Trade-Off Analysis Planning and Procedures Guidebook

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U.S. Army Institute for Water Resources

Decision Methodologies Division

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Trade-Off Analysis Planning and Procedures Guidebook

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PREFACE

Making decisions requires some form of deliberation and evaluation by the decision maker. When there is a single decision maker, the process may not have to be rigid or replicable or even justified to anyone other than the decision maker. In water resources planning and investments, there are multiple decision makers, stakeholders and other interested parties making inputs to the decision making process. Planning for projects involving multiple and competing outputs and stakeholders requires a collaborative effort. This process also requires a more definitive evaluation process, one that can be replicated and used to justify or, at a minimum, explain why specific decisions were made and who was involved in the decision making process. The proliferation of work falling into the category of National Ecosystem Restoration, (NER, i.e., providing non-monetary outputs such as Habitat Units or Acres of Wetlands) and subsequently, the need to formulate for multiple-purpose National Economic Development, (NED, i.e., providing monetary outputs such as Flood Damage Reduction and Navigation) combined with National Ecosystem Restoration projects fostered an increased need for tools and guidance to conduct trade-off analysis and collaborative decision making. This document is a "Trade-Off Analysis Planning and Procedures Guidebook" for Corps of Engineers planning studies.

The work presented in the report was conducted as part of the Investment and Management Decision Making Research Program, part of the Integrated Technologies for Decision Making research area. The Program is sponsored by the Headquarters, U.S. Army Corps of Engineers and is assigned to the Institute for Water Resources, Decision Methodologies Division. Mr. Darrell Nolton is Program Manager of the Investment and Management Decision Making Research Program. Mr. Harry Kitch, Planning Division, Mr. Jerry Foster, Engineering Division, and Mr. Bruce Carlson, Planning Division are the Headquarters' Program Monitors. Field Review Group Members that provide overall Program direction include: Mr. William Fickel, Fort Worth District, Mr. Martin Hudson, Portland District, Mr. Matt Laws, Charleston District, Mr. Dan Sulzer, Los Angeles District, Ms. Teresa Kincade and Mr. Kenneth Barr, Rock Island District. This paper was prepared under the general supervision of Mr. Kenneth Orth, Chief of the Decision Methodologies Division, Institute for Water Resources and Mr. Robert Pietrowski, Director of the Institute for Water Resources.

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I. INTRODUCTION

The blue car has bucket seats. The green car does not. Your favorite color is green, and you prefer bucket seats. A green car with bucket seats is not one of your options, and you are going to buy a car. If you choose the blue car, you get the seats you want but not the color. With the green car, you go without the seats you prefer. You could make your decision based on color or on seat style, or you could combine the two attributes into some composite notion of satisfaction and decide based upon it. Now suppose your spouse, who will also use this car, prefers blue cars and bench seats. The decision has just gotten a bit more complex.

In this simple example are all the basic elements of the most complex water resources planning problem in the world. Because of a problem (lack of reliable transportation) there is a decision to be made (which car to buy). There are one or more decision makers (you and your spouse) and a choice to be made from among options (cars). The decision will be made based on consideration of specific criteria or attributes (color and seat style). There are value trade-offs that cannot be avoided; choosing one thing simultaneously means not choosing the other (you can get the desired color or seat style but not both). One attribute may be more important than another (seat style is more important to you than color). There may not be complete agreement with the weights you give to the criteria (your spouse finds color more important than seat style). Data and analysis are required to describe each alternative's "score" for each criterion (you need to know the colors and the seat styles of each alternative). The decision maker's value system and preferences determine the weights of the various criteria and the significance of the individual "scores" for each criterion (you decide whether seat style is more important than color and you decide whether bucket seats are better than a bench seat). Trade-offs may be unavoidable (you cannot get everything you like best in a single car). Values may be in conflict (you and your spouse disagree on color and seat style), and compromise may be necessary. A process is needed if a decision is going to be made and the problem solved. Not everyone, and perhaps no one, is going to be perfectly satisfied with the process or the ultimate decision. If we cannot get the best decision, we can at least seek the best compromise.

Change the two cars to Plans A and B and change the attributes color and seat style to National Economic Development (NED) and National Ecosystem Restoration (NER). Let Plan A have large NED benefits, and small NER benefits and let Plan B have small NED benefits and large NER benefits and we have an example of the essence of decision making in the Corps of Engineers Civil Works planning process.

There is no need to search the index or the table of contents for the best method to resolve decisions like this to everyone's satisfaction. Such a method does not exist. There is no one method to use. Planning is normative decision making—it is not science. Done well, it is science-based but value-driven. Normative pluralism is a fact of life for planners, and analytical answers simply do not exist.

There may not even be a majority view on the values at stake in water resources planning. A plurality view may wither in the face of the various opposing views. The best technique to use to make decisions in such a world will vary from one situation to the next. Ironically, there are trade-offs in the choice of techniques to be used for trade-off analysis. So you will not find a best method in this manual. You will, however, find a framework, a way of thinking about and approaching these problems. That is essential to their solution. And you will find a number of practical, multicriteria decision-making techniques that can be used throughout the planning process. When there is no optimal solution compromise, alternative solutions have to be considered. The framework presented in this manual provides a systematic way of thinking about what the best compromises are.

PURPOSE OF MANUAL

The broad purpose of this manual is to support decision making in the United States Army Corps of Engineers Civil Works planning process. Very importantly, this manual does not prescribe decisions or techniques for making decisions. It does present a decision support framework fully compatible with the Corps planning process, which, if followed, lends systematic structure and valuable insight to the decision-making process.

The principal focus of this manual is on the selection of the recommended plan from among a final array of candidate plans. The techniques are, nonetheless, perfectly general and can be applied to a wide variety of decisions at various points throughout the planning process.

The first specific purpose of this manual is to provide new and experienced Corps planners with a framework for understanding and thinking about making decisions that involve several alternatives and multiple criteria in order to solve the wicked problems encountered in water resources planning. Wicked problems are problems that do not have a right or wrong answer but only answers that are better or worse. Wicked problems are found at the intersection of science and values.

There is an extensive literature on multicriteria decision making (MCDM) techniques. New techniques continue to be developed. Some of them are quite complex and sophisticated. The second specific purpose of this manual is to provide planners with a range of practical tools and techniques they can use when faced with the necessity of solving wicked problems that involve values in conflict. Consequently, the emphasis in this manual is on techniques that can be applied and understood by planners and stakeholders. These techniques tend toward thought-ordering processes, do-it-yourself methods and commercial software techniques, rather than the state-of-the-art applications found in the literature that require a level of quantitative sophistication not generally available to planners and their stakeholders. Ease of use, transparency, replicability and effectiveness are valued over the rigor that often comes only with complexity and sophistication. A third specific purpose of this manual that is somewhat subsidiary to the second one is to provide some guidance on when to use the various techniques.

ORGANIZATION OF MANUAL

The manual comprises nine chapters. It proceeds in Chapter II with an overview of the Corps planning process and the types of decisions that are made within that process. Trade-offs are encountered during the formulation of alternative plans and in the selection of a recommended plan. But there are many other kinds of decisions encountered along the way that require screening, focusing, identifying, qualifying, rating, ranking and so on that may be aided by the framework and techniques presented in this manual. Chapter II identifies some of those opportunities.

Chapter III presents a framework that will enable planners to systematically address a multicriteria decision problem within the planning process. The eight tasks of the decision support framework are described in detail. Value trade-offs are defined along with some other useful terminology.

Chapter IV describes some simple decision techniques that are basic to the evaluation step of the planning process. These include optimization, conjunctive and disjunctive techniques, elimination by aspects and lexicographic ordering. Although these techniques are perfectly adaptable to the selection of the recommended plan, they appear in a chapter by themselves because these techniques are most likely to be used throughout the planning process rather than during the selection step.

Chapter V develops a case study for use in the remainder of the manual. Having a single, realistic case study will make comparison of the different techniques easier. The case study developed takes its structure from an actual Corps study. Some of the criteria measurements are synthetic to make a richer case study. The chapter includes a discussion of the pre-analysis that is essential to the development of a decision matrix.

Chapter VI introduces some of the basic multicriteria decision-making models found in the literature. Analysts using relatively simple spreadsheet models can apply many of these techniques. Some of them, like multiattribute utility theory, outranking techniques and the analytical hierarchy process, are much easier to use with commercially developed software, however. The examples include weighted products, multiattribute utility models, outranking techniques and other examples.

Chapter VII provides an example application and discussion of the manual's decision-making tools and techniques to the case of cost effectiveness for an ecosystem restoration project. This chapter provides a more extended discussion of the use of the techniques in the evaluation step of the planning process. In practice, the qualification of plans for further consideration in the planning process can spill over and mix with the earlier comparison steps, as demonstrated in the example.

Chapter VIII presents a sampling of the decision support systems that are available through commercial software. Decision Lab 2000 uses the PROMETHEE outranking technique and GAIA graphical presentation methods. Criterium DecisionPlus uses the analytical hierarchy process and multiattribute utility theory in the simple multiattribute rating technique (SMART). Expert Choice is based on the analytical hierarchy process. Each of these programs is used to aid the case study decision problem. The chapter concludes with a short commentary on these three software packages.

Chapter IX provides some perspective on the use of the multicriteria decision models presented. It begins with a discussion of what makes a good decision support technique. It concludes with some thoughts about how to choose a technique for your decision problem.

The multicriteria analysis literature makes extensive use of mathematical functions and relationships. In order to make this manual accessible to the broadest audience possible, reliance on this mathematical language was minimized. Some readers may find the more rigorous, and at times more precise, mathematical presentation of the material more useful. For those readers we have provided an extensive bibliography.

Text boxes are used to separate information and discussion that are not essential to understand the most important aspects of the framework and the techniques used with it. Material of a more technical nature is also separated in text boxes.

SUMMARY: TAKE AWAY POINTS

1. Decisions often require choices to be made from among alternative options.
2. Choices sometimes entail trade-offs; choosing more of one thing simultaneously means choosing less of something else.
3. There is no single best technique for resolving trade-offs that involve people's values.
4. This manual provides new and experienced planners and their stakeholders with a framework, a mental model, for thinking about decision making in a multiobjective situation that fits neatly into the planning process.
5. This manual presents several practical and useful multicriteria decision-making techniques and provides some guidance on when to use them.

LOOK FORWARD

The next chapter provides an overview of the Corps planning process. It then identifies broad categories of decisions that are made throughout that process. Value trade-offs are defined, as are some other useful terms.

II. PLANNING DECISIONS AND TRADE-OFFS

Planning is problem solving. The human reality is multidimensional. Water resource problems are wicked problems. Wicked problems have no right answers. They are multi-dimensional and complex. Any solution to a wicked problem is only better or worse than other solutions.

Planning is decision making. Decision making in a multidimensional, complex environment can be difficult. Decisions rarely are unanimous and more rarely are universally supported. When the solution is not right but only better or worse, the process by which you arrive at it has to be a good one.

In the face of wicked problems it is unrealistic to look for an optimal solution, which rarely exists. It is essential to be able to find compromise solutions. This is not an easy task, especially when decision criteria are conflicting. But if the game we play is compromise solution, then what can a planner do except seek the very best compromises? That requires a systematic and transparent approach to decision making.

Planning requires planners to make many choices and decisions, some of which require trade-offs. This chapter is about planning, the choices and decisions planners make, and the types of trade-offs they face.

THE PLANNING PROCESS

There is a planning process. There is a way to think about and approach the solution of wicked problems. The U.S. Army Corps of Engineers uses the planning process promulgated by the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (also known as Principles and Guidelines or P&G) and Engineering Regulation (ER) 1105-2-100, Guidance for Conducting Civil Works Planning Studies.

The six-step planning process is described in the P&G as follows:

1. Specification of the water and related land resource problems and opportunities (relevant to the planning setting) associated with the Federal objective and specific state and local concerns.
2. Inventory, forecast and analysis of water and related land resource conditions within the planning area relevant to the identified problems and opportunities.
3. Formulation of alternative plans.
4. Evaluation of the effects of the alternative plans.

5. Comparison of alternative plans.
6. Selection of a recommended plan based upon the comparison of alternative plans.

The process can be summarized as a series of analysis and decision steps. We do some analysis, then make a decision, do some more analysis and make another decision. Eventually, the final decision is reached, and the planning process proceeds to implementation of the recommended plan, or it does not.

DECISIONS

Although planning has six steps, it is anything but a nice, neat, sequential process. It is an iterative process that is more marble cake than layer cake. You do not always start at step one, and the steps are not always taken in order. You do a step, and then you do it over and you keep on doing it until it is done. All the steps will be done at least once, and each will be finished before a good planning effort is completed. Along the way, the planning steps may be started in any order and addressed a different number of times to varying extents before they are finished.

The Corps planning process is finished when a plan emerges from the process and is recommended for implementation. Along the way many kinds of choices and decisions have to be made.[1] Figure 1 suggests some decisions that are made in the various steps.

Someone must first decide what the study will be about, what it will do and what it will not do. The first step's decisions include scoping, screening and focusing. Scoping decisions establish the length, breadth and depth of the planning investigations. The scope of the study defines what issues will and will not be considered. Once the scope of the study is established, planners must screen the candidate problems and opportunities that could be addressed in the planning process to identify those that are within the scope of the study. Significant environmental resources have to be identified. Given the problems and opportunities, the planning team must decide what they are going to do to address them. These decisions focus the study on a specific set of planning objectives and constraints.

With problems, opportunities and planning objectives identified, planners now have to identify the criteria they will use to judge their success in meeting the planning objectives. They also have to identify the data they will need to formulate, evaluate, compare and select plans. The analyses required to arrive at the desired answer to the overarching question, "What is the best way to achieve these planning objectives?" is also identified in this step. Identification of the most likely without-project condition is one of the principal outcomes of this planning step.

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[1] The distinction between choice and decision as made here is somewhat arbitrary. Choice is used to represent the selections made by planners and analysts supporting the planning process. A decision is considered a more conclusive process that would involve decision makers who are above the planning team in the plan selection process chain of command. In order to avoid the cumbersome repetitive distinction of terms, decision will be used here to encompass both processes, but a distinction will continue to be made between planners and decision makers.

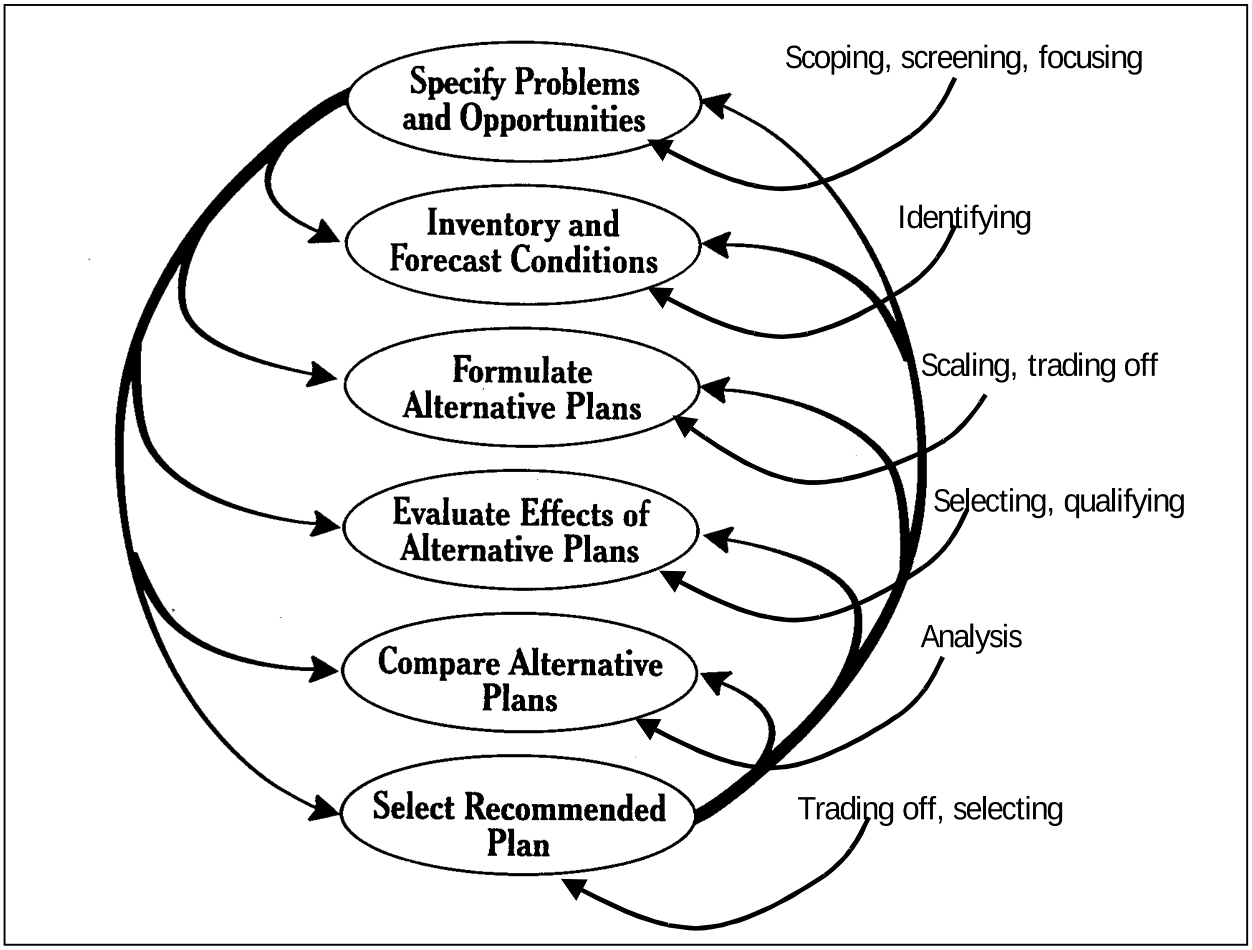

Figure 1. Planning Process

In the plan formulation step, the team decides the component measures, material, scale, location, implementation schedule and such for specific alternative plans. These "scaling" or "plan-building" decisions often provide planners their first encounter with value trade-offs.

In the evaluation step, planners have to select the criteria they will use to evaluate and compare their alternative plans. Then the team decides whether or not each plan qualifies for further consideration based on its own merits. At this point, planners must be sure to incorporate the values of decision makers into their own thought process as they select evaluation criteria.

The comparison step entails the choice of criteria to analyze and compare among plans, and, as such, it requires a keener appreciation for the values of decision makers. The selection process of the last step is the final round of trade-off analysis. Decision makers may follow the recommendation of the planners, or they may impose their own decision. This last step is the responsibility of decision makers, not planners.

DECISION HIERARCHY

Decision Problems

Multicriteria decision problems come in different flavors. The three most common are:

- Choice problem–choose from a set of alternatives the subset that is best with respect to the set of criteria identified. This may be a subset of one.
- Sorting problem–divide a set of alternatives according to some norms, such as qualified and unqualified.
- Ranking problem–rank all the alternatives in the set from best to worst.

Figure 2 shows a decision hierarchy representing the major kinds of decisions made in a typical planning process. The choice of the recommended plan is made last, as shown at the top of the pyramid. This is essentially one decision. Our assumed and abstracted decision maker makes it. This choice is made from among the qualified plans that emerge from the planning process. The multicriteria decision and trade-off techniques described in this manual are most often thought of as being applied in going from the qualified plans to the recommended plan. As noted previously, however, these techniques may be useful at several points in the planning process. They can be especially helpful in the evaluation of plans, as demonstrated in Chapter VII.

Typically the planning team, with the concurrence of their supervisors, will propose one of the qualified plans for designation as the recommended plan, but that decision belongs to the decision maker. The qualified plans are selected from among a larger set of candidate plans that result from the plan formulation process. The planning team decides which plans qualify for further consideration and possible selection as the recommended plan. The candidate plans themselves are identified from a larger set of potential plans that could be assembled from the measures identified in the plan formulation process. These measures are the result of extensive analysis by the planning team members.

