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Risk-Based Prioritization Of The Idaho National Engineering Laboratory Environmental Programs

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Abstract

This paper describes an application of a formal prioritization system to help the Idaho National Engineering Laboratory (INEL) allocate funds for environmental projects. The system, known as the Laboratory Integration and Prioritization System (LIPS), was jointly developed by Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), and the U.S. Department of Energy (DOE). LIPS is based on a formal approach for multi-criteria decision-making known as multiattribute utility analysis. The system is designed to provide a logical, practical, and equitable means for estimating and comparing the benefits to be obtained from funding project work.

Introduction

Each year, INEL funds a variety of environmental projects for the purpose of protecting the natural environment, ensuring the health and safety of workers and the public, and complying with applicable regulations. This work is grouped under five major INEL programs, listed in Table 1. The basic unit of work for environmental projects is called a "work package," a term that denotes that portion of project work to be conducted within a specified funding year. Due to budget constraints, INEL management anticipates being unable to fund fully all of the environmental work packages proposed in their FY1996 and FY1997 budgets. Projections indicate that the shortfall could be in excess of $100M. As a result, some proposed projects will have to be scaled back, delayed, or canceled.

Table 1. Major Environmental Programs at INEL

1. Environmental Restoration
2. Waste Management
3. Technology Development
4. Nuclear Operations
5. Site Services

Deciding which work packages to fund and which to delay is difficult for several reasons. First, the large number and diversity of projects makes it difficult to develop a comprehensive understanding of project motivations. Second, because projects address different objectives, it is difficult to compare those projects without understanding the relative importance of objectives. Third, it is difficult to know whether the benefits to be achieved from proposed projects justify their costs, particularly in light of changing budget constraints. These difficulties present a significant challenge for INEL management.

To help make FY1996 and FY1997 environmental program budgeting decisions, INEL management chose to conduct an application of LIPS. This paper describes the application and is organized into four major sections. The first section briefly outlines the general LIPS model. The second section describes the customization and application of the LIPS model to address funding decisions at INEL. The third section summarizes the results. Finally, the last section provides the conclusions derived from the application.

The LIPS Model

The LIPS model was developed in 1993 in response to a request from DOE to its laboratories to provide a tool for addressing difficult prioritization problems within the DOE complex. To undertake the development, a task force was established composed of managers and technical representatives from LANL, LLNL, and SNL. As a first step, the task force identified a set of requirements and desirable characteristics for the system (Table 2). Next, the task force reviewed and evaluated existing prioritization models and methodologies against the identified requirements.[1]

As a result of this review, the task force determined that no existing model satisfied its full list of requirements. However, the task force was intrigued by several existing systems based on a methodology known as multiattribute utility analysis (MUA). The task force concluded that the best approach would be to develop and tailor to its needs a priority system based on MUA.

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[1] Anderson, R.G., A. Bendure, S. Strait, and A. Kann, *Laboratory Integration and Prioritization System, Supporting Documentation*, Los Alamos Unclassified Report (LAUR) 94–1696, 1994.

Table 2. Model Requirements and Desired Characteristics

1. The model must be able to convert the risks and benefits associated with proposed activities into equivalent dollars of value.
2. The results of the model must be comparable across applications as well as across Laboratories and must be easily interpreted.
3. The model must be able to prioritize a large number of diverse activities.
4. The model must be able to account not only for the benefits of risk reduction but also for other types of benefits (e.g., cost savings or mission enhancements) that activities may produce.
5. The model must have the ability to give appropriate credit for partial, sequential, and phased action plans.
6. The model must be easy to describe and must facilitate communication of results to a wide range of audiences, including DOE, the public, the courts, and outside technical reviewers.
7. The model and methodology must be technically defensible to independent organizations and regulators.

MUA is a formal quantitative approach for analyzing decisions with multiple objectives.[2,3,4] Underlying the approach is a rigorous, axiomatic theory for combining the technical assessments of scientists with the policy judgments of risk managers into a prescribed set of decisions. The approach is applicable to situations in which there are many alternatives, competing objectives, and significant uncertainties.

The task force developed the LIPS model using the step-by-step process employed to develop other MUA-based priority systems.[5] First, a set of fundamental objectives for DOE decision making was identified. These objectives, organized into a hierarchy, are shown in Figure 1. The identified objectives establish 12 criteria for evaluating and comparing DOE projects: 1) worker health and safety, 2) public health and safety, 3) impacts to the environment, 4) impacts to security and safeguards, 5) regulatory compliance, 6) public assessment, 7) science and technology (mission), 8) employee ability and efficiency, 9) facilities and equipment management, 10) business and financial management, 11) cost savings or losses, and 12) employee motivation.

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[2] Keeney, R.W., and H. Raiffa, *Decisions with Multiple Objectives, Preferences and Value Tradeoffs*, Wiley, New York, 1976.
[3] Keeney, R.W., *Value Focused Thinking*, Harvard University Press, Cambridge and London, 1992.
[4] von Winterfeldt, D. And W. Edwards, *Decision Analysis and Behavioral Research*, Cambridge University Press, Cambridge and New York, 1986.
[5] M.W. Merkhofer and R. L. Keeney, "A Multiattribute Utility Analysis of Alternative Sites for the Disposal of Nuclear Waste," *Risk Analysis*, Vol. 7, No. 2, 1987.

