R&D PRIORITIZATION AND RESOURCE MANAGEMENT FOR TECHNOLOGY SELECTION

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ABSTRACT

This paper presents a decision approach, and associated computer software tools, for prioritizing and selecting among technology development activities. The approach elicits and then summarizes technology development preferences from stakeholders, and then integrates preferences into a set of funding recommendations. By formalizing the technology review process, the decision approach builds consensus and clarifies the basis for final budget decisions. The software development was conducted jointly by Pacific Northwest Laboratory and Decisions Science Associates, Incorporated. The U.S. Department of Energy (DOE), Office of Technology Development's (OTD) Underground Storage Tank Integrated Demonstration funded the task; however, the approach should be valuable to other OTD and DOE activities.

INTRODUCTION

In planning a fiscal year program, the U.S. Department of Energy, Office of Technology Development's Underground Storage Tank Integrated Demonstration (UST-ID) uses decision analysis techniques to help prioritize technology development needs and to evaluate proposals submitted to meet those needs. These techniques are useful for providing a comprehensive and consistent basis on which to evaluate proposals, recording both the funding decisions and the basis for those decisions, and providing a starting point for future program reviews. Pacific Northwest Laboratory (PNL) staff and Decision Science Associates, Inc., extended and codified the general decision analysis approach into computerized decision support tools. The tools assume that the funding program has selected its program focus (responding to clearly prioritized needs), has released a request for proposals, and has received multiple proposals in return.** The task now is to determine which of these proposals to fund and how much to spend on one technical area, such as characterization, vis a vis others, such as retrieval, processing, or disposal.

The decision analysis framework and tools have been applied to a number of tasks and settings. Each application has drawn on a subset of the steps described in this paper. In addition to the UST-ID and In Situ Remediation Integrated Program technology development prioritizations, the Hanford Site Tank Waste Remediation System (TWRS) used the general approach to provide input to its Integrated Technology Plan. The application and tools were adapted in two different exercises to allocate internal operations and research and development budgets. This methodology can be easily adapted to many situations with different end goals and types of reviewers.

This paper presents two decision support tools and a general decision approach useful for making initial technology development funding decisions. The first tool, a Prioritization Tool, combines evaluations of individual proposals from multiple perspectives into a comprehensive benefit score and produces candidate rankings for proposals based on benefit or on a benefit cost ratio. The second tool, a Resource Management Tool, combines the evaluations of proposals from one technical area with evaluations of proposals from the other technical areas to help generate a funding portfolio for an entire technology development program.

The overall objective of these tools is to promote technology development that is technically defensible, broadly accepted, and cost-effective. The tools are intended for use with guidance from a facilitator, but they can be used by anyone familiar with basic spreadsheet software such as Excel or Lotus 1-2-3. The software described in this paper can be understood as a series of prompts for information needed in the steps underlying systematic decision making. The Prioritization Tool prompts for the following:

- the set of independent perspectives desired for review (e.g., technical, regulatory, industry, institutional)
- criteria by which to evaluate single proposals from each perspective (what the technology development program wants its funded technologies to accomplish)
- weights for these criteria (which are automatically normalized)
- evaluations of each proposal against the criteria by qualified reviewers
- cost data for funding each proposal, including cost profiles over a 5-year period
- the set of proposals recommended for funding at the lowest, medium, and higher funding levels within a technical funding area (referred to as minimal, recommended, and enhanced "technology packages").

The Resource Management Tool prompts for the following:

- criteria and weights for evaluating technology packages across funding areas (which may differ from individual proposal evaluation criteria)
- evaluations of the technology packages by a technology development program manager or program advisory group.

The tools update and summarize this information to produce candidate priorities among proposals, first within a single technical area and then among technology packages across

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** The general methodology presented here can also be used to prioritize technology development needs prior to a request for proposals.

technical areas. The basis for these priorities can be changed by the users to perform sensitivity analyses or to explore alternate prioritization strategies.