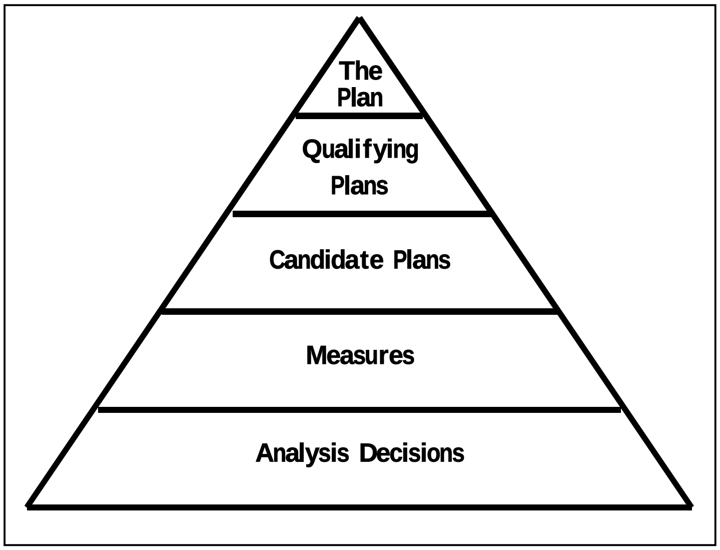

Figure 2. Decision-Making Hierarchy

While there is one decision to be made at the top of the pyramid, there are literally hundreds of decisions to be made by analysts before the formulation process matures to the point of having measures from which alternative plans can be built. Someone must decide what problems and opportunities will be addressed. Someone must identify the planning objectives and constraints. Someone will define the without-project condition. Someone will identify significant resources. Someone will identify, collect, organize, analyze and present data. Someone will decide when to involve which stakeholders in the process and in what ways, and so on. This process involves so many decisions that the final solution set is significantly narrowed by the cumulative decisions of a multitude of people well below the level of the decision makers at the top of our pyramid.

In practical terms the abstracted decision maker can be a single person or a group of people. The analysts may well be de facto decision makers. They make choices throughout the planning process. And though they may not make the final decision, it is not uncommon for the final decision to be little more than a review of the choice made by the planning team.

The important point to take away from all of this discussion for purposes of multicriteria decision making is that the decision process will reflect a value system. In principle that value system should be the value system of the decision makers. In practice it is often the value system of many people throughout the decision hierarchy. Whichever the case may be, a good multicriteria decision process clarifies whose values the decision process reflects.

THE PUBLIC AND COLLABORATIVE PLANNING

There is no such thing as the public. Marketing experts long ago learned the value of market segmentation and tailoring one's sales pitch for that segment. There are many publics for a water resources planning study. There are residents, various levels of government, resource agencies, environmentalists, developers, farmers, city managers, water users and so on. Each holds a different point of view and has a personal interest in the investigation and its decisions. With so many publics, points of view and interests, the planning process in general needs to be a collaborative process.

Collaborative planning is based on the belief that no one party is likely to possess enough knowledge of all the technical and value issues encountered in a planning study to develop the best possible solution. A corollary to that belief is that when people are invited to participate in a planning or decision process, they are more likely to support the resulting solution. Collaborative planning includes both the various "publics" and interagency coordination. Together these "others" are called stakeholders — people and groups with an interest in a study who affect it or may be affected by it.

Collaborative planning is an entire planning method in itself, and, as such, it is larger than the focus of this manual. But the principles and techniques of collaborative planning can be applied at the macro level of a planning study or at the many micro levels of the study team and the extended team. Collaborative planning or decision making can:

- Increase stakeholder understanding and support
- Increase sponsor support and understanding needed for successful operation and maintenance
- Improve understanding of local conditions
- Coordinate projects within the watershed
- Work across political boundaries
- Determine more complete project benefits

- Increase planning efficiency and efficacy through shared capabilities
- Result in a better plan

Collaborative planning may take extra time and attention, but this investment can produce many benefits.

Although the trade-off processes and decision making described in this manual may themselves not be pointedly collaborative in all cases, they should always take place within a collaborative planning process. This will best ensure that the alternatives considered, the criteria used to judge them and the weights assigned to these criteria reflect the views of the plans' collaborators.

Table 1 provides a summary of some of the expected outcomes of the Corps planning process.

Within this framework of expected planning process outcomes several potential roles for stakeholders in the decision-making processes of interest in this manual. These include agreement on project principles, stakeholder-assisted analysis, and gut-level negotiation.

TABLE 1:
SOME DESIRED OUTCOMES FOR EACH PLANNING STEP

Planning Step	Outcomes
Step 1: Specify Problems and Opportunities	• Statement of problems and opportunities • Public, institutional and technical significance of resources • Planning objectives and constraints • Project scope • Stakeholder feedback through Feasibility Scoping Meetings
Step 2: Inventory and Forecast of Conditions	• Understanding of ecosystem structure and function • Conceptual model of ecosystem that identifies key resources and processes • Quantitative ecological model • Without project conditions • Range of variables considered (how to select useful and valid indicators)
Step 3: Formulation of Plans	• A range of alternative plans that meet planning objectives
Step 4: Evaluation of Effects	• Assessments of differences between with- and without-project conditions for each plan • Qualification or disqualification of plan for/from further consideration
Step 5: Comparison of Plans	• Comparison of differences between plans • Trade-off analysis
Step 6: Plan Selection	• Select a draft recommended plan based on trade-off analysis • Stakeholder feedback on draft plan through Alternative Formulation Briefing • Public review of draft document
Overall Process	• Stakeholder awareness of and support for the project and planning process • Interagency coordination • Public involvement • Solid working relationships and trust among stakeholders

Techniques for facilitating these roles for stakeholders can be found in the publication described in the "For More Information on Group Processes" text box.

To obtain agreement on the general principles of any project a group process especially designed for negotiation can get the issues out on the table where some kind of consensus can be negotiated. In a process like this you may not be sure why stakeholders are agreeing or disagreeing, but agreement is reached. This is not a purely random process. In many ways it embodies unspoken trade-offs. It taps into the notion of stimulating win-win within the trade-off context and bringing the project analysis to a reasonable phase for further analysis. Processes like these lend themselves to the use of the processes described later in this manual.

If trade-off techniques can support stakeholders, the flip side of that coin highlights how stakeholders can assist trade-off techniques in stakeholder-assisted analysis. If an analytical trade-off tool like one of the multicriteria decision-making methods of this manual is going to be effectively used to discriminate among alternatives, the tool needs to get buy-in from the stakeholders of the study team. Inputs and assumptions that drive the decision process can be worked through in an open process. A fair and structured group process will greatly assist in setting the foundations of effective use of the trade-off technique.

Negotiation is a constant in collaborative planning. Different points of view and conflicting interests will lead to disagreement. In a less analytical approach, group processes can be used to resolve these differences. What are the agreed upon goals and expectations for the study? How will success be recognized? What should the planning objectives be? How will success be measured? What should the criteria be? Which are the most important criteria? Structured group activities can greatly supplement these activities. Key stakeholders are given a chance to hear and be heard. Others expectations are transmitted among the stakeholders. These are used to set project planning parameters.

There are three general types of communication techniques that are useful for collaborative planning process and facilitating stakeholder roles in the planning process:

- Discussion to increase knowledge and improve working relationships
- Idea generation to increase creativity and solve problems
- Decision making to evaluate and choose among options

Table 2 identifies a few common opportunities for using these communication techniques in the planning process. Determining the criteria and their weights for trade-off analysis takes place principally in steps four and five. Additional details can be found in the related references (i.e., listed in Table 2).

TABLE 2:

COMMON OPPORTUNITIES FOR USING THREE TYPES OF COMMUNICATION TECHNIQUES

	Step 1—Specify Problems and Opportunities	Step 2—Inventory, Forecast and Analysis of Resource Conditions	Step 3—Formulate Alternative Plans	Step 4—Evaluate Effects of Alternative Plans	Step 5—Compare Alternative Plans	Step 6—Select Recommended Plan
Discussion (Knowledge)	●	○	●	○	●	
Idea Generation (Creativity)	●		●			
Decision Making (Evaluation)	●			○	○	●

(Adapted from Capan et al. 1996)

Key: ● Primary Opportunity

○ Secondary Opportunity

Note: This table identifies *common* opportunities to use types of communication techniques. Each planning investigation is unique. Depending on the situation, all three types may be useful in any of the six planning steps.

For More Information on Group Processes

Three useful resources for learning more about the principles and techniques of collaborative planning and group processes are:

1. "Planning Manual Series: Collaborative Planning for Ecosystem Restoration Projects," to be published by the Institute for Water Resources.
2. "Trade-Off Analysis for Environmental Projects: An Annotated Bibliography," IWR Report 95-R-8, August 1995.
3. "Planning Manual," IWR Report 96-R-21, November 1996. Chapter 13 has some pertinent information.

TRADE-OFFS DEFINED

In the broadest sense, a trade-off is giving up one thing to get another. And in this broadest sense any choice looks like a trade-off. In the current context we seek a narrower definition of a trade-off. Some choices entail trade-offs; others do not. Choices that do not entail trade-offs we'll call optimization choices. Consider the simple example of choosing the number of scoops of ice cream you'll have. An optimization choice is usually minimizing or maximizing some single objective. Minimizing the number of scoops leads to a choice of no ice cream, maximizing the number of scoops leads to a choice of all the ice cream. The actual choice is likely to be something between these two extremes, which leads us to the point that the objective being optimized may not be an empirically determined one. In the ice cream example, it could be personal satisfaction that is being optimized. That might happen at three scoops. Scoops of ice cream are optimized over personal satisfaction.

In water resources planning, level of protection lends itself well to an example of optimization. Once it has been decided to protect a community with a floodwall, the next task is

Planning in the Corps

Planning in the Corps of Engineers comes with an upper or a lowercase "p". Uppercase "Planning" contains lowercase planning and a good bit more. The budget process, report review, regulatory review and the consultation process are examples of big "P" planning that the little "p" thought process of the six planning steps does not address.

But not all little "p" planning is done in Planning Division. Anyone who seeks to systematically address the resolution of wicked problems can do planning. The Corps encounters wicked problems and uses planning in many arenas.

Water resources development planning includes the heart of the Corps traditional Civil Works Program. This program currently consists of the following high priority outputs: flood and storm damage reduction, ecosystem restoration and navigation. Watershed planning has recently reappeared as a significant planning activity. Planning assistance to states remains an important planning function. Growing in importance over the last decade or so has been operations and maintenance planning, which includes major rehabilitation, maintenance dredging and master planning.

Regulatory permits planning has long been a small "p" planning function of the Corps. It includes special area management plans and mitigation banking planning among other things. Environmental infrastructure planning is another recent addition to the Corps planning responsibilities. Drought preparation planning has become more important in the last decade.

The Corps has also supported the military missions of the Army and other military organizations through military planning. Among the more common planning activities under this heading are master planning, military construction planning, logistics, project validation assessment mobilization planning.

In more recent years, restoration planning for formerly used defense sites and installation restoration, program planning have been added to the Corps military-related planning activities. Support for others planning is undertaken on an as-requested basis for other military organizations. Strategic planning is a more recent addition to the Corps planning activities.

Planning Division does not undertake all of these planning activities, and often the people involved in these activities may not think of themselves as planners. But they are doing planning. In doing so, they too will inevitably face decisions that may require trade-offs.

to decide how high the floodwall is to be. The objective criterion for optimizing the level of protection, i.e., the height of the wall, is usually maximum net NED benefits. This value is not likely to be maximized at the minimum or maximum possible floodwall height. Instead, like our ice cream example, it is likely to be optimized somewhere between these two. Level of protection is optimized over net NED benefits.

Any choice of how much of a given objective to attain or how much of a criterion is desired is not considered a trade-off in the current context. That does not mean the choice is trivial, it simply means decisions based on such choices do not use trade-off analysis or multicriteria decision-making models. Once an objective function is specified, "Eat the amount of ice cream that will bring me the most pleasure at this very moment and hang the calories," or "Maximize net NED benefits," the choice is easy. There may be a great deal of analysis required to get the information upon which the choice will be based, but in such choice settings the solution is imbued in the model or the decision rule we use. Once the model is chosen, there is no decision to be made. The model makes the decision.

A trade-off means giving up one thing to gain another. When the hot dog stand is right next to the ice cream stand and you can't afford both, the choice of one means giving up some of the other. Reservoir storage reallocation studies encounter trade-offs all the time. Will storage be allocated to hydropower or flood control? Storage filled with water can't be left empty to hold potential floodwaters. An acre-foot of water can be used for withdrawal purposes (irrigation, water supply) or in-stream purposes (navigation, habitat). More of one means less of another. Some choices entail trade-offs.

Some trade-offs, such as the last two examples, are explicit. One more unit of one value means one less unit of another value. When a given land or water resource has competing and mutually exclusive uses, the trade-off is an explicit one, and the terms of the trade-off may be fixed by the laws of our physical universe. An acre of forest can be forestland or it can be cleared for development. This is an explicit trade-off defined by this obvious one-to-one relationship. Not all explicit trade-offs will be so easy to define. More agriculture in a watershed means more fertilizers and pesticides used on crops that can degrade drinking water quality. An increase/decrease in the use of pesticides and fertilizers means a decrease/increase in drinking water quality. The trade-off is explicit, and the laws of our physical universe fix the terms of the trade-off even though we may be unable to ascertain them.

The laws of the natural universe fix the terms of an explicit trade-off. Other trade-offs are implicit. The terms of an implicit trade-off are fixed by the value systems and preferences of decision makers. There is no explicit trade-off between community cohesion and enhancing aquatic ecosystems. The trade-off is implicit because its terms of trade are based on something other than the laws of the physical universe. Explicit trade-offs can sometimes be easier to measure than implicit trade-offs.

Value trade-offs is an additional term we introduce to make another important distinction in the nature of trade-offs. In many decision contexts and in most Corps planning contexts, the ultimate decision involves trading off values. In this sense all trade-offs are implicit. Consider, for example, two plans alike in all respects except that one has 100 acres of wooded urban recreation and the other uses those 100 acres to create wetlands inaccessible to the public. The trade-off is explicit. But weighing these two alternatives will still require an implicit trading off of the decision maker's values. To further complicate matters, it is worth mentioning that a transparent trade-off analysis, and a good trade-off analysis is indeed transparent, makes the implicit nature of a values trade-off explicit. This usually happens through the specification of weights.

One of the motivations for this manual is the recurring need to trade national economic development for national ecosystem restoration and vice versa. Whether the terms of the trade-off are explicit or implicit, the ultimate decision is based on the values of the decision makers. Another common trade-off encountered in water resources planning includes high-priority benefits versus other beneficial effects of plans.

A value trade-off is defined formally based on a modification of Hadari's (1988) definition. A value trade-off exists if:

> A decision-making unit must choose a course of action whose implementation involves at least two values, V_a and V_b, both held as positive values.
>
> A. The alternatives available would each necessarily entail sacrificing, at least to some degree, either V_a to V_b or the opposite. To use technical language: past some point, the values to be upheld are divergent.
>
> B. No common unit of measurement applies to both V_a and V_b: the values are incommensurable.

There is no formal value trade-off if we can overcome the elements of the definition. That is, if there is no divergence, then we do not have to give up one value to gain another. And if the values are commensurable, then in theory this decision could be made using optimization analysis. We need trade-off analysis because of conflicts among values and a lack of a common unit to measure relative gains and losses in implementing plans that reflect a variety of values.

If there are no value trade-offs, then there is no real difficulty with the comparison or selection steps of the planning process. It is simply a matter of identifying the optimum plan. Only when we have to give up something to get something incommensurable do we face a problem in the decision-making process. The optimization paradigm does not often work in the planning process. Planning almost invariably involves analysis that must take multiple criteria into account.

Terms of Trade

Universally accepted terms of trade do not currently exist. Nor are they likely to exist in the near future, if ever. We do not know how many flood damage reduction benefits an additional habitat unit is worth. It is impossible to say how many degrees of decrease in average water temperature a kilowatt of energy is worth.

The rate at which we are willing to trade one project output or impact for another is implicit in the preferences of the decision maker. And although these rates can be inferred in a variety of ways, they are not and should not be determined in a fashion external to the decision process.

TERMINOLOGY

Projects are multipurpose.

The planning process is multiobjective.

Decision making is a multicriteria process.

Multipurpose. Corps projects can be multipurpose. The purpose of a project is to get to a desired outcome. Traditionally some of those outcomes have been specific project outputs like flood damage reduction, navigation services, hydropower and the like. Today the purposes of a project include ecosystem restoration as well. An implicit judgment has been made in the Federal budget process that some purposes are more important than others. At the present time, flood damage reduction, hurricane and storm damage reduction, navigation and ecosystem restoration are the highest-priority purposes of a Corps project. "Multipurpose" is an adjective used to describe a project that serves more than one purpose.

Bundles of Expected Impacts

Plans represent different bundles of expected impacts. It's the decision maker's job to peruse those bundles and choose the best one for society. Some bundles have more NED, others have more NER. One might be more effective or acceptable than another. In this sense the plan selection process is the ultimate trade-off of bundles of impacts. Choosing one plan (bundle) means not choosing the other plans (bundles). When we choose one bundle with more NED, effectiveness and acceptability, we simultaneously give up a bundle with other expected impacts. The trade-off depends on the value one places on the various bundles of impacts.

Multiobjective. The Corps planning process is multiobjective. The word "objective" is used in a confusing and multiply-defined fashion in water resources planning. There is talk of Federal objectives and planning objectives. In a planning study the Federal objectives become the goals or desirable endpoints of a specific planning process. By meeting the planning objectives a project will ultimately contribute to the goals (i.e. Federal objectives) set forth for water resources projects.

Multicriteria. Decision making is a multicriteria process. Good decisions are not made haphazardly. They are based on criteria. Those criteria reflect planning objectives and other significant attributes of a plan.

SUMMARY: TAKE AWAY POINTS

1. There is a formal six-step planning process.
2. A wide variety of decisions are made at various points throughout this process.
3. Selection of the recommended plan is the ultimate decision of the planning process.
4. A value trade-off requires desirable, incommensurable endpoints that become divergent at some point.
5. The selection of a recommended plan is usually a multicriteria decision that involves value trade-offs.

LOOK FORWARD

A framework for thinking about and approaching multicriteria decisions is presented in the next chapter. This framework overlaps comfortably with the six-step planning process discussed in this chapter.

III. MULTICRITERIA DECISION FRAMEWORK

If you have ever agonized over the choice of a vehicle, house, job or other big decision you inherently understand why multicriteria decision making is not very popular with decision makers. Multicriteria decision making[2] is hard work, and it offers a sometimes-unwelcome objectivity. A decision is always easier to make when we consider only one dimension of the problem and when we are the only decision maker. Multicriteria decision making identifies conflicts; it distinguishes that which we know objectively from that which we do not. It can reveal the extent to which our decisions are arbitrary and based on intuition or politics. The ultimate value of multicriteria decision making is that it is a process that helps us to identify and understand conflicts and trade-offs. And that is better than ignorance of them, however much more uncomfortable addressing them may make us feel with our decisions. Multicriteria decision making provides us with the opportunity to address conflicts by identifying them. The iterative planning process practiced by the Corps is ideally suited to such an interactive decision process. Multicriteria decision models do not produce decisions, nor do they resolve conflicts. They provide useful information and insight in support of decision makers faced with solving wicked problems.

The purpose of this chapter is to provide a framework for thinking about decision support systems that are consistent with the planning process and can be used with any multicriteria decision-making technique. The importance of the framework itself derives from the belief that the process by which a decision is developed is every bit as important as if not more important than the as the decision itself.