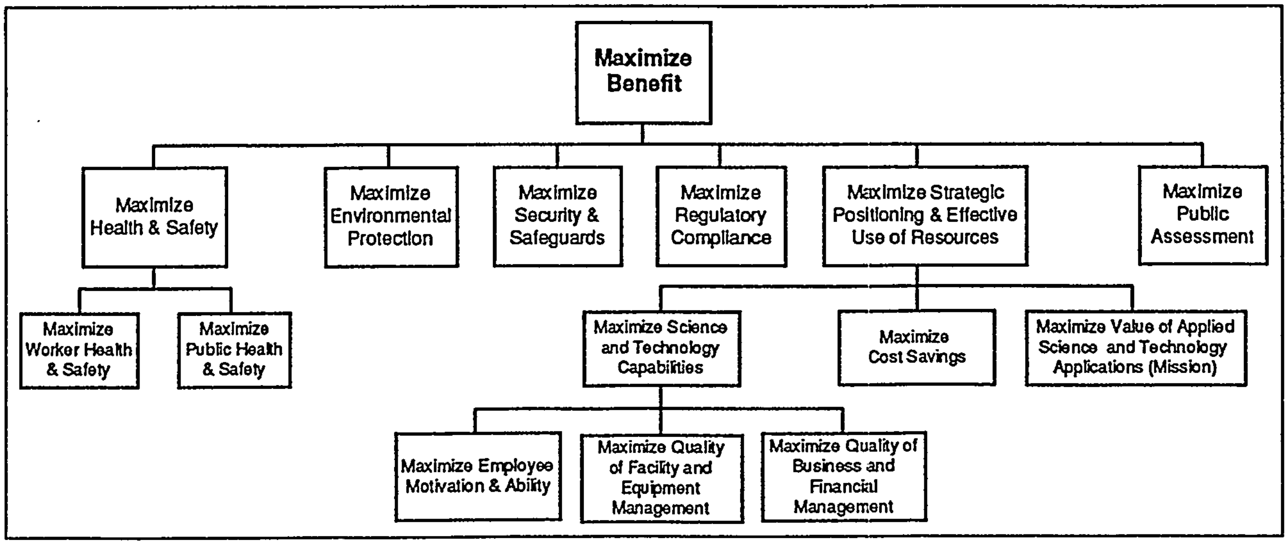

Figure 1. LIPS Objectives Hierarchy

Once the objectives and associated evaluation criteria were identified, measurement scales were developed to quantify the degree to which projects might achieve objectives. Figure 2 shows an excerpt from a typical measurement scale used in the model. This particular scale is designed to elicit judgments regarding the impact of projects on employee productivity, and is one of several measures used to quantify the employee motivation and ability criterion. The model includes one or more such measurement scales for each objective.

Score	Impact on Employee Productivity
3.	**Very large increase.** The productivity of the identified workers is likely to **increase by about 30% (6 days saved per month)** due, for example, to: • a very large increase in employees' knowledge, skills, or abilities.
2.	**Large increase.** The productivity of the identified workers is likely to **increase by about 15% (3 days saved per month)** due, for example, to: • a large increase in employees' knowledge, skills, or abilities. • a very large increase in the quality of management practices affecting these employees.
1.	**Moderate increase.** The productivity of the identified workers is likely to **increase by about 5% (1 day saved per month)** due, for example, to: • a moderate increase in employees' knowledge, skills, or abilities. • a large increase in the quality of management practices affecting these employees.
0.	**No change/status quo.** There is no reason to believe that the productivity of the identified workers will be significantly impacted. Productivity levels are left at the status quo.
–1.	**Moderate decrease.** The productivity of the identified workers is likely to **decrease by about 5% (1 day lost per month)** due, for example, to: • a moderate decrease in employees' knowledge, skills, or abilities. • a large decrease in the quality of management practices affecting these employees.
–2.	**Large decrease.** The productivity of the identified workers is likely to **decrease by about 15% (3 days lost per month)** due, for example, to: • a large decrease in employees' knowledge, skills, or abilities. • a very large decrease in the quality of management practices affecting these employees.
–3.	**Maximum decrease.** The productivity of the identified workers is likely to **decrease by about 100%** because: • the identified workers will not be able to carry out their usual tasks. The worker's program or facility may have temporarily suspended operations, or the worker may have been reassigned to activities which prevent him or her from carrying out usually productive tasks.

Figure 2. Typical LIPS constructed scale. Each measurable attribute in the LIPS model is measured by scales of this type.