The tools do not make decisions nor do they provide final recommendations; their value is as adjuncts to a well-planned funding process with multiple decision makers or reviewers involved in different technical areas. The initial candidate rankings that they produce may be considered a first step toward developing a recommended technology development program. The Prioritization Tool makes this first step explicit by recording and summarizing the criteria weights and evaluations of stakeholders and then recording the changes that expert reviewers may make to that initial ranking to formulate logical sets of proposals to be funded at different concurrent funding levels. Similarly, the Resource Management Tool documents the basis for distributing funds across technical areas, based on input from the first tool.

PROBLEM DESCRIPTION

This paper addresses two issues that, while not unique to technology development, may be particularly problematic for making technology funding decisions. First is the issue of budget planning. In times of increasingly tight budgets and public scrutiny of program decisions, managers are being asked to better articulate the benefits of the technologies they develop and to balance these benefits against their cost. These benefits may be difficult to clarify, especially in the initial stages of development and especially when technical experts are divided regarding a technology's potential. In these situations, programs must be sure that they have systematically reviewed all of the critical performance parameters, incorporated key (and potentially conflicting) perspectives, and documented how they have traded these off to make final decisions. The decision process presented here provides a mechanism for accomplishing each of these steps. In addition to clarifying the basis for initial decisions, the product of this process provides a means for re-allocating budgets when funding levels change during the course of the development program without reconvening experts and expending significant additional resources.

A second, related issue has to do with stakeholder involvement. The general issue of public involvement has received a great deal of emphasis within the Department of Energy. However, the question of how to effectively *do* public involvement has received much less attention. This paper presents one model for involving different perspectives in a budget planning exercise. While the application focuses on technology development budgets, the underlying model is general: elicit the values from key perspectives (weighted criteria), provide a vehicle for these to be expressed (evaluations), and then incorporate these into an overall analysis. The tools described here do not address how these perspectives should be selected or how their evaluations should be elicited (e.g., through focus groups or using representative reviewers), and the analysis process does not replace other kinds of public involvement activities. The tools can, however, be used in conjunction with other activities to ensure that stakeholder inputs are not just heard but are systematically tracked, documented, and formally incorporated into the decision process. The stakeholders to involve and their level of involvement are determined by the program, based on its needs.

The software tools are described in general terms in the following sections. These descriptions are meant to illustrate both the tools and the more general decision model that underlies them. A more complete and fully illustrated description of their application within an integrated demonstration or integrated program is provided in Quadrel, Chinnis, and Ulvila (1).

TECHNOLOGY PRIORITIZATION

The decision analytic process is described in terms of the information the computer software tools require to function. The Prioritization Tool helps to evaluate proposals within a single technical area (e.g., characterization). To do so, it prompts multiple reviewers for their evaluations of how well research and development proposals address different criteria. Reviewers may represent different perspectives (e.g., technical, regulatory, industry, or eventual users), and each perspective may be represented by different criteria. The perspectives and criteria are not fixed and may be specified for different applications, either by the program manager or by the reviewers/participants. The tool consists of three parts: 1) individual evaluations, 2) summary evaluations from different perspectives, and 3) combined evaluations across perspectives.

Individual Evaluations

The first part of the Prioritization Tool records, combines, and processes the results of individual reviewers' evaluations of proposals against a set of evaluation criteria. These criteria may be provided by the reviewers at the time of the evaluation or determined ahead of time by the program, with or without input from the technical reviewers or other stakeholders (2) for one approach to eliciting criteria from stakeholders). Details on how to define and scale decision criteria can be found in Quadrel, Chinnis, and Ulvila (1); a more general and detailed discussion is provided in Keeney (3). The tool combines this information, using a modified additive multi-attribute utility procedure (4). The review process proceeds as follows.