Planning deals with wicked problems. They do not have monocriterion solutions. Consequently, we are not after an aggregation process that combines all the plan impacts into an empirical value that becomes the decision. These are not problems that lend themselves well to an optimization process. Indeed, few people would trust or believe in a final aggregation process that produced "the solution" to a complex planning problem. Rather than identify a best choice, multicriteria decision making exposes the conflicts and trade-offs encountered in solving wicked problems and allows the decision maker's intuition to enter the decision-making process.

We do not want to find ourselves in a situation where we recommend Plan A because it is marginally better than other plans through some abstruse aggregation or optimization function. Multicriteria decision making support tools enable planners to explore the robustness of a decision. The intuitive dimension of multicriteria decision-making techniques is not a reason to reject the techniques — rather it is a source of richness in thinking about wicked problems that better assures that we will consider the multiple dimensions of a decision problem. With sensitivity analysis, these techniques enable us to explore that which is known and not so well known to determine the robustness of the ultimate solution. With or without a clear winner the

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[2] "Multicriteria decision making" as used through the remainder of this manual should be understood to include trade-off analysis. "Multicriteria decision-making" is used because it is a more encompassing term. Experienced planners may be comforted to know that the decision matrix of the multicriteria decision-making techniques is virtually identical in concept to the planner's system of accounts or other summaries of significant plan impacts that have been used over the years. Thus, multicriteria decision models are quite compatible with the planning process used by the Corps of Engineers.

ultimate choice of the recommended plan is left to the decision maker or to some new criteria that better support the discriminating power of our analysis and multicriteria decision-making technique. It may be that the choice between Plans A and B is fundamentally a political one because there is nothing to choose between them based on a robust multicriteria decision-making analysis. Even in this case, everything that has happened right up to the decision has great educational value.

DECISION SUPPORT FRAMEWORK

There are a plethora of multicriteria decision models, and no one of them is best. Some techniques are better suited to some decision contexts than others, but there will never be an instance where there is not a choice from among several multicriteria decision models. Anyone looking for the single best approach should turn back now. It does not exist.

There are, however, many common elements of the various techniques. In this section these elements are distilled into eight generic components that comprise a framework for thinking about and approaching multicriteria decision problems.

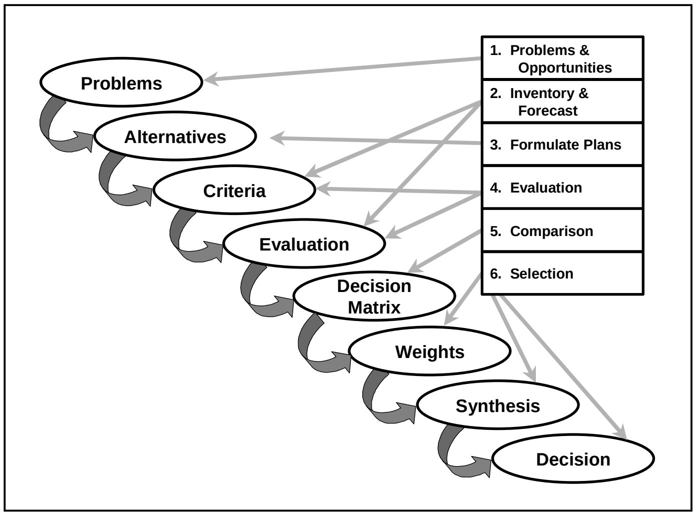

Figure 3: Relation of Planning Process to Multicriteria Decision Support Framework

Figure 3 shows the multicriteria decision support framework in relation to the Corps planning process. The first step in this decision process is to identify the relevant decision problem(s). This is currently done in step one of the planning process. Next, the alternative solutions to the problem are identified. That is accomplished in step three of the planning process.

Criteria for evaluating the alternative solutions to the problem are needed. These criteria are identified in the data collection and evaluation steps, steps two and four of the planning process. All multicriteria decision-making techniques are virtually identical in general concept,[3] though often quite different in practice, through creation of the decision matrix. This work is equivalent to the work done in the comparison step five of the planning process.

Multicriteria decision-making techniques are most distinctive in the manner in which they accomplish the last three steps of the decision support framework. Weights can be applied in a variety of ways. The nature and extent of the synthesis and the final decision are also markedly different. These tasks would be accomplished in the final step of the planning process.

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[3] They each include a set of alternatives, a set of criteria, weights for the criteria and a trade-off algorithm.

Like the planning process, the decision support framework is iterative. Although it is presented in a linear fashion, it may begin at many steps, and the steps may be repeated an asymmetric number of times in any order. The framework provides structure, order, transparency and replicability to the decision-making process when it is followed purposefully and systematically.

The decision support framework presented here supplements the planning process. Just as there are ways to conduct hydrologic, economic, environmental, foundation and other investigations within the planning process, there is a way to make multicriteria decisions. This framework provides an example of such a way. Rather than dislodging or replacing any part of the planning process, multicriteria decision making reinforces the planning process as figure 3 shows.

The People of the Decision Support Framework

There are several distinct roles in this decision support framework that are distinguished from traditional planning roles. These newly distinguished roles are: champion of the multicriteria decision-making process, decision makers and analysts.[4]

Champion

Multicriteria analysis will not be done unless someone champions its use. The champions of the technique are those who initiate and support its use by providing the necessary resources for it. The technique must find its champions within the planning teams of the Corps field offices. It is anticipated these champions will eventually include Planning Division management, project managers and experienced planners.

It is not likely that the District Engineer will ask for these kinds of tools. But decision makers, as broadly construed in the discussion that follows, are turning to multicriteria analysis because so many of their decisions inevitably involve conflicting objectives, trade-offs, qualitative criteria, uncertainty and judgment. Compromise is the only possible lasting outcome of conflict, and compromise requires a thorough understanding of the criteria of all stakeholders and the values in conflict. Multicriteria analysis has great value for providing methods and a structure for informed discussions of the relevant conflicts and values. In the Corps planning experience it is not unusual to be confronted with various single-interest pressure groups. Multicriteria analysis can serve to demonstrate that the final decision is reached through a rational process fully cognizant of stakeholders' criteria.

Decision Makers

The decision maker may or may not be the champion of the multicriteria analysis, but the decision maker is the user of the analysis. The literature is replete with references to decision making and decision makers. Rarely are these people identified. The presumption often seems

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[4] These roles are adapted from Chapter 11 of Pomerol and Barba-Romero's (2000) excellent book.

to be, if you have to ask who the decision makers are then you should not be reading this literature. It's not always that easy.

A planning study involves dozens if not hundreds of significant decisions well before the recommended plan is selected. Analysts make some of these decisions individually; others are made in concert with other analysts or perhaps technical reviewers. The team makes some decisions. Leaders[5] outside the team make other decisions.

The team often recommends a plan for selection. This recommendation may be influenced by or agreed to by other leaders. The Corps top decision makers and those of the non-Federal partner quite often confirm this emerging consensus. And so, although one may, for example, be able to say the Division Engineer and the Governor are the decision makers, it is not unreasonable to pragmatically argue that others made the decision before the decision makers confirmed it.[6]

In this manual, as in most of the literature, the existence of a decision maker is assumed. The decision maker is an important element in a multicriteria decision paradigm. And although we ultimately treat the decision maker as an abstraction, we must first say a few words about decision makers and their role in the framework of this chapter and the techniques of the following chapters.

When the criteria for decision making cannot be conveniently reduced to a single unit of measurement like dollars or habitat units or votes, the decision will be based on multiple criteria. Most multicriteria decision-making techniques require some knowledge of the decision makers' preferences. Are the criteria all of equal importance?

A value system is needed to apply these techniques. Whose value system is that to be? Why, the decision maker's of course. But just who is the decision maker and how are their values discerned?

The decision pyramid presented in Chapter II suggests the actual decision process is spread out over time and throughout the organization. If so, it is important not to make a myth of the instant of decision. The decision may not truly occur at the moment the District Engineer and Governor confirm the team's choice. More importantly, the values reflected in the decision may not be those of any one person.

In a typical planning investigation it may be reasonable to consider the study team as the source of many value judgments. The study team prepares the decision for the ultimate decision makers. It is critically important to understand that multicriteria decision making is a decision aid, not a decision. The final decision maker is free to confirm the team's value judgments or to substitute their own. It is generally not advisable to push analysis right through to a final decision. The method should not make the decision; that must remain the decision maker's job. Multicriteria decision making is a method that aids the decision.

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[5] Leaders may include supervisors, managers and other decision makers within and external to the Corps.

[6] Alternatively in this case, we might suggest that the planning team makes a recommendation based upon their judgments and the decision maker takes it.

Analysts

The third party in the framework is the team of analysts. Most often they are members of the study team. The analyst's job in this context is twofold. One, an indirect multicriteria analysis role, coincides with the traditional responsibilities of an analyst on a study team. These are the folks who identify and measure the criteria and an alternative's contribution to it. They contribute data to the multicriteria decision-making process. The second and more direct role is to carry out the actual multicriteria analysis. That means choosing, developing and presenting the results of the multicriteria model and analysis.

In some planning settings, the champions of multicriteria analysis will want the analysis to directly support their final choice. In these cases it is hoped that the model will "impose" some rationality on the selection process. In a sense the decision maker may be abdicating some of their responsibility to the analysis. In other situations, the multicriteria modeling process, i.e., development of a decision matrix and the resulting compromise, may be the more useful part of the process. The decision in these situations is thrown back onto the decision maker. But the model provides the decision maker the benefits from the process of arriving at an acceptable choice.

A very practical understanding these three parties should try to reach well before the selection process begins in earnest is whether they want a complete ranking of alternatives from best to worst, classification of alternatives as acceptable or unacceptable, selection of an alternative or a negotiated compromise. Multicriteria analysis can contribute to each of these outcomes. How it is actually used will depend to a great extent on where in the planning process it is used. The planner has considerable leeway in the application of these techniques.

In the remainder of this chapter each of the eight components of the decision support framework is discussed in more detail. The detail emphasizes terminology, definitions and basic ways of thinking about these component tasks of the decision support system. Chapter IV illustrates the application of multicriteria decision-making techniques.

COMPONENT 1: PROBLEMS

Multicriteria decision-making techniques all begin with problems that need to be solved. Water resources planning begins with problems and opportunities. Problems are situations to be avoided. Opportunities are situations we hope to attain or realize. Problem and opportunity statements provide the specific reasons for planning. Identifying problems and opportunities is akin to making clear the specific question(s) the planning team is trying to answer.[7] In this sense the problems and opportunities form the mission statement for the planning team.

Given the reasons for the planning study, i.e., the problems and opportunities, the question follows, "What do you intend to do about these problems and opportunities?" The answers to this question come in the form of clearly articulated planning objectives. This is the

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[7] The problems and opportunities give definition to the always-present implicit question, "What is the best way to…*solve these problems*…and…*realize these opportunities?"*

planners' "to do" list. Along with the objectives to be achieved there are a number of planning constraints to avoid. Constraints can be thought of as the planners' "don't do" list.

Water resource problems are wicked problems. They do not have clear and unambiguous answers like the algebra problems of youth.[8] There is no point at which one can confidently say, "I have the answer" and rest assured that all others would agree. The problems are difficult because they are complex and multidimensional. They are wicked because they involve conflicting objectives, conflicting values and a great deal of uncertainty. These problems are addressed by formulating alternative plans that meet the objectives and avoid the constraints. In so doing, the problems are more or less solved and opportunities are more or less realized.

The best plan is identified from among the alternative plans by means of a decision-making process that might involve trade-offs of conflicting criteria but that always involves multiple criteria. These criteria usually include some measure of attainment of the most important planning objectives as well as other criteria of interest to decision makers.

Significantly, simply aggregating some objective function or optimizing a single objective cannot solve these problems. Choosing a plan based solely on maximum net NED benefits would be an example of such an aggregation or optimization process. There have been and may again be instances in which that is done. These decisions problems are trivial, however, because of their reliance on a single criterion. The framework presented here and the focus of this manual is the richer and more complex class of problems that defy such single-minded decision making.

To have an effective decision-making process it is essential that everyone involved in the decision have a clear understanding of the decision context. This includes understanding the problems, opportunities and the planning objectives for the planning investigation. It also means understanding who the decision makers are which is, the subject of the next section.

In summary, a decision support framework is relevant for planning investigations because planning investigations tend to have multiple problems. These problems tend to be multidimensional and complex and involve conflicting objectives as well as conflicting value systems. Aggregating or optimizing any single objective cannot produce solutions to such problems. Solutions generally involve multiple criteria, trade-offs, compromise, conflict resolution and judgment. These characteristics, common to the Corps planning problems, make these problems ideal candidates for multicriteria decision-making techniques.

COMPONENT 2: ALTERNATIVES

The basic planning problem is to select the best alternative from among a set of alternatives. That "choice problem" is the fundamental purpose of multicriteria analysis as well.

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[8] Analytical problems have an answer. Confronted with the problem $-3 + 4x + x^2 = -6$, we might struggle and find this problem difficult, but in time we, perhaps with assistance, would determine that $x = -3$. The problem, difficult though it may be, has an answer. Wicked problems do not have analytical solutions, and their answers are only better or worse than other answers; rarely are they right or wrong.

Alternative plans and their formulation have been described in the *Planning Manual* and several other documents.

Plans are formulated in the third step of the planning process. Planning objectives, derived from problem and opportunity statements, are used to guide the construction of plans from measures that are the building blocks of plans. Ideas are first used to expand the choice set of alternative plans. These ideas are then clothed in information and enriched by details of their most likely performance. Plan impacts are studied, estimated and evaluated routinely in the planning process. They are explicitly incorporated into the latter steps of the decision support framework.

The plan formulation step is a critical part of the multicriteria analysis. In fact, many of the strongest selling points for multicriteria analysis have to do with the structured thought process it imposes on decision making. Most of that structure is already part of the Corps planning process. Without alternatives from which to choose, there is no need for a structured process. When you have only one idea, the decision is much easier.

COMPONENT 3: CRITERIA

The Second Edition of the Oxford English Dictionary defines a criterion as, “A test, principle, rule, canon, or standard, by which anything is judged or estimated.” Criteria are used in multicriteria analysis to judge the alternative solutions to the decision problem. Criteria are used in the planning process to select the recommended plan. There is no change in thinking about criteria required to adapt the traditional planning process to multicriteria analysis.

The language in the literature is a bit messy, and there are some conflicts in the usage of terms in the multicriteria analysis literature and the Corps planning jargon. In lieu of a protracted review of that literature (see Roy [1975, 1985], Bouyssou [1989] and Roy and Bouyssou [1993] for a discussion of the qualities of a good system of criteria), let us simply define some terms for general usage in this manual.

In the Corps planning jargon, criteria are used for study scoping, screening activities, plan evaluation, plan comparison and plan selection. In general, criteria are not used very differently in the decision support framework presented here. However, the set of criteria used in a multicriteria analysis is likely to be a subset of the more numerous criteria used for more and broader purposes in the planning process.

Criteria are used for judging alternative plans; ergo, criteria must be things that are important to people. In a good planning process, candidate criteria for judging alternative plans will surely reflect contributions to the planning objectives and constraints used to guide the plan formulation process. There are other measures that are universally important to judging a plan, such as costs, laws and legal values (endangered species), completeness, efficiency, effectiveness and acceptability. Alternative plans in a specific investigation can have additional, uniquely important attributes. These attributes may also be values, for example, security, sustainability, equity, i.e., things that are intrinsically desirable to people. For the purposes of this framework, "criteria" can include planning objectives and other plan attributes that are important to people.

In the past, planning studies presented Systems of Accounts tables. Their purpose was to summarize the major effects of a plan. Although these effects were presumably important to people, not all of them were used to compare the plans and select the best plan. Some effects were useful in the qualification of plans. Others were presented because they were required. Some of the effects were considered for decision making and others were not.

Different Decisions; Different Criteria

The planning process is rife with decisions. Many of these decisions are based on more or less explicit criteria. Different kinds of decisions require different criteria. For example, scoping is the process of defining the nature and extent of the planning process. It identifies the most important issues to be addressed by the study. As such, its criteria may include policy, geography, politics, authorities and other broad concerns. Once the investigation has been scoped, however, it is reasonable to presume that a successful planning process produces alternatives that meet these scoping criteria. Scoping criteria, however, would not be appropriate decision criteria.

The evaluation step of the planning process qualifies plans for or disqualifies plans from further consideration. Numerous screening criteria are used to do this. Many of these are routinely found in a system of accounts table. The presumption is that every plan meets these qualifying criteria or it would not have qualified.

Some of these evaluation criteria do not discriminate among plans, they simply qualify or disqualify plans. For example, several Corps planning reports reviewed for this manual enumerate environmental quality effects of plans such as air quality, water quality, various kinds of habitat impacts, and endangered species impacts. The descriptions of these effects are often described subjectively and identically as, "no change from existing conditions," "no impact," "no change anticipated" and so on. These criteria, although possibly import screening criteria are not appropriate decision criteria because they do not discriminate among plans. Any criterion that fails to discriminate among plans is of no use as a decision criterion. Some evaluation criteria, however, may be sufficiently differentiated and important enough to carry over as decision criteria.

Decision criteria should reflect measures of achieving critical planning objectives and other attributes of plans that are important to people. It is sufficient to assume that all plans in the final array sufficiently meet any criteria. This assumption also holds true for those that are not explicitly included among the decision criteria.

An effective multicriteria analysis requires a clearly defined set of criteria. Thus, multicriteria analysis requires the analyst to distill the candidate planning objectives and plan attributes down to a coherent set of criteria for use in plan selection and decision making. Roy (1985) defines a set of criteria as coherent if the following three properties are satisfied: (1) exhaustiveness, (2) consistency and (3) nonredundancy.

Exhaustiveness is satisfied when no important criterion has been forgotten. When discriminating among plans, the decision maker should not have to resort to any test, principle, rule, canon or standard that is not explicitly included among the criteria. Slightly more formally,

Planning Objectives and Criteria

The language of planning and decision theory is potentially very messy. Many different terms are used to mean the same thing. And many similar terms are used to mean different things. Our best advice is to understand the meaning of the language being used in your situation but do not get too hung up on precise definitions.

When we talk about criteria we suggest that criteria comprise planning objectives and other important attributes of the plans. In actual practice, objective attainment is reflected through criteria that measure the extent to which an objective has been achieved. So let us be clear in saying that the criteria are not literally the planning objectives but measures of their attainment.

Consider the hypothetical objective, "To create mottled duck habitat." In a Section 1135 study we might use a dichotomous classification criterion to evaluate plans and say, "yes a plan does create habitat" or "no it does not." A next step might be to create ordinal categories of response from decrease, small increase, moderate increase, to large increase to define a criterion. Or we could estimate the number of habitat units each plan would create or destroy as a criterion. In these measures we see an increasing level of quantitative content in a criterion created to measure planning objective achievement.

there can be no pairs of alternatives that are equally weighted according to all criteria if the criteria set is exhaustive. That means if two alternatives are equally weighted, then another criterion is needed to enable decision makers or analysts preparing the decision to discriminate between the tied alternatives.

A good set of criteria is consistent. This means if the decision maker is indifferent between Plan A and Plan B, and then Plan A is improved with respect to one criterion, and/or Plan B degrades with respect to one criterion then it must be true that Plan A is then preferred to Plan B. Otherwise the criteria are inconsistent with respect to the decision maker's preferences. If a set of criteria is exhaustive and consistent, then we call them non-redundant if removing any one single criterion, leads to the remaining criteria no longer being exhaustive or consistent.

If decisions are based on planning objectives[9] and other attributes, the decision criteria should be carefully formulated to express all the objectives and attributes considered in the actual decision. The quality of any decision and the quality of the multicriteria analysis depends on this. The actual choice of criteria will be proscriptive if policy dictates their use and descriptive if a single decision-making entity (e.g., the planning team or the District Engineer) identifies them, or they may be negotiated as dictated by the nature of the conflict.

