasibility, and affordability in light of all previously developed information. Weaknesses and strengths of the decision or recommendation are highlighted.

Communicate Study Results

A communications campaign is designed and executed to carry the study results forward to the study sponsors and into any decision making processes for which the study was commissioned. In addition, the study is fully documented so that those who will be deciding whether to rely on its results may audit it in depth.

In light of the second definition of the word *study* (p. 2), it may be said that no study has occurred unless there is a final report of the study. A study may succeed in influencing decisions, but without a final report the study team may leave the impression (as expressed by a study sponsor) that it does not really know how to fill in the part between the question and the answer.

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