First, scores for the proposal are assessed against the criteria by separate technical reviewers (as many reviewers can be used as is practical and helpful). Selected criteria can be expanded into subcriteria for more detailed evaluations. For example, in the UST-ID program, the technical reviewers wanted to give detailed attention to the extent to which proposals addressed one or more technical needs, which were established by Hanford's TWRS. Each need was presented as a separate criterion (in situ chemical characterization and tank integrity are two example characterization needs), and each criterion was weighted by its priority (also established by TWRS). These weighted values were then rolled up to give an overall value for a single need criterion; this need criterion was subsequently weighted against other technical evaluation criteria: technical feasibility, expected performance, timeliness, and deployability. An example summary of a technical evaluation data sheet for one proposal is shown in Fig. 1.

Second, an overall weighted-average technical evaluation is calculated for the proposal by taking the sum of the products of all technical criteria scores and normalized criteria weights. For all assessments, the responses of each individual reviewer are recorded; however, calculations are made on the averages of individual responses. In application, averaging should occur only after differences of opinions are discussed and reviewers are given the opportunity to modify their assessments, especially when ranges are high. (To facilitate this process, a range is automatically produced for each criterion

P93-035: In situ tank analysis: in situ sampling and analysis in Hanford waste tanks

Short Title:	In-situ tank analysis		
Tracking No./TTP No./Org.:	P93-035	NEW	PNL

Criterion	Technical Reviewers' Evaluations ABC	XYZ			Avg	Range
Technical need	See detail below				45	
Multiple needs	25	30			27.5	5
Technical feasibility	50	10			30	40
Performance	25	25			25	0
Timeliness	50	10			30	40
Deployability	25	25			25	0
Multiple measures	40	0			20	40
Application to industry	40				40	0
Capability of proposing organization	0				0	0
Adequate approach and understand problem	20	25			22.5	5
Development cost ($K)	100				100	0
Capital layouts for hot deployment ($K)	150				150	0
Overall evaluation	50	85			67.5	35

Need	Wt	Scaled	ABC	XYZ			Avg	Prod
1.01: in situ chemical char.	100	1	50	25			37.5	37.5
1.02:meas phy & rad prop,retrieval	90	0.9	50				50	45
1.03:global mapping & modeling	60	0.6	30				30	18
1.04: tank integrity	85	0.85	0				0	0
1.05: remote control end effector	78	0.78	0				0	0
Other need #1	35	0.35	0				0	0
Other need #2	35	0.35	0				0	0
Total								100.5

Fig. 1. Example technical evaluation data sheet.

per proposal, showing the extent to which reviewers disagreed.)

This evaluation process is repeated for each additional perspective included in the review. One or more regulators, industry representatives, end users, or public stakeholders may participate using criteria established for their particular objectives/concerns.

Summary Evaluations from Different Perspectives

The second part of the Prioritization Tool combines the individual technical assessments into a technical summary for each proposal. The software allows the technical evaluations of all proposals to be viewed on a summary page that includes a full identification of each proposal, its average score on each criterion (averaged across reviewers), its calculated weighted-average evaluation (overall technical benefit score), and its assessed costs. This allows a decision maker to review, in one place, most of the data that contribute to the evaluations of all proposals.

This part of the Prioritization Tool also contains similar summaries of analyses of proposals from industry, regulators, and other stakeholders and produces a summary of the funding profiles for all proposals. Five-year cost estimates used in the tool would generally come from the proposers and should be subject to an independent cost analysis or review. These are recorded and summarized along with the overall scores for each proposal, providing important information regarding the multi-year funding profile of each proposal. Later these estimates can be used to explore cumulative out-year profiles of the final technology packages.

Combined Evaluations Across Perspectives

The third part of the Prioritization Tool is a combined evaluation of proposals. This part summarizes data from other parts of the tool and allows an exploration of the implications of various funding decisions. Information displayed for all proposals includes proposal identification, a total evaluation that combines technical with other stakeholder evaluations, component details of the total evaluation, and cost profiles.