Criteria are the basis for measuring the achievement of planning objectives and levels of important attributes. Effective criteria are:

- Directional—there is a clear preference for the direction in which they are to be driven, i.e., minimized, maximized or otherwise optimized
- Concise—providing the smallest number of measures that allows all significant impacts to be assessed
- Complete—covering all aspects of success so that no significant impact goes unmeasured
- Clear—defining how measurements are to be made whether in quantitative or qualitative terms

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[9] If they are not, there is something wrong with either the planning objectives or the practice of the planning process.

Rational decision makers generally satisfy consistency. If a decision maker is indifferent between two plans based on their mix of NED and NER contributions, and one is modified to increase its NED benefits, or the other is modified to degrade its NER benefits then the absolutely or relatively improved plan would be preferred. This is a reasonable expectation, but it is very difficult to prove in practice. Pragmatically, analysts must be on guard against situations that lead to inconsistencies in choice.

Redundancy is of particular importance in multicriteria analysis of Corps water resources studies. The risk with redundancy is that too much importance can be afforded to a criterion that appears in two or more closely similar forms. For example, suppose for simplicity we value flood damage and warm water fisheries equally. Now suppose our criteria are flood damage reductions, preservation of catfish habitat and preservation of bass habitat. Channel catfish and bass are both warm water fish. Including them both is redundant, and if all criteria are equally weighted it could result in overstating the importance of warm water fisheries. Combining the two criteria into a single warm water fisheries criterion can eliminate the redundancy.

Practical checks on the exhaustiveness and redundancy of a set of criteria are easy to investigate. Once your set of criteria is identified you can begin by checking for ties among alternatives.[10] If any plans are actual or virtual ties across all criteria then your criteria set does not enable sufficient discrimination among plans. Consequently, new and discriminating criteria are needed, or the plans should be revised. Thus, the iterative nature of the planning process is fully compatible with the iterative nature of this framework. Next it is important to see if the values of different and, especially, conflicting stakeholders are reflected in the criteria set. If they are not, the set may not be exhaustive.

Criteria are often correlated. Although there is no reason to expect criteria to be independent, they should not be redundant. For example, there can be many environmental objectives in a planning process, and there may be many environmental attributes. Including each one among your criteria may add nothing to your ability to discriminate among plans, identify trade-offs or resolve conflicts among values. Once your initial set of criteria is developed, try combining closely related criteria. Then try eliminating each criterion. If nothing of value is lost to the decision maker, the eliminated criterion is redundant for decision-making purposes.

It is important to note at this point that criteria can be measured in different ways. Anticipating the discussion that follows in the evaluation section, the "Criteria Measurements" text box provides a classification of criteria measurements.

When personal or societal values comprise a criterion, there is no effective, non-controversial way to measure it quantitatively. Thus, criteria like security and equity will most likely be qualitatively described. The Corps four planning criteria of completeness, efficiency, effectiveness and acceptability may be subjectively estimated. Other criteria may involve qualitative measures. For example, an alternative's compliance with a law may be a simple yes or no measurement.

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[10] We have previously stated that if a criterion has the same measurement for every alternative, it is of no use in choosing the best plan. The example given simply provides a context for defining exhaustiveness, and it should not be literally construed as a contradiction to the previous discussion.

There will be other criteria that in theory could be estimated quantitatively. Flood damage reductions, changes in habitat units, pH, temperature and so on are all criteria that can potentially be quantified. For purposes of this manual we assume that any criterion that can be quantified can be estimated empirically or subjectively. Any criterion that can be estimated quantitatively can also be estimated qualitatively.

Criteria Measurements

It is conceptually an arbitrary choice to separate the identification of criteria from their measurement. The two concepts are joined at the hip. However, the pragmatic accomplishment of the work of identification and measurement are functionally separated enough that we treat them here and again in the evaluation section.

Qualitative: Empirical–plan does comply with law

Qualitative: Subjective–plan is equitable

Quantitative: Ordinal: Empirical–big, bigger, biggest

Quantitative: Ordinal: Subjective–good, better, best

Quantitative: Cardinal: Empirical–expected annual benefits of $2,315,000

Quantitative: Cardinal: Subjective–about 5 acres, about 21 acres

COMPONENT 4: EVALUATION

The next component of the decision support model is the evaluation step. This is where measurements are made for each criterion. An estimated measurement is prepared for each criterion and for each alternative. The framework calls this estimation "evaluation", and the term is used differently from the way the Corps uses it in its planning process.

This criterion evaluation process routinely takes place in the planning process. Some of it is done during the data collection and definition of the without-project condition in step two of the planning process. The rest of this quantitative and qualitative measurement takes place in step four, the planning process's evaluation step where with project-condition impacts are estimated. In the Corps planning process the evaluation task is defined more broadly than it is used here and includes qualification of plans for further consideration, refinement or abandonment.

The criteria are first divided into qualitative and quantitative criteria. Generally, the latter are numerical, the former are not. That definition is extended here, and we use quantitative in the broadest numerical sense of conveying meaningful magnitudes. Thus, nominal expressions of magnitude such as "large" and "small" are considered quantitative here. The types of measurements or evaluations, in the decision theory jargon, can be further subdivided. This taxonomy, though somewhat arbitrary in construct, can be helpful when choosing the most appropriate multicriteria decision-making technique for a specific situation.

Qualitative data are divided into empirical and subjective categories. Empirical data are based on observation or experience. It can be empirically determined whether or not a construction schedule will interfere with the mating season of a wildlife species. It is also a matter of discernable fact whether there are threatened or endangered species in a project area. Observable and discernable facts that can be described qualitatively comprise this category of qualitative empirical evaluations and form one of the categories of criteria identified in the "Criteria Measurements' text box.

Not all qualitative impacts can be empirically determined. Some must be expressed in qualitative terms such as equitable or inequitable, acceptable or not acceptable, sustainable or unsustainable and so on.[11] Others are, by invention and intent subjective judgments. An example of a qualitative-subjective measurement of the first type might be the impact of a project on local air quality during construction. An example of the latter might be the extent to which a plan is effective or efficient.

Quantitative measurements are expressed numerically. The first natural division of the quantitative criteria is based on the quantitative content of the numbers used. Hence, quantitative criteria can be ordinal or cardinal. Ordinal data can be used to order or rank the alternatives for an individual criterion.[12] These ranks can be expressed in nominal terms, such as large, medium, small, or in numerical terms, such as first, second, third or one star, two stars, three stars. As

More on Qualitative and Nominal Data

Qualitative data may be dichotomous, such as yes/no, pass/fail, acceptable/unacceptable and so on. It may also be nominal with categories like ducks, geese, egrets and herons. Ordinal data may be presented as ordered categories such as low, medium, high or very poor, poor, average, good, very good. When data are presented in these fashions it is important to understand what the data mean.

A first point to consider is the theory of the value. Are we measuring a truly discrete phenomenon or are we using discrete levels for convenience when the phenomenon is actually continuous?

Another important point to consider is that we want the data to mean the same thing to all decision makers. There are two potential points of disagreement. First, decision makers may differ in the definition of the criterion itself. Community cohesion, sustainability, biodiversity, risk, adaptive management, physical environment and significant resources are but a few examples of potential criteria that lack clear universal definition and understanding. Second, even when there is common agreement on the definition of the criterion, there may be disagreement about the meaning of the measurement categories or levels. Even if we craft a common definition of water quality we might not agree on what is low, average or high quality. Likewise, “acceptable” and “unacceptable” may differ in meaning for different decision makers.

The solutions to these problems are well known but remain difficult to obtain. Careful communication is the solution. Criteria need to be carefully and explicitly defined. Each criterion should have a written definition that has been arrived at via discussion, negotiation and compromise.

Each measurement level or category for such a criterion should be carefully defined. If precise definition is not possible, a scenario should describe it. Thus, for example, low water quality should be described in terms of specific thresholds for things like dissolved oxygen levels, temperature and pH. Likewise the medium and high levels should be described so that everyone rating or using these criteria has a common understanding of their meaning. High acceptability of a plan cannot be objectively defined in such a way, but it still should be carefully described in words that have a common meaning to all.

It is vitally important to the stability of a decision that all decision makers have the same definition of the criteria and their measurements.

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[11] Subjective judgments that can be expressed as high, medium, low or negligible are covered in the discussion of quantitative data.

[12] Ordering can be understood to include classification where there is some order evident in the classifications. For example, good, average and poor is a classification with evident order. Because the classes have an implied order of preference, we consider this ordinal in the broadest sense.

used here, ordinal data also include interval data. Hence a classification of less than ten, ten to twenty, more than twenty would be considered ordinal data.

Ordinal data are distinguished from qualitative subjective rankings here by the assumption that they embody a magnitude order of some type. For example, noise disruption described as high, medium, low is quantitative ordinal while noise disruption described as noisy or not noisy is qualitative subjective. Knowledge of an ordinal ranking can be based on empirical experience. For example, the amount of noise during construction for different plans can be empirically ranked based on the experience of engineers and their knowledge of the numbers and types of equipment required for construction. On the other hand, the amount of noise disruption attributable to humans after the project is completed may be a matter of speculation. In this second instance the same high, medium, low rank has a different nature. If such distinctions give you a headache, you are normal, a qualitative subjective judgment on the author's part. Although the distinctions are often useful, correctly categorizing these types of measurements is less important than accurately estimating them.

Cardinal data are ratio scale data. Ratio data are measured in fixed units of measure such as real numbers, degrees, dollars and the like. They can be used for ranking, and the ratio of such measures is meaningful. A plan that ranks third in water quality impact is not necessarily three times worse than the plan that ranks first, because the ratio between these numbers is not meaningful. If one plan creates three habitat units and another creates one, the first creates three times as much habitat because these are cardinal numbers and the ratio of cardinal numbers is meaningful. Quantitative cardinal numbers can only be expressed numerically. There is no meaningful option to express these values nominally.

The third level of distinction for both the ordinal and cardinal measurements is the subjective and empirical distinction also made for qualitative data. Ordinal data can be empirical. An impact can be first, second, third, etc. because it has been measured, observed or calculated to be so. Or it may be a subjective first, second, or third because you believe it to be so but lack empirical evidence for your position.

Cardinal measurements can be the result of sophisticated analysis of extensive amounts of quantitative data. They can also be professional opinions or anything in between. Following a two-year investigation that includes rainfall records, topographic surveys, damage surveys, and hydrologic, hydraulic and economic analysis, one may estimate reductions in expected annual flood damages to be $2,350,000. That is a quantitative cardinal measurement based on empirical evidence. By contrast one may use his or her experience absent any data or analysis to estimate flood damage reductions to be $2,000,000. This is a quantitative cardinal measurement that relies on subjective information.

Some Examples

Quite apart from the taxonomy of criteria types, a number of different measurements appear repeatedly in planning studies. Measures of criteria can be orders of magnitude, which are classes or categories of impacts in which any member of the class is identical. Examples include better or worse, more or less, increase or decrease. Ordinal measures rank options from highest to lowest, best to worst and so on in a wide variety of ways. A scale can identify the best and worst and array the others between them. For example set the best = 100 (or 5 stars) and worst = 0 (or 1 star); all others stand in relation to these two subjectively measured quantitative values.

On a different note, because human cognition is limited, it becomes difficult to make meaningful comparisons with too many criteria. Some research has suggested that six or seven criteria are good numbers. This is enough to make meaningful distinctions without overloading the brain. Good visual information can extend the ideal set by a few criteria. No serious analysis can be performed with more than around twenty decision criteria (Pomerol and Barba-Romero 2000). Large numbers of criteria should be rearranged into smaller sets. This may be done by aggregating or grouping related criteria or by dividing the criteria into a hierarchical structure with no more than seven or so criteria at each level. Alternatively, one forces the choice between a quantum leap in analytical requirements into expert systems or a slide into a cognitive load so high that no meaningful or stable information can be expected from a decision maker. Once the criteria have been identified and measured, the decision process centers on the multicriteria procedure used to arrive at a decision. With a problem and alternative solutions identified, and criteria for evaluation and measurements of those criteria in hand, it is time to consider the decision matrix.

Scenarios

Criterion measurements are often nominal or ordinal in nature. Plan effects are often described as “No significant change,” or “High, medium, low,” or they are rated on an ordinal scale like 1 to 5. The decision process would be greatly aided if the analysts responsible for measuring the contributions of a plan on one of these scales would give a careful definition to the scenarios that are possible. This definition begins with a listing of the possible measurements.

If a nominal scale is used to describe aquatic habitat impacts, then the analysts should identify the potential categories by which an impact can be classified before measurement begins. For example, these might include no change, no significant change, an increase or a decrease. Defining these categories beforehand informs the analyst of the shades of gray allowed in his judgment. It will subsequently inform users of the decision matrix and the results of the multicriteria decision process.

The next step is to provide as precise and explicit a definition for each of these categories as possible. If the boundaries of these categories can be defined quantitatively, they should be. For example, we might define “too cool” as temperatures below 20 degrees Celsius, “too hot” may be above 26 degrees Celsius and “ideal” may be between 20 and 26 degrees.

When categories cannot be defined in quantitative terms, they should be described in empirical terms or by means of a list of examples or some other suitable definition. No study should present criterion measurements in words or in any kind of ordinal rank unless the body of the text has described what those ratings mean.

In the case study presented later, for example, the acceptability criterion is rated from a low of 1 to a high of 5. In the context of that study there was no way to know what a 4 represented or how it differed from a 3 or a 5. It is particularly important for criterion like this that are deemed important to the final decision to offer some description of the scenario that would warrant a rating of 1, 2, etc. If that is not done and the ratings are undefined, subjective opinions “the report should at least identified by whose opinions they are.

COMPONENT 5: DECISION MATRIX

This task usually has three distinct parts.[13] First, there is the construction of the matrix. Second, there is the pre-analysis of the matrix. Third, there is the normalization of the pre-analyzed decision matrix. The matrix described in this section is based on deterministic measures of plan effects.

The decision matrix summarizes the performance of each alternative for each criterion. By decision theory convention, the alternatives are listed in the rows and the criteria in the

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[13] The third part, normalization, though not required, is common to the more popular multicriteria decision-making techniques.

columns. Planning investigations have more often followed the opposite convention with plans in the columns and plan effects in the rows. The decision matrix is often called by other names including effects table, performance table, multicriteria tableaux, effects matrix and so on.

Construction of Matrix

The decision matrix is similar in construction to a planner's system of accounts, commonly used to summarize national economic development (NED), regional economic development (RED), environmental quality (EQ) and other social effects (OSE) of water resource plans. It differs in a significant respect, however. The system of accounts may include a wide variety of plan effects. Some of them may directly influence the decision, while others are for information purposes that may not weigh directly in the decision process.

The decision matrix, on the other hand, is distinguished by the fact that it includes only those criteria and all those criteria upon which the decision will be based. The decision matrix consists only of alternative plans from which the recommended plan will be picked. The values entered in the matrix express the performance of each plan relative to its criterion. The information in the decision matrix forms the basis for either the recommendation to the decision maker or the decision maker's selection of the recommended plan.

A simple, hypothetical example of a decision matrix is presented in Table 3.

There are four alternative plans. Three of the criteria are quantitative cardinal and empirical. One of them, aquatic habitat, is quantitative ordinal and subjective. Considering all of the analysis that has been done to arrive at these estimated criteria measurements and the formulation of these plans, the decision matrix summarizes the relevant information that will be used to make the final decision.

TABLE 3: DECISION MATRIX

	Net NED Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	$477,000	$15,663,000	Slight decrease	+45HUs
Plan 2	$196,000	$19,610,000	Modest increase	+40HUs
Plan 3	$260,000	$13,450,000	No change	+30HUs
Plan 4	$294,000	$17,403,000	Slight increase	+60HUs

Depending on the decision rules used, whether they are monocriterion rules or multicriteria methods, the decision matrix could be subjected to further transformation. For example, one method entails conversion of all the evaluation measurements to a numeric ordinal rank. How such a transformed decision matrix would look is shown in Table 4.[14] This and other transformations will be discussed in the next chapter.

Initial decision problems are not always well defined. The decision matrix often provides a viable way for structuring and presenting the problem to decision makers and stakeholders as well. When the criteria used are closely tied to the problems and opportunities through the use of

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[14] This transformation is not an example of normalization.

planning objectives, for example, this process is quite compatible with the Corps planning process.

TABLE 4: TRANSFORMED DECISION MATRIX

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	1	2	4	2
Plan 2	4	4	1	3
Plan 3	3	1	3	4
Plan 4	2	3	2	1

Pre-Analysis

Once the preliminary decision matrix is assembled, it should always be subjected to a simple, structured review before the analysis proceeds. We call this step the pre-analysis. The alternatives identified in the matrix have presumably survived the evaluation step of the planning process. This means they have been subjected to some sort of disjunctive or conjunctive process as described in the following chapter that has qualified them for consideration for selection. The next step in the pre-analysis is to eliminate any criterion that does not vary from one alternative to the next. These criteria, as important as they may be to qualifying a plan, serve no useful purpose in the decision matrix. They do not discriminate among plans and therefore are not essential to the choice of a recommended plan. Though they may need to be documented in the planning process to establish compliance with the National Environmental Policy Act or other laws, they do not belong in the decision matrix.

The final step in the pre-analysis is to eliminate alternatives from the matrix that are dominated by one or more other alternatives. If any one alternative dominates all others, there is no need to proceed with the decision process. The decision has been made, or it is time to go back and formulate more plans. In some cases a plan may dominate one or more but not all other plans. In these cases the dominated plan(s) should be eliminated from the decision matrix or reformulated to avoid domination. An example of this task is provided later in the manual.

Normalization

Many techniques work more handily when the criteria measurement data are transformed, i.e., “normalized,” to a zero to one scale and the weights applied to them also sum to one. The choice of scale of measurement is not a trivial one. In some multicriteria methods, such as the weighted sum, there is compensation among the various values obtained by a single alternative according to various criteria. That means a high score on one criterion might offset a low score on another criterion when the weighted criteria measurements are added. This is best done when all the criteria are measured on the same scale. That scale is most often a zero to one scale.

When using pencil and paper or spreadsheet techniques, it is almost always desirable to normalize your data for the final decision matrix. Software support tools enable the user to input data in a variety of forms but most of them perform some type of data transformation before proceeding to a synthesis of all the matrix data.

There are a variety of normalization routines. The goal is to take a series of measurements for a given criterion and convert it into a series of normalized values between zero and one. For simplicity, assume all criteria are maximized. For example, planners often maximize habitat units, net benefits and such. Negative impact criteria, i.e., those where larger values are less desirable, for example, costs, loss of habitat and such, can still be maximized.

One method for maximizing negative impacts is to change the sign of their measurement. Thus, 2 acres lost and 10 acres lost become -2 and -10 and by maximizing these we identify -2 acres, the larger of the two numbers, as the best. Alternatively, planners can sometimes maximize the reciprocal of a value that would ordinarily be minimized. For example, if costs are 10 and 25 for two plans, the reciprocals yield 0.1 and 0.04. If we choose the maximum reciprocal value we are obtaining the lowest cost alternative as desired.

For the normalization procedures that follow, we assume that all criteria measurements in the decision matrix are positive. Thus, positive values that we would ordinarily minimize (costs and habitat loss) are converted using the reciprocal. Negative values are converted to positive values and can be further converted by taking their reciprocal if necessary. Hence, it is always possible to prepare a decision matrix of all positive values. That is done in the examples that follow.

Suppose we begin with the decision matrix in Table 5. Three criteria are cardinal; one is ordinal.[15] Because we presume to maximize our values, the ordinal scale must be structured so that the highest values are preferred, otherwise they must be converted by one of the methods above. Three criteria measurements can be maximized directly, but we prefer to minimize costs.

TABLE 5: ORIGINAL DECISION MATRIX

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	$477,000	$15,663,000	1	+45HUs
Plan 2	$196,000	$19,610,000	4	+40HUs
Plan 3	$260,000	$13,450,000	2	+30HUs
Plan 4	$294,000	$17,403,000	3	+60HUs

The matrix is transformed to the form shown in Table 6 by taking the reciprocal of first costs and expressing it in scientific notation.