Once a full set of measurement scales was specified, a "utility function" was defined to represent decision makers' preferences regarding their willingness-to-pay to achieve benefits or avoid adverse impacts of various types. According to multiattribute utility analysis, an additive function is appropriate for aggregating impacts on different objectives if the measures established for objectives are additive independent.[6] This independence condition was assumed to hold for the LIPS objectives. As a result, benefits of activities are calculated by the LIPS model using an equation of the form:

$$\text{Utility} = \sum_{i=1}^{N} w_i U_i,$$

[6] Keeney, R.W., and H. Raiffa, *Decisions with Multiple Objectives, Preferences and Value Tradeoffs*, Wiley, New York, 1976.

where the w's are "weights" that reflect the tradeoffs managers are willing to make between objectives and the U's are referred to as single-attribute utility functions. The single attribute utility functions reflect the tradeoffs managers are willing to make between different levels of achievement on a single objective. Figure 3 shows a typical single attribute utility function used in LIPS.

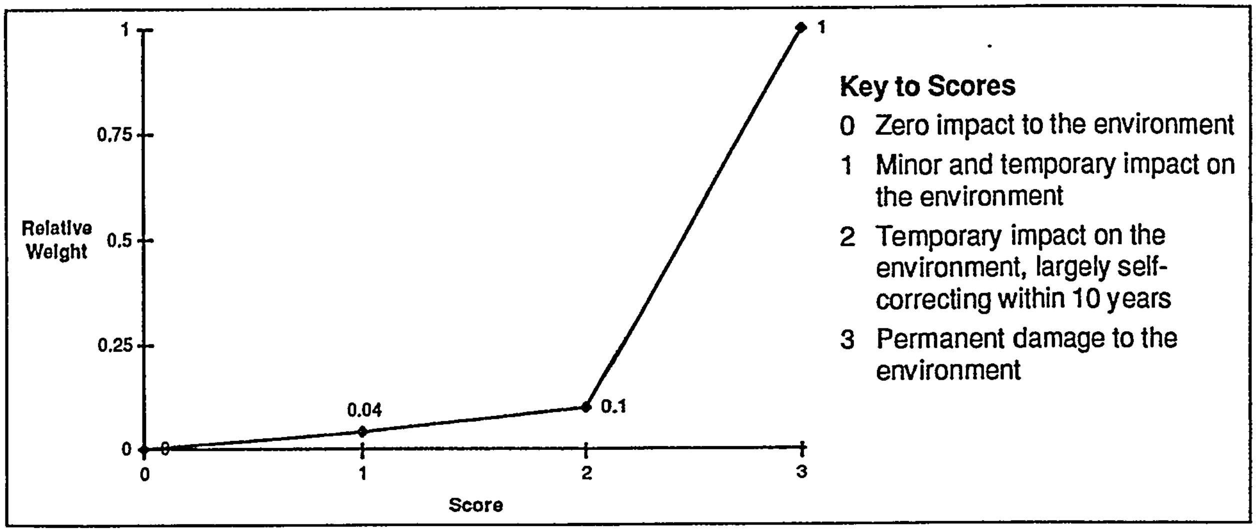

Figure 3. Typical single attribute utility function used in the LIPS model. Each scale in LIPS has an associated function.

The weights and single-attribute utility functions used in LIPS were derived through a formal elicitation process with senior managers from the participating laboratories (LANL, SNL, and LLNL). The weights obtained in this way are referred to as "unrefined values" (meaning they do not necessarily represent any one laboratory but are generally accepted by the laboratories as acceptable ranges for values) and are shown in Table 3. These unrefined values are provided only as a reference. It is recommended that each application of LIPS include a re-assessment of the weights to ensure that the values of the relevant decision-makers are accurately reflected.

In the application, each proposed activity is evaluated against each of the objectives. LIPS is designed to measure activity benefits rather than baseline conditions. Thus, LIPS asks technical experts to estimate conditions that will exist first assuming that an activity is not implemented (e.g., baseline risk), and then assuming the activity is implemented (e.g., modified risk). The difference between these two judgments is used to measure the benefit of the activity according to each criterion (e.g., risk reduction).

Once the activities' impacts on the criteria are quantified, LIPS converts the impacts into equivalent dollars based on the value judgments (weights) described above. The total benefit value of each activity is then compared to the estimated resources required to complete the activity. A benefit-to-cost ratio is produced for each activity, and a ranking of activities by this ratio is used to help the decision makers determine the most cost-effective portfolio of activities to conduct given constraints on funding and other resources.