The total evaluation is determined from a weighted average of the technical and other stakeholder evaluations. The weights used in this calculation can be readily modified in order to perform sensitivity analysis (e.g., by weighting regulatory and technical reviews more or less heavily relative to other perspectives).

The evaluation summary data, described above, also describe cumulative cost profiles (i.e., cost profiles implied by funding down a ranked list of proposals). The summary data are seen as the primary decision-aiding tool, and it can be used to examine the implications of various prioritization methods (e.g., based on total evaluation, based on total evaluation divided by total cost, or based on alternate evaluations determined by changing weighting schemes). These implications include the cumulative cost profile generated by funding any number of top-priority proposals. This part also includes a space that can be used to record additional comments related to the proposals (e.g., reviewers comments on outstandingly good or bad criteria scores). Finally, users may record a "user-specified" priority for each proposal based on their review of candidate rankings. The user-specified priorities form the basis for recommending technology packages at different funding levels as described below.

After reviewing alternate rankings, participants may assign priorities from anywhere in the proposal list to build a set of technology packages. The packages should be logical groupings of technologies (technologies that can/should be funded concurrently). For example, if all top-ranked proposals address hydrogen sensors, but the funder has decided that both hydrogen sensors and on line process monitors need to be funded, then reviewers may need to dip down in the ranking to find a good proposal that addresses process monitoring. Similarly, if it makes no sense to fund a hydrogen sensor without a deployment mechanism, another lower-ranked proposal may be funded. The mechanism for identifying these final recommendations is left open. The UST-ID relied upon its technical review team, using inputs from the complete set of evaluations. This allowed technical experts to decide what proposals made sense to fund concurrently and which could be added on with additional funding, based on the underlying technical logic and testing process. Packages were built for what technical experts considered minimum, recommended, and enhanced funding packages. These funding packages comprise the input data to the Resource Management Tool, discussed next. The packages provide a means for relaying the underlying logic to upper management and ensuring that the final technology program is inherently sensible.

RESOURCE MANAGEMENT

The Resource Management Tool aids in the allocation of resources across technical areas within a program. The primary objective of this tool is to provide upper level managers with a means for allocating budgets across technical areas. At this point, program managers are not evaluating individual proposals; instead, they are trading off the prioritized technology packages built by expert reviewers. In this sense, the technology packages provide the "building blocks" for final program recommendation or decision and thus serve to reinforce the technical and stakeholder input that they reflect. Because expert technical, regulatory, and other input is already reflected in the technology packages, the criteria for prioritizing packages across technical areas may be more programmatic (e.g., schedule for completed products, commercialization opportunities). The Resource Management Tool consists of two parts: 1) information and evaluation across technical areas and 2) combined analysis.

Evaluations Across Technical Areas

The first part contains information on individual technical areas, including descriptions of recommended technology packages for the technical area at different budget levels. This could include a listing of proposals and their suggested levels of funding (and funding profiles) at each of several different budgets (e.g., minimum, recommended, and enhanced). For each package, information can also be provided on how the package addresses the program-level criteria to be used in this step. (This information can be developed in the *initial* packaging step if those who build the technology packages are provided with a list of the resource management criteria and weights.)

First, the program evaluator(s) assess scores against the criteria for each level of funding, using the supplied technology package descriptions. Next, the evaluator(s) assess relative weights of the importance of the criteria, using the same weights across all technical areas. The tool then calculates a weighted-average evaluation for each level of funding that is comparable across technical areas. The tool also summarizes the weighted-average evaluations and funding profiles for all levels of all technical areas. Figure 2 shows a page from the UST-ID resource management evaluation. Proposals are listed along the bottom, with their recommended funding levels for the minimum, recommended, and enhanced technology packages (in the 3rd, 4th, and 5th columns). The program level criteria are listed above that grid, to the left, with their respective weights. Scores for each package against these criteria are provided in the next four columns, starting with zero funding for the entire set and moving through each of the funding levels.