TABLE 6: DECISION MATRIX OF VALUES TO BE MAXIMIZED

	Net Benefits	Reciprocal of First Cost	Aquatic Habitat	Upland Habitat
Plan 1	$477,000	6.384E-08	1	45
Plan 2	$196,000	5.099E-08	4	40
Plan 3	$260,000	7.435E-08	2	30
Plan 4	$294,000	5.746E-08	3	60

Now we see Plan 3 has the highest value for first costs. Plan 3 also has the lowest first cost. Consequently, by maximizing all the criteria measurements we move toward the most preferred plan.

The first normalization technique is to calculate each criterion measurement as a percentage of the maximum value for that criterion. The matrix is shown in Table 7.

First, note that all values are expressed as numbers between zero and one. That will be true for all the techniques presented here. This is the most widely used technique, but not the only one. Scales from 1 to 10, 1 to 100 or others ranges can be used. This percentage of maximum technique respects cardinality and preserves proportionality. Note the values do not sum to one.

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[15] The careful reader will note this ordinal ranking is the opposite of the one in Table 2. That is because maximization has redefined the ordinal scale.

The values for each cell are obtained by identifying the maximum value in a column. Then each column value is divided by that maximum to obtain the normalized vector shown. For example, $477,000 is the maximum net benefit. The Plan 3 value is $260,000/ $477,000 or 0.5451.

TABLE 7: DECISION MATRIX NORMALIZED BY PERCENTAGE OF MAXIMUM

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	1.0000	0.8587	0.2500	0.7500
Plan 2	0.4109	0.6859	1.0000	0.6667
Plan 3	0.5451	1.0000	0.5000	0.5000
Plan 4	0.6164	0.7729	0.7500	1.0000

One weakness of this technique is that it does not cover the interval [0,1]. Another frequently used normalization technique is the percentage of range approach, which is designed to do just that. That matrix is presented in Table 8.

TABLE 8: DECISION MATRIX NORMALIZED BY PERCENTAGE OF RANGE

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	1.0000	0.5502	0.0000	0.5000
Plan 2	0.0000	0.0000	1.0000	0.3333
Plan 3	0.2278	1.0000	0.3333	0.0000
Plan 4	0.3488	0.2769	0.6667	1.0000

Notice that each criterion now has a zero value and a one value. This technique respects cardinality, but it does not preserve the proportionality of the original values. To derive these weights, you calculate the range for a criterion and then divide each criterion value less the minimum by its range. For example, the range in benefits is $477,000 - $196,000 = $281,000. Then ($260,000 - $196,000)/$281,000 = 0.2278. Other values were calculated similarly. Note that these values do not sum to one either.

A third normalization procedure that is frequently used, for example in the analytical hierarchy method, is presented in the matrix in Table 9. This is the percentage of total method. Adding all the criterion measurements then dividing each criterion value by this sum normalizes the values.

TABLE 9: DECISION MATRIX NORMALIZED BY PERCENTAGE OF TOTAL

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	0.3888	0.2588	0.1000	0.2571
Plan 2	0.1597	0.2067	0.4000	0.2286
Plan 3	0.2119	0.3014	0.2000	0.1714
Plan 4	0.2396	0.2330	0.3000	0.3429

The Plan 3 value for benefits is obtained by adding all the benefit measurements, $477,000 + $196,000 + $260,000 + $294,000 = $1,227,000, then dividing each measurement by this sum. Hence, Plan 3's benefit value is $260,000/$1,227,000 = 0.2119. This technique respects cardinality and preserves proportionality of the data. It is the only technique presented here where the normalized values are guaranteed to sum to one. For this reason, this technique is one of the most useful techniques for normalizing weights.

The final normalization technique presented here is the unit vector technique. Once again a denominator common to each measurement for that criterion divides the individual criterion measurement. In this case the denominator is the square root of the sum of the squares of all the individual criterion measurements. The values are presented in the matrix of Table 10.

Once again the values are arrayed between zero and one. This technique respects cardinality and preserves proportionality. The modulus of the normalized vector always equals one with this technique, whereas in the others it is a variable value. To obtain the value for Plan 3 benefits we take $\$260{,}000/(\$477{,}000^2 + \$196{,}000^2 + \$260{,}000^2 + \$294{,}000^2)^{.5} = 0.4012$.

TABLE 10: DECISION MATRIX NORMALIZED BY UNIT VECTOR

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Plan 1	0.7360	0.5127	0.1826	0.4992
Plan 2	0.3024	0.4095	0.7303	0.4438
Plan 3	0.4012	0.5971	0.3651	0.3328
Plan 4	0.4537	0.4614	0.5477	0.6656

These four techniques are variations of a single method. Ordinarily you will want to transform the decision matrix using one of these techniques. That is not essential, but it is common practice. There is a certain loss of transparency when criterion measurements are transformed from their natural units of measurement, but there is also a gain in simplicity of synthesis. The choice of normalization technique can make a difference in the answers you obtain from a multicriteria analysis. Whether and how much it will matter depends on the techniques used and the differences in the normalization results obtained.

Table 11 shows the different normalized values for net benefits. The choice of technique affects the values obtained. Decision support software packages often use one of these techniques or a related one.

TABLE 11: NORMALIZED VALUES FOR NET BENEFITS

	% of Maximum	% of Range	% of Total	Unit Vector
Plan 1	1.0000	1.0000	0.3888	0.7360
Plan 2	0.4109	0.0000	0.1597	0.3024
Plan 3	0.5451	0.2278	0.2119	0.4012
Plan 4	0.6164	0.3488	0.2396	0.4537

The choice of a normalization technique is a matter of some judgment. A first consideration is the nature of the measurements for a criterion. The example measurements range from lowest to highest. Sometimes one end of the scale represents the worst value and the other end represents the best value. Examples of this include costs or habitat units created. In these instances, zero and one measurements may be useful. But that is not the case for all criteria. First, the zero and one values may add no utility to the decision making. Second, not all variables can be defined by a worst to best scale. Some are simply better or worse. For example, some criteria, such as water temperature or pH, have a range, but the optimum may not be seen at either end of the scale. When that is the case, the techniques above can be modified by creating a new variable that is the absolute value of the optimum criterion value minus the actual criterion measurement. This resulting variable is then minimized, so it must be converted via the reciprocal before inclusion in the matrix.

Suppose a temperature of 23 degrees Celsius is the ideal value for a fish species, and we have measurements of 20, 22, 25 and 30. We convert these values to a new series using the formula above, $|23 - 20| = 3$, and so on, to obtain 3, 1, 2 and 7. Because small numbers are closer to the ideal temperature, we want to minimize these values, so they are further transformed by reciprocals to 0.33, 1, 0.5 and 0.14, and we can now maximize. This leads us to choose 1, which is 22 degrees and closest to the ideal.

Once the decision matrix has been completed and normalized, it is time to use it to help make a decision. The next crucial step in this process is to establish weights for the various criteria. Normalization addresses the desire to transfer the data for the analysis that follows. Proportionality-preserving techniques do not change the "weights" inherent in the natural metric of the criterion. Assigning weights to the criteria is often the most contentious task in multicriteria decision making because it is by definition the most subjective task. Weights are often normalized using the same techniques described for criteria measurement.

Math Alert

Because the verbal descriptions of the normalization techniques are not as precise as the mathematical definition, we offer the math here. Although this manual purposely minimizes its reliance on the more precise language of mathematics, an exception is made here to ensure that the reader understands the nature of these normalization techniques. Let a stand for the measurement of a criterion. Let a_i stand for the criterion measurement for plan i. We will use v_i to stand for the normalized value of a_i.

Percentage of Maximum

$$v_i = \frac{a_i}{\max a_i}$$

Percentage of Range

$$v_i = \frac{a_i - \min a_i}{\max a_i - \min a_i}$$

Percentage of Total

$$v_i = \frac{a_i}{\sum_i a_i}$$

Unit Vector

$$v_i = \frac{a_i}{\left(\sum_i a_i^2\right)^{1/2}}$$

COMPONENT 6: WEIGHTS

All criteria are not always going to be equally important. A decision maker may find one criterion more or less important than another. A weight is a measure of the relative importance of a criterion as judged by the decision maker. Assigning weights is really a technique for collecting data on human judgments about the relative value of a series of criteria. Analytical methods for establishing the relative importance of several criteria are often not feasible or desirable. In these cases we rely on subjectively expressed expert judgment.

Wait a minute, which normalization technique should I use?

Each of these techniques has its strengths and weaknesses. It is important to be aware of the different techniques. Pencil-and-paper or homemade spreadsheet models of multicriteria analysis are often appropriate and may be common for smaller-scale studies. If you are doing one of these analyses, the very best advice is to normalize using each method. Then do some sensitivity analysis using different sets of normalized values.

Pick the one you favor. If you want the scale to blanket the [0,1] interval, then use percentage of range. If you want the values to sum to one, then use percentage of total. If your quantitative background suggests the value of the unit vector, use it. Otherwise, if you have no basis for favoring one over the other, then use the percentage of maximum. It is the most commonly used technique. If you use commercial software the choice may have been made for you.

Weights, which may be ordinal or cardinal in nature, are used to define the relative importance of the decision matrix criteria. There is a subtle but important distinction that must be made at the outset because there are two relationships at play here, and each must be understood. First, we consider the set of criteria as a whole and use weights to establish the relative importance among these criteria. This is the most easily recognized function of weights.

In the example, it might mean the aquatic habitat impact is most important followed by first cost. These two may be trailed by the remaining criteria, which are equally important. The criteria may be given a complete ordinal ranking by assigning ordinal weights such as first aquatic habitat, second first cost, third upland habitat and fourth net benefits. Alternatively, the weights could be cardinalized as follows: aquatic habitat = 0.4, first cost = 0.3 and upland habitat = net benefits = 0.15, for a sum of weights equal to one. There could be a blend of the two notions. For example, suppose net benefits and upland habitat are equally important and that first cost is twice as important and aquatic habitat is three times as important as either of these. The specific manner in which weights are assigned for selected techniques is revisited in the examples of the next chapter.

Second, there is the relationship between the weights just assigned and the scales used to measure each criterion. The point here is that for some multicriteria decision analyses, the choice of measurement scale is important. To illustrate the point, consider a trivially simple example.

To begin, assign the following cardinal weights to the four criteria: aquatic habitat = 0.4, cost = 0.3 and upland habitat = net benefits = 0.15. The weights sum to 1. Because high cost is a negative impact, simply take the negative of these values. Using the values presented in Table 12, Plan 3 is "best" if we maximize the total score. However, if costs are entered to the nearest million (Table 13), Plan 1 is "best." None of the essential information is changed, only the scale of measurement was changed.

TABLE 12: WEIGHTED PRODUCT EXAMPLE

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat	Total	Rank
Plan 1	$477,000	-$15,663,000	1	+45HUs	-4627343	2
Plan 2	$196,000	-$19,610,000	4	+40HUs	-5853592	4
Plan 3	$260,000	-$13,450,000	2	+30HUs	-3995995	1
Plan 4	$294,000	-$17,403,000	3	+60HUs	-5176790	3
Weight	0.15	0.3	0.4	0.15		

TABLE 13: WEIGHTED PRODUCT EXAMPLE WITH CHANGED SCALE OF COSTS

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat	Total	Rank
Plan 1	$477,000	-$16	1	+45HUs	71552.35	1
Plan 2	$196,000	-$20	4	+40HUs	29401.6	4
Plan 3	$260,000	-$13	2	+30HUs	39001.4	3
Plan 4	$294,000	-$17	3	+60HUs	44105.1	2
Weight	0.15	0.3	0.4	0.15		

Changing the scale from dollars to millions of dollars changes the weighted products. It is possible to develop a set of weights for Table 13 that would allow the change from dollars to millions while preserving the ranking obtained in Table 12. There is no practical reason to do that, but the implied point is important to understand. When determining the weights to be used in the decision process one must consider not only the relative importance of the different criteria but also the units of measurements for those criteria. Weights and the metric and scale of criteria measurements interact in some multicriteria methods in unanticipated ways.

This unit-of-measurement issue will be more important with some multicriteria decision-making techniques than others. Research suggests decision makers fail to grasp this point

(Nitzsch and Weber 1993). Instead they tend to think that weights have an absolute meaning, and they rarely make any corrections to their weights when scales are changed. This results in a host of difficulties when using quantitative cardinal measurements. Scales and weights must be considered together.

That distinction in place, it is time to recall the argument of the preceding normalization section that suggests normalization of the decision matrix values to the zero/one scale. This eliminates the kinds of problems shown above. Nonetheless, there are many examples in the literature and in practice that use non-normalized criteria.

Even with normalized data there remain any number of issues associated with the determination of weights. Perhaps first among them is whose weights are to be used. That answer is closely tied to the previous discussion about who the decision maker is. Criteria weights are often estimated by the decision analyst or planning team because of the practical difficulties in obtaining the ultimate decision maker's input early in the planning process. Ideally, the decision maker determines the weights. If the planning team is preparing the planning investigation and report to support the ultimate decision maker, then as a practical matter the weights most often reflect the views of the planning team. In some cases that means the weights reflect the views of the team itself; in other cases the team may be motivated to reflect the views of stakeholders, senior management or the ultimate decision makers.

Analysts must be careful not to over-weight any one criterion. This is a fairly common problem because the criteria, be they based on planning objectives or attributes of the plans, are not independent. There is often a strong correlation among them. Consider for example the following attributes listed in a system of accounts table: sedimentation and erosion, water quality, air quality, noise conditions, aquatic habitat, riparian habitat, wetland habitat, upland habitat and endangered species.[16] To use these nine attributes and, say, a tenth one that addresses economic attributes of the plans would certainly tip the analysis toward environmental factors if all factors were assigned equal weights. That is fine when it is intentional and appropriate, i.e., helps the decision maker discriminate among the plans in a meaningful way. It is misleading when the preponderance of environmental criteria is unintentional and is not noticed.

Multicriteria analysis has an analytical component and a judgmental component. The judgmental component relies on subjective preferences held by the assumed decision maker. The analytical component comprises the extensive analyses undertaken in the planning studies that lead to the identification of alternatives and criteria as well as their detail, description and measurement.

Weighting the criteria is the major judgmental component of the multicriteria analysis. The principal task of the framework's weighting component is to develop a set of cardinal or ordinal values that indicate the relative importance of each criterion. These values are subsequently used in a ranking algorithm to determine the relative value of each alternative, given the criteria and their relative importance.

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[16] Alternatively, the first four attributes might be combined into something we might call "physical environment" and the last five might be called "biological environment".

The decision maker determines the weights in an ideal situation. Consequently, weighting techniques should be suited to the needs of the decision maker. Hajkowicz, McDonald, and Smith (2000) evaluated several weighting techniques used in natural resource management. They evaluated fixed point scoring, rating, ordinal ranking, a graphical method and paired comparison for ease of use and ability to help clarify the decision problem. They found that, in general, decision makers assign similar weight values to criteria when they use different methods. Minor changes in weights can, however, result in different rankings. To explore this potential in a decision problem, more than one weighting technique should be used.

When choosing a weighting method, the analyst must make trade-offs between thoroughness and detail of information against complexity and the amount of time taken to develop the weights. There is quite a range of sophistication and complexity in the methods available for determining weights. Readily understandable, simple, intuitively appealing techniques were generally favored by natural resource management decision makers. Allowing decision makers to explore the implications of their choice of weighting methods and scenarios is ideal. Computerized and interactive multicriteria methods have much to offer in this regard.

Fixed Point Scoring

This weighting method begins with a fixed number of points such as 100, 10 or any other number. The decision maker then distributes these points amongst the criteria. More points allocated to a criterion indicate greater importance. Percentages are sometimes used. Allocating weights that sum to one is another variation of this theme. The key is that the decision maker apportions the points directly.

Simplicity and transparency are advantages of this technique. It also has the advantage of forcing the decision maker to make trade-offs. The only way to give greater importance to one criterion in a fixed-point approach is to give less importance to another criterion. This advantage then is also the greatest weakness of the method. Decision makers may find making these trade-offs difficult. Nonetheless, this method may well be the most direct way to obtain information about the decision maker’s preferences.

Table 14 shows how the four criteria introduced in the example might be weighted using the fixed point scoring method. All are mathematically equivalent to the weights summing to one. Usually decimal weights or percentages are preferred. Nonetheless, the decision maker may be comfortable allocating points from 0 to 100 or some other scale. No matter how that is done, the weights can always be subsequently normalized to the [0,1] interval.

TABLE 14: FIXED POINT SCORING EXAMPLES

	Decimal	Points	Weight (%)
Net Benefits	0.15	15	15
First Cost	0.30	30	30
Aquatic Habitat	0.15	15	15
Upland Habitat	0.40	40	40
Total	1.00	100	100

Rating

The rating techniques allow the decision maker to place each criterion on a scale by assigning a number to each criterion. For example, movies are often rated on a scale of one to four stars. Rating systems use a common scale for each criterion and there is no limit on the number of points that can be assigned to a criterion other than the limit imposed by the choice of the scale. Scales of 1 to 100 and 1 to 10 are common. Likert scales are also used. Two examples of Likert scales are shown in Figure 4.

lowest level highest level
1 2 3 4 5 6 7 (circle one)

Most important Least important

1 2 3 4 5
|___|___|___|___|

Figure 4: Likert Scale Examples

The numbers in a Likert scale are used to indicate importance. The interval distance between values is implicitly identical with Likert scales. The choice of the number of integers used is somewhat arbitrary, as is the definition of the scale, e.g., lowest to highest, highest to lowest. Circumstances of the decision problem will usually dictate those choices, but some level of importance is likely to be most meaningful for addressing the weighting of criteria for multicriteria analysis. It is helpful to develop a consistent pattern in the use of any rating scale.

This method does not constrain the decision maker's responses. It is possible to change the weight of one criterion without affecting the weight of another. A fixed point scoring method forces the decision maker to make explicit trade-offs; the rating technique does not. This is the most important difference between these two methods.

Ordinal Ranking

Ordinal ranking requires the decision maker to rank the criteria in order from least important to most important. This is an easy task to handle conceptually. An issue of some concern with this technique is that it is often still necessary to derive cardinal weights from the ordinal ranking because some aggregation techniques require cardinal rankings.

Table 15 clearly illustrates the decision maker's ordinal preferences for these criteria. However, it is not yet clear how they might be combined with the criteria measurements in this form. One common approach is to transform the ordinal weights into cardinal weights. The naïve approach to this conversion is to scale the ordinal rankings to an [0,1] interval such that the new rankings sum to one. In the example, this would mean a rank with weights as shown in Table 16.

TABLE 15: ORDINAL RANKING

	Ordinal Ranking
Net Benefits	4
First Cost	2
Aquatic Habitat	3
Upland Habitat	1

Note that the ordinal ranking is first reversed in the "importance points" column to establish the desired relationship between rank order and weights. The points assigned to each rank are then summed and prorated in the last column. This is the simplest technique for developing cardinal weights from ordinal rankings. More mathematical techniques exist, such as the expected value method, but they are not easily summarized (see for example, Hajkowicz et al. 2000), so they are not presented here.

TABLE 16: NAÏVE APPROACH

	Ordinal Ranking	Importance Points	Cardinal Weights
Net Benefits	4	1	1/10
First Cost	2	3	3/10
Aquatic Habitat	3	2	2/10
Upland Habitat	1	4	4/10
Sum	10	10	1

Graphical Weighting

Graphical weighting techniques generally rely on presenting the decision maker with a visual scale for indicating preferences. One of the simplest techniques is to have the decision maker make a mark on a horizontal line, such as the one shown in Figure 5.

Figure 5: Graphical Weighting Example

The mark is then scaled against the total length of the line to obtain a cardinal weight. Many other visual techniques such as color wheels and interactive bar charts have been used.