Table 3. "Unrefined" LIPS Weights

Decision Objective	Weight	Rationale
Worker Health & Safety	$2.25M	$2.25 million per worker. This value reflects management's willingness to pay to reduce the probability of an employee statistical death and is comparable to the value issued by a wide range of federal agencies.
Public Health & Safety	$5.5M	$5.5 million per member of the public. This value reflects management's willingness to pay to reduce the probability of a statistical death to a member of the public and is comparable to the value issued by a wide range of federal agencies.
Environmental Protection	$30 M	This value reflects management's willingness to pay $30 million to prevent the permanent elimination of an endangered species.
Safeguards & Security	$45 M	This value reflects management's willingness to pay $45 million to prevent a security or safeguards incident resulting in loss, diversion or theft of category I or II quantities of SNM.
Regulatory Compliance	$25 M	This value reflects management's willingness to pay up to $25 million to prevent non-compliance resulting in criminal penalties.
Public Concern	$10 M	This value reflects management's willingness to pay up to $10 million to address items and issues of high public concern.
Achieve Mission Objectives	$100 M	This value reflects management's willingness to pay up to $100 million to prevent critical adverse mission impacts, e.g. threat to existence of Laboratory.
Skilled Workforce	$13 K	$13K per worker. This value reflects management's willingness to pay to maintain a skilled workforce.
Motivated Workforce	$7 K	$7K per worker. This value reflects management's willingness to pay to maintain a motivated workforce.
Facilities & Equipment	$30 M	This value reflects management's willingness to pay up to $30 million to ensure facilities and equipment are up to industry standards.
Business & Financial Systems	$30 M	This value reflects management's willingness to pay up to $30 million to ensure business and financial systems are equal to the highest industry standards.

Customization and Application of LIPS to INEL Environmental Programs

The application of LIPS to the INEL environmental programs involved seven steps: (1) specification of application goals, (2) pilot testing and model modification, (3) training, (4) value assessment, (5) scoring of activities, (6) quality assurance, and (7) analysis. The first six of these steps are described in this section. The analyses performed and results generated as a result of the application are explained in the subsequent section.

Step 1: Specification of the Goals of the Application

The first step was to specify the basic goals to be achieved by the application. Goals were identified in a series of meetings with a prioritization task group composed of representatives from each of INEL's five environmental programs. Three basic goals were identified:

1. Provide an estimated dollar-value of the benefits to be produced from each work package.
2. Determine the source and nature of these estimated benefits for each work package.
3. Provide a cost-benefit analysis to senior management to assist them in deciding how to allocate available funds.

Step 2: Pilot Testing and Model Modification

A key step in any application of LIPS is the customization of the model to account for application-specific and site-specific issues. In particular, it is generally necessary to review the LIPS decision objectives for completeness and to review the scales associated with each decision objective to ensure that all important issues can be adequately captured.

For the INEL application, a pilot test was conducted to determine the extent of necessary customization. The pilot test involved scoring and evaluating a subset of work packages selected by the task group. The version of the LIPS model used in the pilot was a customized version that had been applied successfully in previous applications at other facilities. The results of the pilot test indicated that the model adequately measured benefits for the test cases without major revisions. The only revisions made involved wording changes to some scales to better fit the nature of the work to be evaluated and to improve clarity.

Step 3: Training

In order to ensure that those providing inputs to the LIPS model do so consistently and appropriately, a significant amount of training is required. Experience shows that the significance of training within a formal prioritization process cannot be overestimated. Most organizations have little experience in the use of a formal prioritization system, so the application of such a system represents a major change. As with any such major change, those accustomed to the old approach to making funding-allocation decisions will resist a new approach unless they thoroughly understand it and are convinced that it is superior to the old approach. The consequences of a failure to obtain the buy in of participants in the process are severe: lack of cooperation, low quality model inputs, and generally unusable results. Thus, LIPS training is focused on developing a thorough understanding and appreciation for the LIPS prioritization process. The end goal is to train those providing inputs and others involved in the process so that they not only can perform their necessary role, but so that they also understand why the process makes sense.

To this end, training was provided to the two types of participants critical to the scoring process--work package managers (generally the authors or proposers of work packages) and scoring teams (individuals with broad understanding selected to score the work packages based on information provided by the work package managers). Each of the five major environmental programs assembled its own scoring team of subject matter experts (total of about 35 individuals). The scoring teams were given two days of detailed description and practice on both the theory and the application of LIPS. Work package managers were given a two hour general overview on the LIPS model.

Step 4: Value Assessment

Weights for each of the LIPS objectives were elicited from a group of five senior managers from INEL. Weight assessment was accomplished using a formal elicitation process.[7] The managers were asked a series of tradeoff questions that determined how much achievement with respect to one objective they were willing to give up to improve achievement of another objective by a specified amount. The unrefined utility (scaling) functions used in LIPS were also reviewed and received minor modifications from these senior managers.

Step 5: Scoring Environmental Activities

Prior to the actual scoring of work packages, it was necessary for the scoring teams to review all packages to ensure that they were properly defined. Of particular importance for this review was the consideration of whether each work package was 1) independent of other work packages (in the sense that neither the costs nor benefits of any package depended on whether any other packages were conducted) and 2) appropriately sized. When dependencies or excessively small work packages were identified, these packages were grouped to facilitate evaluation. This consolidation effort resulted in a decrease of total work packages from about 1200 to about 700. It also resulted in a more consistent sizing of packages.

To conduct the scoring process, each scoring team first established a schedule for scoring their activities. In each scoring session, work package managers were invited to participate in the scoring discussions regarding their activities. To maintain consistency, the scoring team (rather than individual work package managers) made the final scoring decisions and entered all scores onto a scoring sheet (depicted in Figure 4). To further promote consistency across scoring teams, LIPS experts served as facilitators for each team. Scores from each session were sent to a central data handling center and processed. The initial scoring for this application took about five working days.