Combined Analysis

The second part of the Resource Management Tool calculates and displays several types of output to assist in final budget decisions. The most basic output shows the order in which technology packages would be added to the program (from different technical areas) with an increasing overall budget. This order is determined to maximize the benefit of the funded program (the weighted-average evaluation of each package) subject to constraints on the funding budget. From this order, the best allocation of any given budget can be determined. One or more budget levels may be specified, and the tool determines and displays how this budget should be allocated across the technical areas, and what technology packages are "picked up" from each technical area. Figure 3 shows the basic output displayed as a cost-benefit curve; the "efficient frontier" of this curve shows the most cost-effective set of packages from all technical areas for any program budget. In addition, to suggest an *initial* allocation of responses, this output indicates how the program might be changed if budgets changed during the year.

The tool also provides output showing how each technical area impacts each criterion at each budget allocation. With properly specified criteria, this can show how different budgets affect such things as each technical area's level of industry involvement or testing schedule. The final type of output shows the implications of trial solutions. Trial solutions are user-specified allocations indicated by choosing a funding level for each technical area (e.g., $5 million for characterization, $2 million for retrieval, $8 million for processing, and $5

ELEMENT 2 NAME: Characterization

Funding Level Name:	Zero	Minimum	Recom'd	Enhanced
FY93	$0	$2,587	$3,887	$6,927
FY94	$0	$2,636	$3,598	$5,971
FY95	$0	$4,004	$6,376	$11,477
FY96	$0	$2,636	$3,433	$5,684
FY97	$0	$0	$0	$0
Total	$0	$11,863	$17,294	$30,059

Criterion	Wt	NormWt				
Tech merit	10	0.18	0	60	75	100
Spin-off	5	0.09	0	50	70	100
EM 30 need	10	0.18	0	55	75	100
Mult sites	8	0.15	0	55	70	100
Demonstrat'n	10	0.18	0	55	75	100
Disruption	7	0.13	0	50	75	100
Tech dev't	5	0.09	0	60	70	100
Overall Ben:			0.00	55.27	73.36	100.00

Enter any explanatory text below:

Fig. 2. Example program element information sheet.