Paired Comparisons

A paired comparisons technique requires the decision maker to consider each single criterion against every other criterion in pairs. The number of pairwise comparisons, p, of c criteria is given by:

$$p = \frac{c(c-1)}{2}$$

With four criteria there are six comparisons. With seven criteria there are 21 comparisons and with 20 criteria there are 190 comparisons. This supports the previous notion that the number of decision criteria needs to be limited. After a point, the task of making comparisons becomes overwhelming, inconsistent and ultimately of little use.

One of the most popular ways to make pairwise comparisons is the analytic hierarchy process. An application of it is presented below. The same four criteria presented in the example are used with roughly the same preference order among criteria.

Circle one	**Circle one**
Net benefits is (more, equally, **less**) important than cost by a factor of	2 3 **4** 5 6 7 8 9
Net benefits is (more, **equally**, less) important than aquatic habitat by a factor of	2 3 4 5 6 7 8 9
Net benefits is (more, equally, **less**) important than upland habitat by a factor of	2 3 4 5 6 7 **8** 9
Cost is (**more**, equally, less) important than aquatic habitat by a factor of	2 3 **4** 5 6 7 8 9
Cost is (more, equally, **less**) important than upland habitat by a factor of	2 **3** 4 5 6 7 8 9
Aquatic habitat is (more, equally, **less**) important than upland habitat by a factor of	2 3 4 5 6 7 **8** 9

The weights are derived from these judgments using eigne values according to a method proposed by Saaty (1987). A sample calculation is shown in Tables 17 and 18. The first table summarizes the results of the pairwise comparison in matrix form. The values are presented in the form of the ratio x/y where x is the weight of the row value and y is the weight of the column value in the comparison. For example, the value 1/3 in the second row means that first cost is less important than upland habitat by a factor of 3.

The ratios in Table 17 are calculated to obtain the values in Table 18. The "sum" column is a horizontal summation of the values for the four criteria. The value 0.333 in row two is simply the 1/3 from Table 17. The sum is 9.333 = 4 + 1 + 4 + 0.333. The total of the sums is 34.083, and this value is then prorated across the four individual sums to obtain the weight expressed as a percentage.

TABLE 17: RESPONSES IN MATRIX FORM

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat
Net Benefits	1/1	1/4	1/1	1/8
First Cost	4/1	1/1	4/1	1/3
Aquatic Habitat	1/1	1/4	1/1	1/8
Upland Habitat	8/1	3/1	8/1	1/1

TABLE 18: NORMALIZING TO PRODUCE WEIGHTS

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat	Sum	Weight (%)
Net Benefits	1	0.25	1	0.125	2.375	6.97
First Cost	4	1	4	0.333	9.333	27.38
Aquatic Habitat	1	0.25	1	0.125	2.375	6.97
Upland Habitat	8	3	8	1	20.000	58.68
Total					34.083	100.00

The mathematics of other techniques or even more complete examples can get more involved than is appropriate for this manual. There is a rich literature on the use of more sophisticated weighting techniques than those presented here. The references in this manual provide access to many of these techniques.

Normalization of Weights

The weights, however obtained, may be expressed in a variety of ways. There is some value in normalizing weights to the zero to one interval. This can most easily be done by dividing each weight by the sum of the weights. Normalizing to 100 percent as was done in the last example is mathematically equivalent. Preserving the proportionality of the weights is essential and cannot be violated.

Summary

The practical and theoretical issues associated with determining weights are often considered the Achilles heel of multicriteria analysis. The five techniques described here are representative of the most commonly used techniques but they are far from exhaustive. The previously mentioned Hajkowicz study measured techniques ease of use of use on a scale of 1 (hardest) to 7 (easiest) and found decision maker preferences as follows: ranking (mean score = 4.5), paired comparison (4.3), graphical (4.2), rating (4.0) and fixed point (2.8). In terms of the technique's ability to clarify preferences and the decision problem, the rank of the techniques was: ranking (3.8), rating (3.4 with less variance), paired comparison (3.4 with more variance), fixed point (3.0) and graphical (2.9). The lesson appears to be to keep it simple.

COMPONENT 7: SYNTHESIS

The Second Edition of the Oxford English Dictionary defines synthesis as: "the putting together of parts or elements so as to make up a complex whole; the combination of immaterial or abstract things, or of elements into an ideal or abstract whole." This is the step in the decision framework when the alternatives, the criteria, the weights and the decision matrix are combined to aid the decision maker. The sensitivity of those results is subjected to analysis and review. The differences in plans, i.e., the conflicts and trade-offs as well as their sensitivity to our assumptions, are made explicit in this step.

Opportunities to resolve conflicts cannot emerge unless and until the conflicts are recognized and understood. These opportunities may come in the form of additional iterations of the planning process. New plans may be formulated. Criteria may be added for better discrimination among plans; other criteria may be omitted. Values may be varied through the exploration of other weights. The opportunities for conflict resolution may be presented through formal conflict resolution techniques, and resolved through the finality of a political decision.

Synthesis Methods

In the framework presented in this manual, synthesis begins with the decision matrix. Most multicriteria methods of synthesis fall into one of two groups. Aggregation methods combine the criteria into a single criterion and produce a commensurable measure of an alternative's achievement. Outranking methods, on the other hand, use pairwise comparison to develop a ranking. Examples of each are found in the next chapter.

The synthesis combines all the decision framework efforts and prepares them for use in the final step of the decision support framework: decision making. The precise manner in which that is done is extremely varied and depends on the decision-making model employed. A principal purpose of the next three chapters is to describe some of these techniques, which range from simple ranking to summation of the products of value measurements and their weights to quite complex mathematical algorithms.

The synthesis step combines all the separate analyses and judgments and prioritizes the alternatives of the decision problem. Discussion is an important component of the synthesis step. Decision makers must have a clear understanding of the elements of the decision matrix. They must have a clear understanding of the alternatives, the criteria and their measurements. They must understand the nature of the weights and the value systems that enter the decision process. They need a rudimentary understanding of the algorithm used to synthesize the analysis. Most importantly, they need a clear understanding of the results of the synthesis.

The process does not stop there. It may begin to end there, but it does not end there. Sensitivity analysis must be part of any good decision-making technique. Because every complex decision is characterized by substantial uncertainty, it is essential that every significant decision consider the most important of those uncertainties.

This sensitivity analysis need not be protracted or complex. Identifying the elements of the decision matrix that are known with certainty and those that are not is a minimal level of sensitivity analysis. If the synthesis depends critically on any assumption(s), the impact of a range of reasonable alternative assumptions on the synthesis results should be considered. In some cases, the subjective nature of value systems or decision maker's weights will warrant explicit consideration in a sensitivity analysis. Some decision support software packages provide ample opportunity to explore the sensitivity of results to underlying assumptions. Three of these software packages are demonstrated in Chapter VIII.

Compromise is the third element of this step, synthesis and the discussion that embodies a sensitivity analysis being the other two. This compromise must explicitly involve the decision makers, and it is the key transitional activity that bridges the gap from synthesis to decision, the next and final step of this framework. If the discussion and sensitivity analysis show the results of the synthesis are particularly sensitive to a component of the decision matrix that is reasonably uncertain, it will be necessary to resolve the treatment of this situation. The resolution of this issue will presumably take place by some arbitration or consent based on mutual concessions. This may involve a blending of the alternative positions or the predominance of one position over another. There is no formulaic way to resolve these differences. There is no Deus ex machina in any of these techniques. They all aid decisions; they do not make decisions. The difficult tasks of thinking, making value judgments and compromising will remain, no matter how simple or complex the technique, no matter how slick and sophisticated the software. What is critically important is that discussion and compromise be explicit components of the synthesis step.

COMPONENT 8: DECISION

The simplest step of the process to describe is the hardest one to complete: making a decision based upon the information provided by the decision support system. Quite simply, it is time to make a decision.

If the decision support system has involved the decision maker directly, all the preceding steps through the synthesis will reflect the decision maker's views. The structure of the decision framework provides an opportunity to focus attention on the important objective and subjective elements of the decision. In this case, the results of the synthesis may be tantamount to a decision because they reflect the decision maker's views.

If the analysts have been executing the steps of this framework in preparation for the decision maker, the final step may be more complex. It could result in a new iteration of the larger planning process in which it is embodied. New alternatives, additional criteria and analysis, new synthesis and so on could be in order if the decision maker's views differ substantially from those of the analysts. Or it could result in either the decision maker confirming the judgments of the study team and analysts or rejecting their results and choosing an entirely different alternative based upon a decision process and model known only to the decision maker.

If there are multiple decision makers, the compromise element of the previous step may be protracted and difficult. In the more common case of a centralized and concentrated decision authority for a planning process with multiple and diverse stakeholder interests, it is more likely that the final decision will not be unanimously supported. There is nothing about multicriteria analysis or the planning process that promises or should even suggest unanimity in support for the final decision.

This framework offers better decisions, not perfect ones. Conflicts are identified but not always resolved. Trade-offs are illuminated but not universally supported. Decisions remain difficult with or without multicriteria analysis.

SUMMARY: TAKE AWAY POINTS

1. It helps to have a structured and systematic way to think about making complex decisions like the choice of a recommended plan.
2. There is a multicriteria decision-making framework that is not only consistent with but which also reinforces the Corps six-step planning process.
3. The framework comprises the following eight components: (1) Problem, (2) Alternatives, (3) Criteria, (4) Evaluation, (5) Weights, (6) Decision matrix, (7) Synthesis and (8) Decision.

LOOK FORWARD

Application of multicriteria decision-making techniques begins in the next chapter. We present a couple of simple techniques and apply them to a case study, which is used throughout the next three chapters. The chapter concludes with a pre-analysis of the case study that sets up the work in Chapters V and VI.

IV. SIMPLE DECISION RULES

Planning is decision making. And although the planning process culminates in the choice of a recommended plan, there are countless decisions that have to be made to get to that point. Some of the most important decisions made in the planning process are those that are made in the evaluation step.

Evaluation uses analytical results and judgment to decide which formulated plans make significant contributions to the planning objectives. Plans that do are qualified for consideration as the best plan. Plans that do not are eliminated from further consideration. Plans may be omitted altogether, or they may be reformulated to improve their contributions to the attainment of the planning objectives.

Evaluation is always multicriteria in nature. It is also preliminary in nature, and as such it does not get or perhaps warrant the kind of detailed attention the choice of a recommended plan will get. The decisions made are nonetheless important. The purpose of this chapter is to present a few simple decision rules that are used in multicriteria decision making. Decision rules may find their greatest value in making evaluation decisions, a point revisited in Chapter VII. These decision rules are not multicriteria decision-making techniques.

The techniques presented in this chapter are simple to understand and apply. They are well suited to noncontroversial decision problems. They also work best when the analyst is the de facto decision maker. Although these techniques can be used for any kinds of decision making, they may prove most useful for a project manager or a branch chief making the more routine kind of decision that will not be subjected to the same level of scrutiny to which the choice of the recommended plan will be subjected. These techniques may be well suited to Section 1135 studies and other studies done under severely limited budget or time constraints.

SIMPLE RULES FOR DECISION MAKING

The rules presented in this section are most applicable with routine, noncontroversial decisions for which it is not difficult to determine the relative importance of the decision criteria. A new heading identifies each decision aid. Following the heading is a description of the key information requirements associated with that technique. The first indication will be whether the technique requires a commensurable (or an exactly measurable unit with a common unit) or incommensurable metric. Some work with both. Next is an indication of whether the technique requires cardinal or ordinal data. Finally, there is an indication of whether the technique requires the decision maker to specify criteria preferences or not. Some techniques require the decision maker to explicitly identify a preference ordering. This can be done by assigning weights or providing a rank order. In other cases, the preferences are revealed more indirectly. For example, pairwise comparisons can be used to derive explicit weights of the criteria. Consequently we indicate whether the weights are needed and if so whether they are directly provided or indirectly provided.

OPTIMIZATION

Information requirements for optimization include:

- Commensurable Metric
- Cardinal or Ordinal Data
- Direct Weights

Optimization means to make something as perfect, effective or functional as possible. To optimize, we need a clear understanding of how perfection, effectiveness or functionality are defined. In practice, optimization usually involves making some value as large as possible (maximization) or as small as possible (minimization), or achieving a specific level of it (goal seeking, targets).

We need an “objective” and an “objective function” to optimize. The objective is to maximize or minimize or to attain a specific level of something. Once the objective function, i.e., the value or system we want to optimize, is known, there is a process by which the objective is attained. This might be a mathematical process, a negotiated process, a political process or one of any number of decision-making processes.

Optimization may be unconstrained or constrained. Simple examples of unconstrained behavior include politicians maximizing the votes they receive, businesses maximizing their profits, nations maximizing their share of an export market, homeowners minimizing their energy usage, dieters minimizing their calories and businesses minimizing their costs. Event organizers may strive to raise a specific amount of money, sports teams want to fill their stadiums, and so it goes. These are common examples of optimizing behaviors. Many decisions are based on optimizing behaviors.

Constrained optimization is quite common. Homeowners might minimize energy requirements subject to the constraints of remaining warm in the winter and cool in the summer. Consumers seek their happiness in the market place subject to the income they have and the prices they face.

In recent decades the decision criterion for much of the Corps Civil Works planning process could have been described as constrained optimization. *The Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (P&G) identifies the Federal objective of water resources planning as follows:

> The Federal objective of water and related land resources planning is to contribute to national economic development consistent with protecting the Nation’s environment, pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements.

The Corps optimizing behavior effectively became maximizing net national economic development (NED) benefits. But it was not an unfettered search for maximum net benefits. The search was constrained to that subset of plans that protected our human and natural environment. In practice that meant plans were formulated to achieve planning objectives while protecting our environment. In the vast majority of cases, the decision criterion was to choose from among a set of plans the one that had the largest excess of NED benefits over NED costs. Once a plan had complied with the relevant constraints, there was no need to consider anything else but the plan's NED impacts. The objective of the choice was easy: maximize net NED benefits. This remains a viable decision criterion for some planning situations.

The decision matrix for such a decision rule is quite simple. Although the plans may undergo a rigorous formulation and evaluation process, the decision is simple. The final decision matrix for an optimization rule contains the plans and their net NED benefits as shown in Table 19.

TABLE 19: OPTIMIZATION

	Net NED Benefits
Plan 1	$477,000
Plan 2	$196,000
Plan 3	$260,000
Plan 4	$294,000

Plans 1 through 4 all meet the relevant constraints.[17] Plan 1 optimizes the NED objective. The ultimate decision maker is absolved of any responsibility for making a decision. The decision is automatic. The real decision making takes place during the planning process as formulation and evaluation criteria are identified and applied. By the time we reach step six of the planning process, the decision has been made if a constrained optimization technique is used.

Although this decision technique may still be relevant for planning studies, it does not meet the needs of planners as it once did. Over time, the "constraints," as the term is used here, have grown more complex and become objectives themselves. Interest groups have taken a greater interest in some of these studies. Changes in cost sharing since the promulgation of the P&G have led to partnerships with people who have objectives different from the Federal objective. An evolving Civil Works program is stressing multiobjective planning. Together, these factors have resulted in a gradual but nearly complete break from the reliance on optimization techniques in planning decisions. Consequently, this technique is regarded as being of limited applicability for the current state of planning. Explicit trade-offs are not used in this technique.

DOMINATION PROCEDURES

Information requirements for domination procedures include:

- Commensurable or Incommensurable Metrics
- Cardinal or Ordinal Data
- No Weights

The first decision technique that should be applied to every planning decision is the domination procedure. Long before any more sophisticated techniques are attempted look at the decision matrix. If one plan is better at every criterion, choose it. It is the best plan. If the array

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[17] Constraint is used differently here than it is in the context of planning objectives and constraints. Here a constraint is more like a minimum level of acceptable achievement for all other formulation and evaluation criteria.

of plans from which it is selected results from a good planning process, there can be no ambiguity about which plan is best.

In Table 20,[18] where higher values are better, no plan performs better on any criterion that Plan 3 does. Plans 1 and 3 have identical scores for criterion 3, but Plan 3 is better than Plan 1 on every other criterion. Hence, Plan 3 is clearly the best plan.

TABLE 20: DOMINATION PROCEDURES

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Plan 1	5	5	8	2	6
Plan 2	9	4	7	4	6
Plan 3	10	6	8	9	7
Plan 4	6	2	4	7	2

Unfortunately, a dominant plan does not often exist. Even when there is not a dominant plan, however, there may be a plan that is dominated by another plan. Such dominated plans can be immediately and unambiguously omitted from the decision matrix. This should be done in the pre-analysis step mentioned in the last chapter and demonstrated in the next chapter.

This situation is illustrated in Table 21. This time Plan 3 does not dominate because Plan 2 performs better on criterion 5, and if this is more important than the other criteria, combined it could make Plan 2 the best plan. No other plan dominates in this situation either. Plan 4 is dominated by Plans 2 and 3. Notice that Plans 2 and 4 are tied for criterion 2, but Plan 4 is lower on every other criterion. Plan 4 is strictly dominated by Plan 3. Plan 4 outperforms Plan 1 on the first criterion and ties it on the fourth. So neither plan dominates the other. Nonetheless, it is sufficient to omit a plan from further consideration if it is dominated by at least one other plan. There would be no reason to choose Plan 4 when Plan 2, for example, is as good or better on every criterion. Thus, Plan 4 can be safely eliminated from consideration and the decision matrix.

TABLE 21: A DOMINATED PLAN

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Plan 1	6	5	8	4	6
Plan 2	9	2	7	7	7
Plan 3	10	6	8	9	6
Plan 4	7	2	4	4	2

If this procedure is to have any value for decision makers, it is essential that the criteria in the decision matrix consider all the relevant decision criteria. Once the decision matrix is final the rule is simple. If any one alternative dominates all others, choose it. If any alternative is dominated by any other, eliminate it. This procedure should always be the first procedure applied to decision making in planning. Explicit trade-offs are not used in this technique.

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[18] The simple decision rules that follow are illustrated with generic plans and criteria. The measurements of the plans for each criteria are such that larger values are more desirable than smaller values.

CONJUNCTIVE PROCEDURES

Information requirements for conjunctive procedures include:

- Incommensurable Metric
- Cardinal and Ordinal Data
- No Weights

Conjunctive procedures are best used for reducing a final array of plans to a smaller number of plans or, ultimately, to a single plan. But that is not their most common usage. Conjunctive procedures are mentioned here more for their usefulness in evaluating alternative plans in step four of the planning process. Conjunctive techniques could potentially be extended to the selection of a final plan.

Conjunctive procedures are intended to identify those alternatives that experience a confluence of qualities judged desirable by decision makers. Minimum standards are established for every criterion used in the screening process.[19] In the current example, that would be every criterion in the decision matrix. If an alternative meets the minimum standard for all criteria, it is acceptable: if it does not, it is unacceptable. Failure to meet the minimum standard on one criterion is not offset by exceeding the standard on another criterion.

For example, consider Table 22. No alternative dominates. None is dominated. Suppose for the moment there was a reasonable way to establish minimum standards for criteria 1 through 5 as 4, 3, 1, 0 and 5, respectively. Using our conjunctive procedures, we see every plan qualifies on criteria 1, 3 and 4. Plan 2 fails on criterion 2 and Plan 4 fails on criterion 5. Thus, this procedure helps to narrow the choice to Plan 1 or 3 but it does not lead to a choice in this example.

TABLE 22: CONJUNCTIVE PROCEDURES

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Plan 1	6	8	8	4	6
Plan 2	9	2	7	7	7
Plan 3	5	6	8	9	6
Plan 4	7	3	4	4	2

The obvious weakness of this technique is the method by which minimum standards are set. When objective standards exist, there is little problem.[20] Net NED benefits for an NED project must be nonnegative by policy. It may be unanimously agreed that a significant resource not be adversely affected in a given situation. A minimum amount of dissolved oxygen may be established scientifically if it is a life requisite for an indicator species of wildlife. But in other instances, the choices may be more difficult. If we are trying to create habitat, will there be a

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[19] Note that we say minimum standards for convenience. We could as easily speak of maximum standards. But the choice of language is arbitrary here. For example, a maximum number of razed houses is easily expressed as a minimum by taking the negative of the razed houses. If we say the number of razed houses cannot be less than -5 houses, this is equivalent to saying there cannot be more than 5 houses razed.