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[7] R.L. Keeney, *Siting Energy Facilities*, Academic Press, New York, 1980.

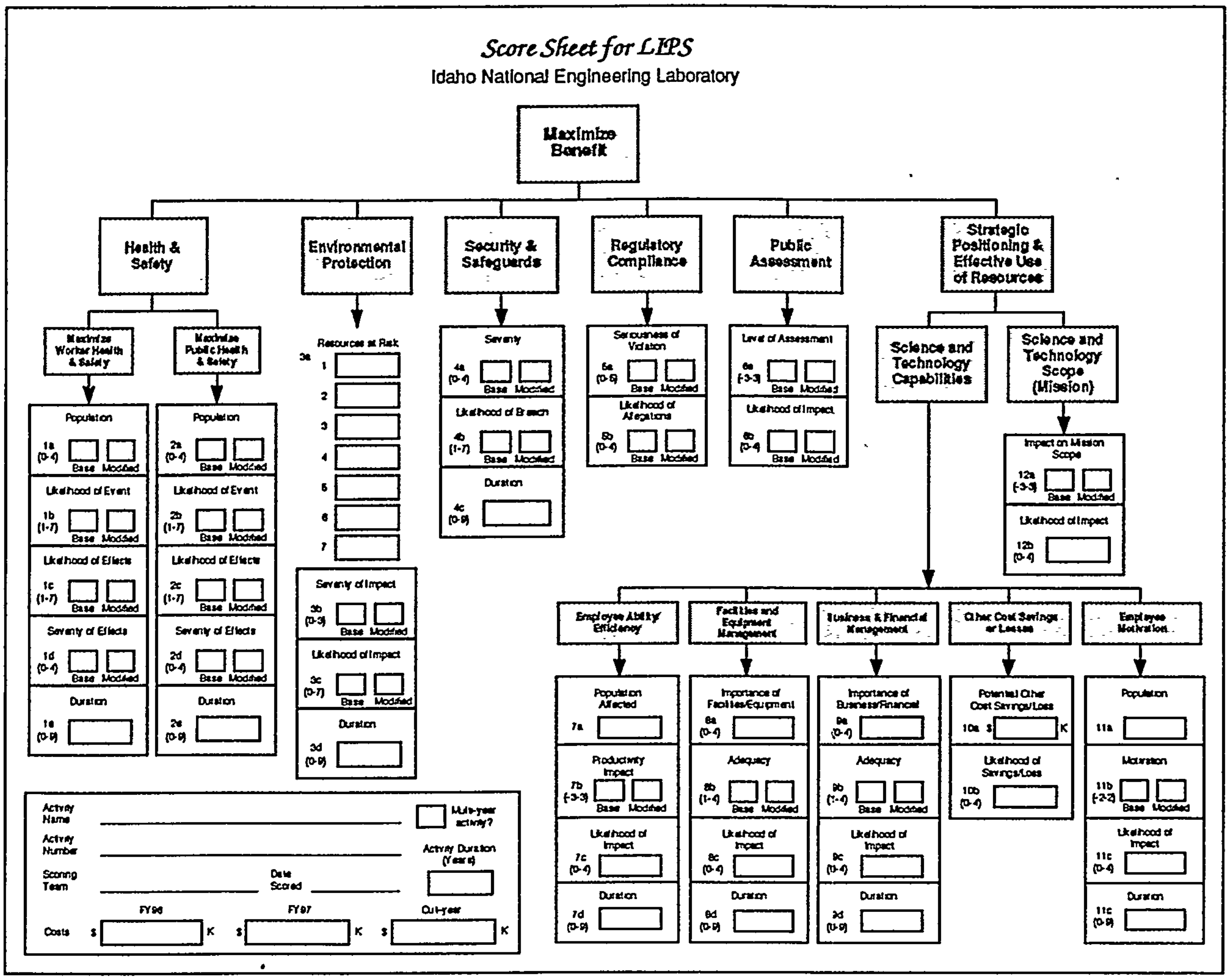

Figure 4. LIPS Scoring Sheet

Step 6: Quality Assurance

Quality assurance (QA) of scores was conducted in two stages, first by individual program area scoring teams, and then by a central team with representation from all program areas.

The individual scoring teams provided the first level of QA. After completing their scoring, each team was given a report summarizing the results of the scoring exercise. The reports provided an analysis of how each work package scored, including the estimated total benefit of the package in dollars, a breakdown of benefit by objective, the cost of the work package, and the benefit-to-cost ratio for each package. The facilitated QA process involved three primary steps. First, scoring teams reviewed lists of work packages ranked by benefits in each objective category and noted potential errors or other problems. Second, the teams reviewed a ranking of packages sorted by overall benefit-to-cost ratio, again identifying potential discrepancies. Finally, the scoring team rescored all those packages identified as potential problems.