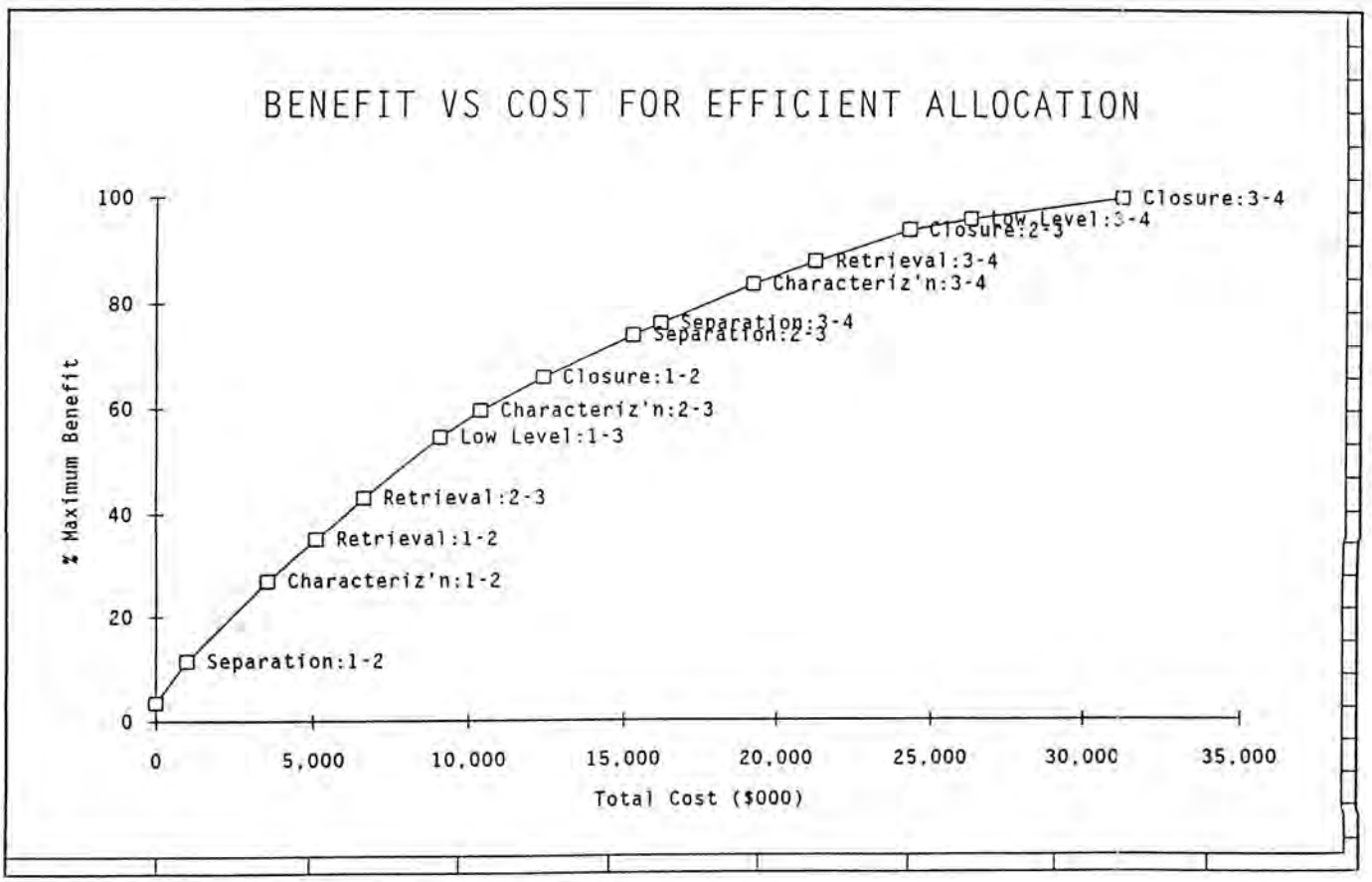

Fig. 3. Example frontier graph.

million for disposal). The tool uses this information to determine a better allocation that does not exceed the cost of the trial solution. The tool shows, for both the trial solution and the better allocation, the amount of funding for each technical area, the overall evaluation of the allocation, and the impact of each technical area on each criterion.

DISCUSSION

The software tools developed for the UST-ID do not replace good fiscal year planning. Instead they facilitate good planning by prompting program managers for the information required to make defensible decisions. This includes utilizing information sources that may otherwise not be involved in the process. The process and supporting software offer some advantages over other available prioritization schemes. Specifically, the process has the ability to:

- accommodate various levels of stakeholder involvement (and make this involvement an explicit part of the decision process)
- allow criteria and weights to change as needed
- handle programmatic and technical considerations independently, preserving the latter during final budget decisions
- incorporate data from a broad range of sources, easily combining best engineer/reviewer judgement with modeling data
- use data "on line" in the course of a workshop(s) or for off line analyses after the appropriate inputs have been elicited

The most basic benefit of the software tools is the organization they bring to a broad and diverse set of planning activities.

REFERENCES

1. QUADREL, M. J., J. CHINNIS, J. ULVILA. 1993. R&D Prioritization and Resource Management for Technology Selection: An Underground Storage Tank Integrated Demonstration Report. Volume 2. PNL-8664, Pacific Northwest Laboratory, Richland, Washington.

2. MCCABE, G. H. 1992. Phase I Involvement for Potential Stakeholders of the VOC-Arid Integrated Demonstration. Pacific Northwest Laboratory, Richland, Washington.

3. KEENEY, R. L. 1992. Value-Focused Thinking. Harvard University Press, Cambridge, Massachusetts.

4. VON WINTERFELDT, D. AND EDWARDS. 1976. Design Analysis and Behavioral Research. Cambridge University Press, Cambridge.