[20] Standards may be said to be objectively set when they are based on law or policy, science, fact, compelling data or evidence or if they enjoy the support of a significant majority of the publics.

minimum number of habitat units required for qualification? Is there a maximum number of houses that can be razed for a project?

The second weakness, is that the objectively set minimum performance standards may not lead to a single best choice. If more than one plan meets the conjunction of criteria standards, then the minimum standards must be raised and the process repeated until only one plan remains, or another process must be used to progress beyond this point.

This technique can be very effective as a screening tool used to qualify a set of plans for consideration as the best plan. It is not likely to be as useful in identifying the best plan in an unambiguous way unless the minimum standards can be objectively set at levels high enough to eliminate all but one alternative. Explicit trade-offs are not used in this technique.

DISJUNCTIVE PROCEDURES

Information requirements for disjunctive procedures include:

- Commensurable and Incommensurable Metric
- Cardinal and Ordinal Data
- No Weights

Disjunctive procedures can be used in situations similar to those suited to conjunctive procedures. They also may be better suited to the evaluation step of the planning process than the plan selection step.

An alternative plan qualifies for further consideration if it meets at least one preset standard or threshold. This differs significantly from the conjunctive approach in that the plan need not meet all standards. If it is good enough on the measure of one criterion, then it is good enough to qualify for further consideration in the planning process.

Suppose the performance thresholds for the criteria 1 to 5 are as follows: 6, 5, 7, 6 and 8 (for example, see Table 23). Plan 4 qualifies under criterion 1, but it fails to qualify under any other criterion. That is still sufficient for Plan 4 to be considered further. Plans 1 and 3 qualify under criterion 2. Although it is not necessary to consider another criterion, we note that Plan 1 would qualify under criterion 3 also. Plan 3 would qualify under no other criterion.

TABLE 23: DISJUNCTIVE PROCEDURES

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Plan 1	2	5	8	4	3
Plan 2	1	2	7	7	7
Plan 3	5	6	3	5	6
Plan 4	7	3	4	4	2

Plan 2 qualifies under criteria 3, 4 and 5, but it gets no additional consideration for doing so. A plan must qualify under only one criterion. Once it does, it qualifies as legitimately as any other plan.

Because these plans all qualify, we would need to set more discriminating thresholds or switch to another decision technique to further narrow the choice. This technique has its greatest value as a plan evaluation tool that is designed to avoid premature elimination of candidate plans from the final array. As long as a plan makes a significant contribution to at least one criterion, it is considered further. This technique will not produce a single best plan unless the performance thresholds become increasingly demanding or are initially set at a level high enough to eliminate all but one plan.

The weaknesses of this approach in the plan selection decision stage are the limited number of thresholds that can be set objectively and the failure of this technique to produce a single best plan in many instances. Explicit trade-offs are not used in this technique.

ELIMINATION BY ASPECTS

Commensurable and incommensurable metrics, cardinal and ordinal data, direct weights

Information requirements for elimination by aspects include:

- Commensurable and Incommensurable Metrics
- Cardinal and Ordinal Data
- Direct Weights

Elimination by aspects begins by identifying the most important criterion and then determining a cutoff value for that criterion (Tversky 1972). All alternatives with values below that cutoff are eliminated. The process proceeds to the most important remaining criterion and sets a cutoff value for it. The process continues in this vein until only one alternative remains. Alternatives with values below the cutoff are eliminated.

Suppose that we considered cost as the most important criterion. We might ask how many plans cost under $15 million, if that is the maximum the sponsor can afford. All those under $15 million proceed to the next aspect we will use to eliminate alternatives. The next question might be how many plans increase dissolved oxygen? Those that do not would be eliminated from consideration. And so the process continues to the next aspect of an implementable plan.

The aspects are the criteria in the decision matrix. They are chosen in an order that reflects the decision maker’s value system. The importance order of the criteria could involve one or more of the weighting techniques in Chapter III or any other method of establishing priorities. At its most basic, this technique requires a simple rank order for the criteria. We then pose questions about some particular aspect of a criterion. This is tantamount to establishing a threshold or minimum standard, as with the two preceding techniques. The technique works well when the priority rank of the criteria is reasonably clear and when the threshold level is reasonably obvious.

A variation of this technique is the satisficing strategy (Simon 1955). This technique considers one alternative at a time. Each criterion of the current alternative is compared to a threshold or cutoff, such as was expressed in the questions above. If a criterion measurement fails to meet the threshold or exceed the cutoff, the first alternative to pass all the cutoffs is selected.

As with the other techniques in this section, elimination by aspects requires both a sufficient number of criteria to winnow through the array of plans and a means of developing reasonable thresholds, cutoffs or standards. It also requires a priority ranking for the criteria. Explicit trade-offs are not part of this technique.

LEXICOGRAPHIC RULES

Information requirements for lexicographic rules include:

- Commensurable and Incommensurable Metrics
- Cardinal and Ordinal Data
- Direct Weights

This strategy begins by ranking the criteria.[21] It then ranks the alternatives according to the most important criterion. If the ranking produces a clear winner, the process ends here with a selection on the basis of one criterion only. If there is a tie for the first position, the process proceeds to the second most important criterion to break the tie. The tied plans are then ranked based on the second criterion. If no ties result, the process ends. Any remaining ties are broken by going to the third most important criterion, the fourth criterion and so on.

This technique is better suited to producing complete rankings of a set of alternatives than it is to identifying the best alternative from a set. As constituted, it is similar to the optimization technique presented earlier when it is used solely to identify the best plan. That is because it requires the decision maker to identify the most important criterion. It then tacitly requires the decision maker to agree to make a decision solely on that criterion if there are no ties on the performance of the alternatives for that criterion.

TABLE 24: LEXICOGRAPHIC RANKING

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Plan 1	2	5	8	4	3
Plan 2	1	2	7	7	7
Plan 3	2	6	3	5	6
Plan 4	7	3	4	4	2

Suppose we have the decision matrix presented in Table 24 and we have determined that the criteria are listed in order of their importance. That is, 1 is most important, 5 is least important. Using this technique we rank the plans according to criterion 1. Plan 4 scores highest on the most important criterion, and the process ends unceremoniously right here if this criteria is used to identify the best plan. All we have done is identified a single most important criterion and the plan with the highest criterion measurement for it. This ignores all the other information in the decision matrix. This is optimization.

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[21] A simple example of a lexicographic ordering, and the one that gives it its name, is entering words in a dictionary. Alphabetical order is a perfect example of a lexicographic ordering.

A complete application of the first round of the process would produce a rank of Plans 4, 1 and 3 tied for second, and plan 2 in last position. To break the tie we go to criterion 2 and see that Plan 3 ranks higher than 1. Consequently, the final ranking of plans is 4, 3, 2, 1 using lexicographic ranking. Note that if there were no ties for criterion 1, there would be no reason to consider any other criteria.

This technique is reasonable when it is reasonable to rank the criteria and say that the first criterion is more important than all the others. Then we're implying that the second criterion is more important than all those ranking below it, etc. It is a rare situation when that is true. But this technique could have utility to decision makers when the decision is routine, there is more or less a single objective, you are in a data-poor environment and you will implement more than one of your alternatives. For example, this technique could be useful if you are looking for operation and management solutions that principally are cheapest or toxins storage solutions that are most environmental friendly, and your measurements of the various criteria are subjective and nominal. This situation is likely to produce a number of ties, and the structure of the approach produces clear decisions based on the available information and the judgments made.

SUMMARY: TAKE AWAY POINTS

1. Some decision rules will be more useful in the evaluation step of the planning process than in the recommended plan selection step.

2. Most of the simple decision rules do not directly engage explicit trade-offs among the multiple criteria.

LOOK FORWARD

It would help to have a single, well-defined example decision problem if we're going to explore the strengths and weaknesses of the various multicriteria decision-making techniques. That case study is developed from an actual Corps planning report in the next chapter. It is subjected to a pre-analysis, and then the decision matrix that will be the basis for the analyses of Chapters VI and VIII is presented.

V. CASE STUDY

The need for trade-off analysis in Corps planning studies is real. The role for multicriteria decision-making models is real and growing. One of the principal goals of this manual is to provide realistic examples. Real examples require real data. It is the purpose of this chapter to present a case study that will form the basis for a decision matrix that will be utilized throughout the remainder of this manual.

The technical review panel for this manual recommended numerous Corps studies. Those studies and several others were examined for use in this manual. The hope was that different data sets and examples could be used for each example. The reality is that the Corps does not yet follow a very formal approach to multicriteria decision making, and none of the candidate studies was adequate for the purposes of this manual. But that discovery is of some value to Corps planners in and of itself. Consequently, this chapter begins with the presentation of an actual decision matrix from a Corps planning study.

That matrix is subjected to a pre-analysis for two reasons: first, to illustrate the method and value of a pre-analysis; second, to illustrate the need for a case study that is a hybrid of real and synthetic data.

Several Corps planning reports were made available for use in the development of this manual. The hope was that one or more of the reports could be used to develop decision matrices for use in this manual. These reports have been modified and used in this manual in the previous chapter as well as in this and subsequent chapters. An actual "ranking matrix" is presented in this chapter for the opportunity it provides for discussion of a number of issues raised earlier in this manual. Table 25, is from an ecosystem restoration project. The rating[22] defined low = 1 and high = 5. This was an undefined relative scale. However, a 1 is considered the minimum acceptable level of a criterion because an unacceptable plan would not survive into the final array. Sometimes a high is good, as for the first seven criteria. Sometimes a high is bad, as for the eighth and ninth criteria. Definitions of the criteria offered by the Corps planning team are in the "Case Study Criteria" text box. Once a matrix has been developed to this point, it is time to submit it to a pre-analysis.

PRE-ANALYSIS

Before a decision matrix is presented to the decision maker for a final decision, it should always be subjected to what we call a pre-analysis. A significant part of the pre-analysis is already routine in a good planning process. The evaluation step of the Corps planning process

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[22] The report calls the assignment of a value from one to five a ranking. The language is messy, and ranking is often used in this way. A plan is ranked on a scale. However, in the current context we are interested in producing an overall ranking of the plans, so we will call this measurement of the criterion a rating rather than a ranking. We do not prescribe any particular language here but do advise that it is always important to clarify the use of terms in any particular application.

TABLE 25: RANKING MATRIX FROM A CORPS STUDY

	Institutional Recognition	Public Recognition	Technical Recognition	Acceptability	Completeness	Effectiveness	Efficiency	Risk	Uncertainty	Acres Restored	Cost
No-Action	1	1	1	1	5	1	1	1	4	0	0
Plan 1	5	5	2	2	5	2	5	2	4	46	5.3
Plan 2	5	5	3	3	5	3	5	2	4	285.4	32.5
Plan 3	5	5	4	4	5	4	5	2	4	326.3	37.2
Plan 4	5	5	5	5	5	5	5	2	4	379.3	43.4
Plan 5	5	5	5	4	5	5	1	2	4	379.3	43.6
Plan 6	5	5	5	3	5	5	1	2	4	379.3	45.2
Plan 7	5	5	5	1	5	5	1	2	4	379.3	57.7
Plan 8	5	5	5	1	5	5	1	2	4	379.3	58.7
Plan 9	5	5	5	1	5	5	1	2	4	379.3	61.7
Plan 10	5	5	5	1	5	5	1	2	4	379.3	70.6

includes the screening of all candidate plans and measures to assure that each one of the plans in the final array would be a satisfactory solution to the problems and opportunities that motivate the planning process. Thus, the planning process assures that each plan has reached or exceeded some minimal level of satisfaction for each criterion.[23] If that is not true, a good planning process would have either rejected the plan or modified it to make it qualify for further consideration. The pre-analysis eliminates inferior plans and useless criteria.

The first part of the pre-analysis is to eliminate plans that failed to reach a satisfaction threshold for each criterion. If everyone knows a plan will not be recommended for implementation, the reasons for knowing that should be documented and the plan screened from the final array. You may think of the pre-analysis as a formal task in the evaluation or comparison steps to identify a final array of plans from which a selection will be made.

The second part of the pre-analysis is to eliminate all criteria that do not allow you to discriminate among and between plans. Then eliminate any plan that is dominated by another plan.

The ranking matrix of Table 25 would not be suitable as a decision matrix in its current form because several of the criteria listed failed to discriminate among the plans. These include institutional recognition, public recognition, completeness, risk and uncertainty. The ranking for each formulated plan is identical for each of these criteria. Take uncertainty for example. Every plan was ranked a four. This criterion offers decision makers no information to aid the decision-making process. It may be important to note that all plans have an above-average level of uncertainty. Indeed decision makers should know this, but it is not a useful criterion for a decision matrix.

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[23] Some criteria reflect negative impacts of plans. The notion of a satisfaction threshold does not fit so comfortably in this context. We nonetheless assume that the negative impact is not prima facie unacceptable or the plan would not have qualified for further consideration. So even negative impacts may be thought of as having a satisfaction threshold in the form of a maximum acceptable negative impact.

Case Study Criteria

The Corps report defines the criteria in the case study as follows.

Institutional Recognition. The importance of the environmental resources as evidenced by existing laws, plans and policy statements from international, national, regional, state, local and tribal entities.

Public Recognition. The importance of the environmental resource as evidenced by the general public's interest in, participation in and funding of resource-related groups and activities.

Technical Recognition. The importance of the environmental resource as evidenced by the scientific knowledge and understanding of critical characteristics of the resource, such as its scarcity, representativeness, status of disturbance, level of biodiversity, use for RTE animals and plants, etc. (current vs. future conditions).

Acceptability. Is the plan acceptable to Federal and state resource agencies and local government?

Completeness. Does the plan provide and account for all necessary investments and actions?

Effectiveness. Does the plan make a significant contribution to addressing the specified restoration problems or opportunities?

Efficiency. Does the plan represent a cost-effective means of addressing the restoration problems or opportunities?

Risk. What level of risk is associated with the desired restoration outcome?

Uncertainty. What level of uncertainty is associated with the estimation of ecological outputs (AAHUs)?

Several other criteria have one score for the no-action plan, also known as the without-project condition, and another score for all other plans. Because we are trying to discriminate among plans, these criteria offer no additional information. Yes, public recognition does change from a one, without a plan, to a five, with a plan, but the change is identical for every plan. The options in this instance are to omit the criteria from the decision matrix, measure the criteria with a finer scale that is capable of producing different measurements among the plans or reformulate some of the plans so they contribute differently to these criteria.

The ranking of each plan for each criterion is ordinal in nature for all but the last two criteria, which are cardinal measurements. A total ranking was obtained in the actual report by adding all of the ordinal ranks.[24] For the criteria institutional recognition through efficiency, higher rankings are good. For risk and uncertainty, higher rankings are bad. When they are added, the overall effect is ambiguous. So the usage of this matrix in actual practice was flawed.

The cost variable provides an opportunity to illustrate concerns raised previously about choice of criteria and their measurement scale. Costs are offered in millions. The difference between Plans 5 and 6 is 0.2. If the scale were thousands, it would be 200. Using a dollars scale the difference is 200,000. Depending on how the importance of various criteria is ranked and how the information is combined and synthesized, the differences in this one criterion could obliterate the differences in other criteria. For example, Plans 4 and 5 differ by 1 for acceptability. This is five times the cost difference measured in millions of dollars and 0.000005

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[24] These totals are not reproduced here because, as noted, they are problematic. However, it is a simple matter to reproduce them if desired. The total for the no-action plan was a 16. In this case, because the risk and uncertainty rankings are identical for all plans, the overall effect of this error is identical and cancels out. The ranking of the plans was consequently unaffected. That is just dumb luck, however, because there is a fundamental flaw with this approach.

the differences measured in dollars. Some of the criteria are imprecisely defined. For example, completeness is defined in the ranking matrix as follows: “Does the plan provide and account for all necessary investments and actions?” Although imprecise definition of some criteria may be unavoidable at times, it is in everyone’s best interest to define the criteria and their ranks as completely as possible.

Effects tables and ranking matrices examined for this manual raised similar concerns. Because this kind of ranking matrix represents good effort and is rather common among Corps planners, the matrix is modified and used to demonstrate the application of a number of techniques below.

There are several options for proceeding to develop a case study from these real data. One is to omit those criteria that do not discriminate among the alternatives and use the remaining real data for the examples. Another option would be to use the basic alternative and criteria definitions but to manufacture some synthetic data for the criteria to create a richer case study for the examples that follow. Because the original matrix quickly reduces to an almost trivial example, as indicated in the paragraphs that follow, the latter is used.

For now, however, pre-analysis of the ranking matrix continues. Details about the nature of the project are purposely not provided to provide anonymity for the project. The choice of criteria suggests that ecosystem restoration was an important purpose of the study measures. The decision matrix of Table 26 shows the original table (Table 25) without the criteria that fail to discriminate. All plans are identical on the basis of the eliminated criteria. The table can be further reduced by examining the matrix for dominant and dominated plans.

TABLE 26: REVISED DECISION MATRIX

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
No-Action	1	1	1	1	0	0
Plan 1	2	2	2	5	46	5.3
Plan 2	3	3	3	5	285.4	32.5
Plan 3	4	4	4	5	326.3	37.2
Plan 4	5	5	5	5	379.3	43.4
Plan 5	5	4	5	1	379.3	43.6
Plan 6	5	3	5	1	379.3	45.2
Plan 7	5	1	5	1	379.3	57.7
Plan 8	5	1	5	1	379.3	58.7
Plan 9	5	1	5	1	379.3	61.7
Plan 10	5	1	5	1	379.3	70.6

Plan 4 is as good or better than every other plan on all criteria except for Plans 3, 2 and 1, which are less costly and preferable to Plan 4 on the cost criterion. This is not a trivial result. There is no reason to pick any of Plans 5 through 10. None of them exceeds the performance of Plan 4 on technical recognition, effectiveness or acres restored. None performs as well on acceptability or efficiency, and each is more expensive.

When the nondiscriminatory criteria and the dominated plans are removed the original matrix is reduced to that in Table 27. Plan 4 is clearly as good as or better than any other plan for every criterion except cost. And so an important point can be made at this early juncture. Although there are a great many multicriteria decision-making methods available, several of which are quite sophisticated, many planning decisions can be clarified and simplified through the application of a few simple tools in a pre-analysis. Here we have required that a true decision criterion must enable the decision maker to make distinctions among plans, and we have applied the dominance guidelines. This has taken us from an initially intimidating 11 by 11 matrix to the 5 by 6 matrix of Table 27, where the real decision seems to be boiling down to how important cost is, because on every other criterion we have a clear winner, Plan 4. Before presenting the decision matrix used for the remainder of this manual, two of the simple techniques presented in Chapter IV are briefly revisited. The analysis that follows refers to the matrix as presented in Table 25. The next two examples assume the no-action plan is not a viable option.

TABLE 27: NONDOMINATED PLANS

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
No-Action	1	1	1	1	0	0
Plan 1	2	2	2	5	46	5.3
Plan 2	3	3	3	5	285.4	32.5
Plan 3	4	4	4	5	326.3	37.2
Plan 4	5	5	5	5	379.3	43.4

OPTIMIZATION

Optimization techniques, the quest for the best, would result in the identification of the plan with the desired optimum value for a single criterion or perhaps a more complex objective function. It would be unusual, but not impossible, to optimize based on the value of an ordinal criterion such as technical recognition or effectiveness. In this case, that would not result in a uniquely identified alternative. Maximizing the number of acres restored also fails to produce a unique first choice. Minimizing costs identifies Plan 1 if we use a constrained optimization. For example, choose the plan that minimizes cost subject to the condition that we take some action. Normalization of the decision matrix is not required for this decision technique. It does not appear that optimization will yield a clear choice in this example, but it is always wise to consider the possibility that it might.