The second level of QA was provided by another team consisting of one representative from each scoring team and one additional representative from each program area who was not involved in the initial scoring. This central team again concentrated on rankings of activities by benefit in each category and by benefit-to-cost ratio. When concerns were raised, the scoring team representatives were required to provide the rationale for the scores. Again, selective changes were made to scores as necessary.

Results

This section describes the analysis and three main outputs generated: (1) an overall benefit versus cost curve for INEL environmental programs, (2) individual benefit versus cost curves for each program, and recommended funding allocation curves.

Cost-benefit theory dictates that when funding is constrained, independent activities should be ranked by benefit-to-cost ratio and funded from the top down until the budget is exhausted. This logic is used by the LIPS system to determine how any given level of funding should be allocated across programs and activities. Assuming the optimal allocation of funding, an overall cost versus benefit curve can be generated to illustrate the total benefits obtainable from alternative total funding levels. Such a curve is depicted for the INEL application in Figure 5. The x-axis in this graph represents alternative levels of total funding available for INEL environmental work in FY1996. The y-axis represents the total estimated benefit that could be achieved from each level of funding, assuming that funding is allocated optimally across work packages (highest benefit-to-cost ratio first).

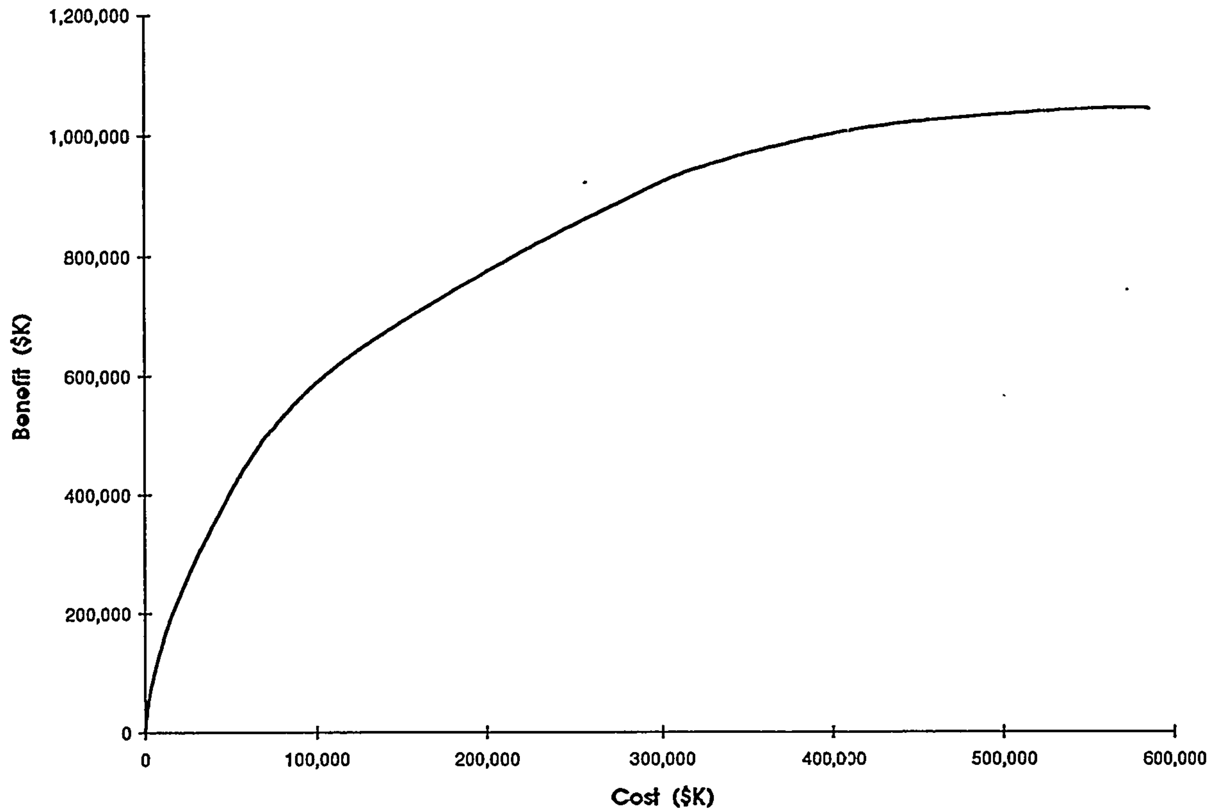

Figure 5. Total Cost Versus Total Benefit Curve for Environmental Programs

Similar cost-versus-benefit curves can also be produced for the individual programs. Figure 6 illustrates such curves for each of the five programs at INEL, plotted on the same set of axes to facilitate comparison. Here, the x-axis represents program funding and the y-axis represents program benefit, assuming that program funds are allocated optimally.

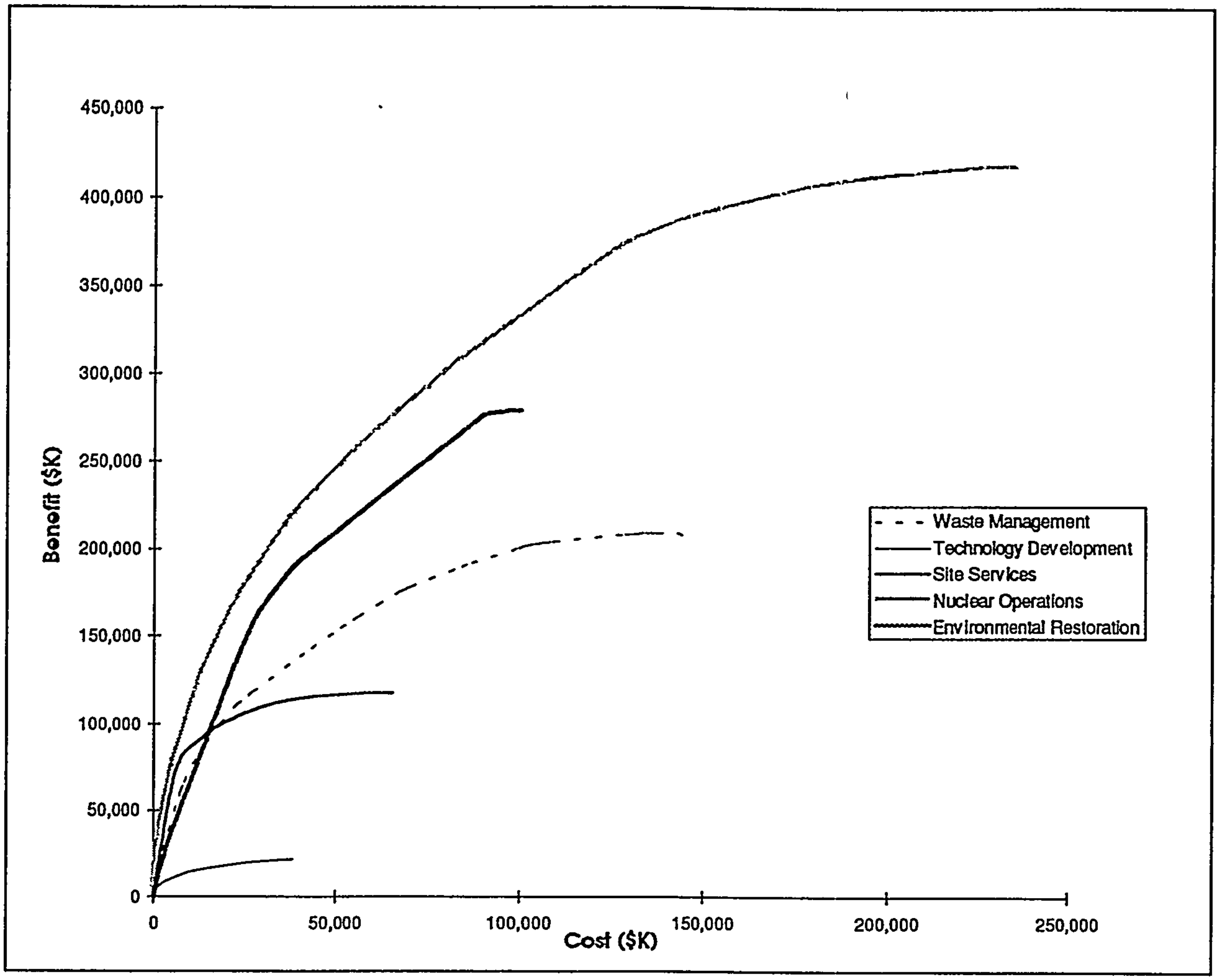

Figure 6. Cost Versus Benefit Curves for Individual Environmental Programs

For any total funding level, the LIPS model can produce a recommendation of how that funding should be allocated across programs (or across any other meaningful organizational distinction, for that matter) based on the benefit-to-cost ranking of activities. Figure 7 graphically depicts the model's recommendations for how various total funding levels should be allocated across environmental programs.

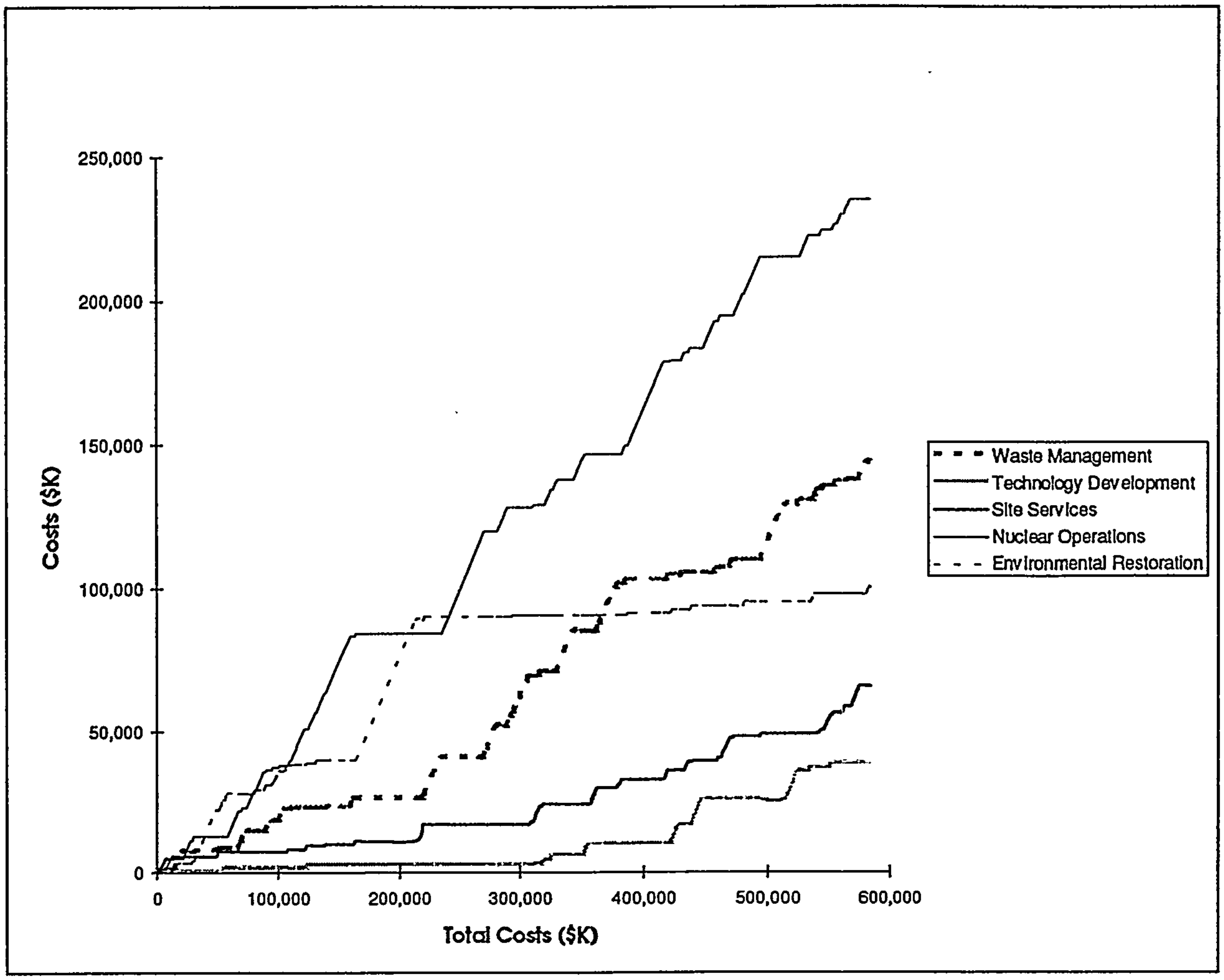

Figure 7. Recommended Allocations of Funding Across Environmental Programs

Management Decision-Making

Less than six weeks after initiation of the application, the complete set of LIPS outputs, including the above results, were provided to the management team responsible for providing funding recommendations for approval by senior INEL management. The team then proceeded to make adjustments to the rankings based on various considerations judged by the team to be beyond the scope of the formal system. For example, some ranking changes were justified on the basis of interdependencies among work packages, which were ignored by the model. Such adjustments by decision makers are an integral part of any LIPS application, as no system could possibly capture all considerations judged by decision makers to be relevant. The LIPS system is meant to be an aid to the decision-making process, not a rigid "straight jacket" for decision making. Although numerous ranking adjustments were made, very few of the changes caused work packages to cross the cutoff line established when the target (anticipated) level of funding was specified. As a result, final funding recommendations were very similar to LIPS recommendations. Including all of the changes introduced by the management team, the total estimated benefit was reduced by less than 1% from the estimated benefit of the LIPS recommended allocation.

Overall reaction from participants regarding the worth of the LIPS application varied, but was mostly positive. During the early stages of the team's efforts to adjust the LIPS ranking, there were some complaints regarding the amount of time and effort that was spent developing the LIPS inputs. However, as the process progressed, participants admitted that they would not have been able to achieve confidence in an agreed upon ranking without the LIPS exercise. In addition, it was observed by most participants that the LIPS process provided a much more systematic, well-documented, and defensible basis for the final recommendations than would have been possible without LIPS.

Conclusions

Applications of the LIPS prioritization model can usefully aid and support the difficult process of allocating scarce resources among competing activities and programs. Though applications take significant time and effort, the resulting information base and understanding can dramatically improve decision making. Applications provide a means for stakeholders to share information and participate in the decision-making process. The result is typically a much greater degree of consensus and confidence in final choices that are made. Organizations that have applied LIPS, including INEL, have unanimously felt the process provided a significant increase in the level of organizational understanding of the work to be conducted and the reasons for conducting it. This type of formal prioritization approach is likely to become more and more important within DOE as funding constraints become tighter.

Acknowledgments

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