LEXICOGRAPHIC ORDERING

Lexicographic ordering could be useful with a decision matrix like the one in Table 28. Suppose the primary purpose of this project is to restore habitat. That becomes the most important criterion, and it produces the plan rank shown in the column entitled "First Criterion" in Table 28. Six of the ten plans are tied for first place because six of them provide the same amount of restored acreage. Further suppose the decision maker has determined the following order or priority for the criteria: acres restored, acceptability, cost, effectiveness, efficiency and technical recognition. To break the tie we would choose the second most important criterion.

TABLE 28: LEXICOGRAPHIC RANK OF CASE STUDY

	First Criterion	First 2 Criteria	First 3 Criteria
No-Action	5	8	11
Plan 1	4	7	10
Plan 2	3	6	9
Plan 3	2	5	8
Plan 4	1	1	1
Plan 5	1	2	2
Plan 6	1	3	3
Plan 7	1	4	4
Plan 8	1	4	5
Plan 9	1	4	6
Plan 10	1	4	7

Using acceptability as the second most important criterion, we get the ranking shown in the next column of the table. We now have a clear "winner." Notice the second criterion only affects the rank of those plans that were tied after considering the first criterion. Four plans remain tied for fourth place. If we go to the third most important criterion, cost, we find we get a complete ranking of all the plans. There is no reason to go to any other criterion; our ranking is complete. Normalization is not required for this decision technique.

This technique does not require much information; it is ultra-simple and needs no calculations. The weights assigned to our criteria only need to be ordinal and to have an order, e.g., acres restored is first, acceptability is second, etc. This simplicity is the weakness of this method as well as its strength. If we change the order of the weights, say to make costs first, the order will change drastically. Nonetheless, there are occasions when a simple technique is adequate. Deciding the priority order of the criteria upon which a decision will be based can make many internal decisions. All other things equal, a simple decision process should be preferred to a complex one.

CASE STUDY DECISION MATRIX

TABLE 29: CASE STUDY DECISION MATRIX

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
No-Action	1	1	1	1	0	0
Plan 1	1	2	1	4	46	5.3
Plan 2	2	1	5	5	285.4	32.5
Plan 3	1	5	5	4	326.3	37.2
Plan 4	5	3	1	5	379.3	43.4
Plan 5	4	1	1	5	379.3	43.6
Plan 6	5	3	1	5	379.3	45.2
Plan 7	2	2	5	5	379.3	57.7
Plan 8	2	4	3	3	379.3	58.7
Plan 9	4	2	3	5	379.3	61.7
Plan 10	1	2	3	5	379.3	70.6

In an effort to strike a balance between reality and simplicity of exposition, the scaled down decision matrix of Table 29 will be used. The non-discriminating criteria are eliminated from the matrix of Table 25. More criteria do not substantially change the analysis; they only make it more complex without providing additional insight. The actual measurements for the remaining criteria produce a greatly simplified analysis, as shown when Table 26 reduces to Table 27. To make the example decision matrix richer and more interesting, we have randomly generated data and replaced some of the criteria measurements. The case study in subsequent chapters is based on the reality-based, hypothetical decision matrix of Table 29.

The decision matrix is a draft matrix until the pre-analysis has been completed. When the matrix is as complete as it is going to get, it's called the final decision matrix. It is the final decision matrix that is the take-off point for the two chapters that follow. The reader should underestimate neither the importance of this matrix nor the work that is entailed in obtaining it.

NORMALIZATION OF CASE STUDY

Using the percentage of maximum technique from Chapter III, the decision matrix of Table 28 was normalized and is presented in Table 30.

TABLE 30: PERCENTAGE OF MAXIMUM NORMALIZED CASE STUDY DECISION MATRIX

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
Plan 1	0.2000	0.4000	0.2000	0.8000	0.1213	1.0000
Plan 2	0.4000	0.2000	1.0000	1.0000	0.7524	0.1631
Plan 3	0.2000	1.0000	1.0000	0.8000	0.8603	0.1425
Plan 4	1.0000	0.6000	0.2000	1.0000	1.0000	0.1221
Plan 5	0.8000	0.2000	0.2000	1.0000	1.0000	0.1216
Plan 6	1.0000	0.6000	0.2000	1.0000	1.0000	0.1173
Plan 7	0.4000	0.4000	1.0000	1.0000	1.0000	0.0919
Plan 8	0.4000	0.8000	0.6000	0.6000	1.0000	0.0903
Plan 9	0.8000	0.4000	0.6000	1.0000	1.0000	0.0859
Plan 10	0.2000	0.4000	0.6000	1.0000	1.0000	0.0751

When Likert-scale measurements are used, as was the case here, one can make a good argument for using the percentage of range normalization. This forces the Likert scale into the [0,1] interval, which has a logical appeal. The case study is normalized using this technique in the matrix of Table 31.

TABLE 31: PERCENTAGE OF RANGE NORMALIZED CASE STUDY DECISION MATRIX

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
Plan 1	0.0000	0.2500	0.0000	0.5000	0.0000	0.0000
Plan 2	0.2500	0.0000	1.0000	1.0000	0.7183	0.4165
Plan 3	0.0000	1.0000	1.0000	0.5000	0.8410	0.4885
Plan 4	1.0000	0.5000	0.0000	1.0000	1.0000	0.5835
Plan 5	0.7500	0.0000	0.0000	1.0000	1.0000	0.5865
Plan 6	1.0000	0.5000	0.0000	1.0000	1.0000	0.6110
Plan 7	0.2500	0.2500	1.0000	1.0000	1.0000	0.8025
Plan 8	0.2500	0.7500	0.5000	0.0000	1.0000	0.8178
Plan 9	0.7500	0.2500	0.5000	1.0000	1.0000	0.8637
Plan 10	0.0000	0.2500	0.5000	1.0000	1.0000	1.0000

Comparison shows that the specific values for each matrix vary while each preserves the proportionality of the original data. Although there may be some value in contrasting the results of the techniques in Chapter VI using each of these matrices, the resulting redundancy would far outweigh the benefits obtained. The interested reader may feel free to use the matrix of Table 31 to replicate the analyses that follow. The examples in Chapter VI use the percentage of maximum normalization decision matrix found at Table 30.

SUMMARY: TAKE AWAY POINTS

1. A single, realistic case study will be a valuable aid to understanding and comparing the results of the different multicriteria decision-making techniques.

2. A pre-analysis of the decision matrix is essential, and it often simplifies the decision problem appreciably.

3. Pre-analysis includes the elimination of non-discriminating criterion and the elimination of dominated plans.

4. The case study for the remainder of this manual is based on an actual decision matrix, which has been simplified through a pre-analysis and made richer by changing some criteria measurements.

LOOK FORWARD

With a standardized case study, it is time to explore some of the more detailed multicriteria decision-making techniques. The next chapter includes examples of the basic techniques found in the literature. Many of them can be implemented with pencil and paper or analyst-built spreadsheet models, although the reader is sure to agree some would be easier to work with than others.

VI. POPULAR METHODS

This chapter begins with the presumption that the planning team has prepared a decision matrix, has normalized it as shown in Tables 29 and 30 and is now ready to proceed to the decision. The techniques presented in this chapter are all suitable for identifying a most preferred plan from among the alternatives in the final decision matrix. The popular techniques described in this chapter form the conceptual basis for the software techniques of the next chapter, although those techniques tend to be more complex and sophisticated. These techniques can be implemented with nothing more than pencil and paper or spreadsheet software, but the more sophisticated techniques are greatly enhanced by software developed for those applications. At times the decision matrix is simplified to aid the demonstration of a technique.

The chapter begins with some common weighting methods, a couple of which have already been seen in earlier chapters. These are followed by some ordinal ranking techniques. Additive utility methods are the third category of multicriteria techniques demonstrated in this chapter. The chapter concludes with a look at an outranking technique.

The discussions of these techniques are intended to be sufficient to enable the reader to understand and apply them. Each of these techniques has a rich literature attending it. There are also a large number of variations on each of these techniques. No attempt is made to be comprehensive in describing either the variations of the techniques or in enumerating their strengths and weaknesses.

WEIGHTING METHODS

Information requirements for weighting methods include:

- Commensurable and Incommensurable Metrics
- Cardinal and Ordinal Data
- Direct Weights

Weighting methods are the simplest to use and to describe. They are not always the most intuitive methods, however. The idea is simple. You generally multiply the criteria measurement by a weight and sum these products for each alternative. These methods can be used with commensurable and incommensurable metrics that are cardinal or ordinal. However, when incommensurable metrics are used or when cardinal and ordinal data are mixed, the resulting sum of products can be meaningless at best and misleading at worst. The best techniques are those that use a normalized decision matrix.

Examples of non-normalized and normalized weighted products are provided: the former because they have been used in the past by planners, and reproducing them here enables an examination of their weakness. The latter are provided because they represent a simple and reasonable way to make trade-offs commensurable.

NON-NORMALIZED WEIGHTED PRODUCTS

An example of a weighted product using incommensurable data was provided earlier in this manual to make a point about an issue encountered when determining weights. That example is repeated in this section. The case study will not be used to illustrate this method because, in general, the method is not recommended. It is presented here because it is used, and it ordinarily should not be used.

The information from Tables 12 and 13 are repeated in Tables 32 and 33 for the reader's convenience. A few conventions are repeated as well. The matrix has been structured so that each criterion is to be maximized. Consequently, costs that are to be minimized have been expressed as a negative number, which can be maximized. Clearly, it makes no sense to sum dollars, ordinal values and habitat units. The common sense response then is to do what makes sense. The totals for each table can be ordered from best (1) to worst (4), but the units for the numbers in these columns are meaningless.

TABLE 32: WEIGHTED PRODUCT EXAMPLE

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat	Total	Rank
Plan 1	$477,000	-$15,663,000	1	+45HUs	-4627343	2
Plan 2	$196,000	-$19,610,000	4	+40HUs	-5853592	4
Plan 3	$260,000	-$13,450,000	2	+30HUs	-3995995	1
Plan 4	$294,000	-$17,403,000	3	+60HUs	-5176790	3
Weight	0.15	0.3	0.4	0.15		

TABLE 33: WEIGHTED PRODUCT EXAMPLE WITH CHANGED SCALE OF COSTS

	Net Benefits	First Cost	Aquatic Habitat	Upland Habitat	Total	Rank
Plan 1	$477,000	-$16	1	+45HUs	71552.35	1
Plan 2	$196,000	-$20	4	+40HUs	29401.6	4
Plan 3	$260,000	-$13	2	+30HUs	39001.4	3
Plan 4	$294,000	-$17	3	+60HUs	44105.1	2
Weight	0.15	0.3	0.4	0.15		

The use of a weighted product with non-normalized data is less problematic when the criteria measurements are commensurable. For example, suppose for the moment that there were four criteria in the tables above that were all measurable in dollars. Were that the case, the values in the "total" columns would be dollar values weighted by the relative importance of their category.

Even when the data are commensurable, problems can remain. The scale of the measurements can be varied, and the rankings can change accordingly. But when the data are commensurable, the fix for this problem is easy if not immediately obvious. All values should be expressed to the same level of detail. With dollars, for example, every measurement should be in dollars. Or every measurement should be in thousands of dollars and so on.

To summarize, non-normalized incommensurable data should not be combined in a weighted product. This has been done in previous Corps studies and should not have been done. Non-normalized but commensurable data can, however, be combined in this way as long as the scale of measurement for the common metric is the same for each criterion.

Trade-offs get buried in the arithmetic of this approach and others that follow. Once the totals have been computed the nature of the trade-offs become invisible. That is precisely why the discussion and sensitivity analysis are so important to the decision framework.

NORMALIZED WEIGHTED PRODUCTS

The examples in Tables 32 and 33 relied on a non-normalized decision matrix for synthesis. The weighted product example presented in Table 34 uses the normalized decision matrix. Suppose the weights have been determined by the decision maker as shown in the second column of Table 34. The weights were subsequently normalized as shown in the table using the percentage of total technique to assure all weights sum to one.

TABLE 34: NORMALIZED WEIGHTS

	Weights	Normalized Weights
Technical Recognition	1	0.1
Acceptability	2	0.2
Effectiveness	1	0.1
Efficiency	1	0.1
Acres Restored	3	0.3
Cost	2	0.2
Sum	10	1

The normalized matrix is presented with weights and weighted products in Table 35. This synthesis uses the percentage of maximum normalized case study decision matrix of the last chapter (Table 30). The weighted product for Plan 1 is calculated as follows: (0.1 x 0.2) + (0.2 x 0.4) + (0.1 x 0.2) + (0.1 x 0.8) + (0.3 x 0.1213) + (0.2 x 0.1) = 0.4364. Other scores were calculated in a similar fashion.

The normalized matrix has the advantage of making non-commensurable metrics commensurable in their proportion and weights. Based on the criteria measurements and the weights assigned, Plan 3 ranks first and Plan 1 ranks last.

TABLE 35: WEIGHTED PRODUCT MATRIX–
PERCENTAGE OF MAXIMUM NORMALIZATION

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost	Weighted Product
Plan 1	0.2000	0.4000	0.2000	0.8000	0.1213	1.0000	0.4364
Plan 2	0.4000	0.2000	1.0000	1.0000	0.7524	0.1631	0.5383
Plan 3	0.2000	1.0000	1.0000	0.8000	0.8603	0.1425	0.6866
Plan 4	1.0000	0.6000	0.2000	1.0000	1.0000	0.1221	0.6644
Plan 5	0.8000	0.2000	0.2000	1.0000	1.0000	0.1216	0.5643
Plan 6	1.0000	0.6000	0.2000	1.0000	1.0000	0.1173	0.6635
Plan 7	0.4000	0.4000	1.0000	1.0000	1.0000	0.0919	0.6384
Plan 8	0.4000	0.8000	0.6000	0.6000	1.0000	0.0903	0.6381
Plan 9	0.8000	0.4000	0.6000	1.0000	1.0000	0.0859	0.6372
Plan 10	0.2000	0.4000	0.6000	1.0000	1.0000	0.0751	0.5750
Weights	0.1000	0.2000	0.1000	0.1000	0.3000	0.2000	

Sensitivity analysis is important at this stage because a different normalization technique or a different set of weights can produce a different ranking of the ten plans. When the rankings do not change, the result is robust. When the ranking changes, the differences must be resolved through a directed discussion of the critical weight assumptions or normalization technique.

The weighted product calculation was repeated using the normalized decision matrix of Table 30. The weights are unchanged, so all differences are due to the normalization technique. The results are shown below in Table 36. The rankings of the two products are summarized in Table 37. The differences are not very significant in this example, but there is a difference in the ranks of Plans 8 and 9.

TABLE 36: WEIGHTED PRODUCT MATRIX–PERCENTAGE OF RANGE

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost	Weighted Product
Plan 1	0.0000	0.2500	0.0000	0.5000	0.0000	1.0000	0.3000
Plan 2	0.2500	0.0000	1.0000	1.0000	0.7183	0.0951	0.4595
Plan 3	0.0000	1.0000	1.0000	0.5000	0.8410	0.0729	0.6169
Plan 4	1.0000	0.5000	0.0000	1.0000	1.0000	0.0509	0.6102
Plan 5	0.7500	0.0000	0.0000	1.0000	1.0000	0.0503	0.4851
Plan 6	1.0000	0.5000	0.0000	1.0000	1.0000	0.0456	0.6091
Plan 7	0.2500	0.2500	1.0000	1.0000	1.0000	0.0181	0.5786
Plan 8	0.2500	0.7500	0.5000	0.0000	1.0000	0.0165	0.5283
Plan 9	0.7500	0.2500	0.5000	1.0000	1.0000	0.0117	0.5773
Plan 10	0.0000	0.2500	0.5000	1.0000	1.0000	0.0000	0.5000
Weights	0.1000	0.2000	0.1000	0.1000	0.3000	0.2000	

TABLE 37: COMPARISON OF RANKINGS

	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan 9	Plan 10
Range Normalization	10	9	1	2	8	3	4	6	5	7
Maximum Normalization	10	9	1	2	8	3	4	5	6	7

The lessons from this comparison should be clear to planners who will use these techniques. Rankings can change with different techniques. The way you present the data can matter. The normalization technique can matter. Your choice of weights can matter. Both normalizations in the example result in the same best plan, and the differences are not significant. However, that is not a general conclusion.

This is why sensitivity analysis is always recommended. If you are using one of these simple techniques, try several of them to test the robustness of your result. If the same plan keeps coming up best under a variety of approaches, then you can confidently consider it the best plan. Most importantly, these results stress the point that the synthesis of the decision matrix and weight information produces only information, not a decision. Multicriteria decision models are tools. The decision maker still must take this information into consideration in making a final recommendation.

There is no one best way to produce a weighted product for all situations. Different techniques can and do produce different results at times. Decisions that rely on these simple weighting techniques inevitably face these issues. They are unavoidable.

EFFECTS MATRIX

Information requirements for an effects matrix include:

- Commensurable Metric, Cardinal or Ordinal Data
- Direct Weights

An adaptation of the simple ranking index from the *Planning Manual* is known in Corps jargon as the effects matrix. It is mentioned here because Corps planners have frequently used it in the past and because it is a simple weights and measures approach.

The identification of alternatives and criteria is assumed, as usual, to proceed from a good planning process. The effects of the plans, what we have called criteria measurements, are measured on a -10 to +10 scale. The measurement itself may be subjective or objective. This enables the planner to show positive or negative impacts as well as to gauge the magnitude of those impacts. These features obviate the need to maximize or minimize all criteria. A weight for each criterion or effect is also included on a 1 to 10 scale.[25] The effects are multiplied by their weights and summed. The largest resulting sum is the best plan.

The Remaining Step

Throughout this chapter there are numerous examples of how to get from a set of alternative plans to a best plan or the highest-ranking plan. That is not necessarily the same as getting to the recommended plan. The final decision may confirm the results of the multicriteria analysis, or it may go in another direction and select another plan. The main point is that the synthesis of the decision matrix information and the result of the multicriteria analysis are separate from the choice of the ultimate decision maker(s).

As noted earlier, if the decision matrix reflects the values of the decision maker and if the weights used reflect his or her preferences, there is likely to be agreement with the results of the process. It is, however, entirely possible that the final decision will be something other than the result of the multicriteria analysis. This provides the decision maker with the opportunity to explain the differences in criteria and weights used for his or her decision. Then the opportunity exists to amend the decision matrix, although it may be anticlimactic to do so at this point. Alternatively, the decision maker may decline to explain the reasons for the final selection, in which case planners can find refuge in the certain knowledge that political considerations external to the planning process have influenced the choice. This, too, is an entirely appropriate outcome.

The example in Table 38 is taken from the *Planning Manual* rather than from the current case study because this technique, though common in the past, is not considered on a par with the other techniques presented in this manual. The first value in each cell is the criterion

TABLE 38: EFFECTS MATRIX

	Increase Dissolved Oxygen	Improve Habitat	Maintain Minimum Flow	Restore Natural Salinity	Limit Human Disturbance	Score
Plan 1	+7/8	+2/9	-3/7	-1/2	0/5	51
Plan 2	+7/8	-2/9	0/7	-1/2	-4/5	16
Plan 3	-6/8	0/9	-1/7	+3/2	0/5	-43
Plan 4	+8/8	+3/9	+2/7	-2/2	-6/5	71

Source: Planning Manual

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[25] A zero weight would mean the criterion does not belong in the decision matrix, so zero weights are not used.

measurement, normally a subjective magnitude of the plan's impact for that criterion. The second value is the subjective weight[26] denoting the relative importance of the criterion. This method reveals Plan 4 with 71 points to be the highest ranked plan.

The effects matrix lends itself better to early stages of planning when analytical measurements of criteria are not available. The -10 to + 10 scale enables the decision maker to indicate the expected sign of the impact and its relative magnitude. Thus, we find this technique most appropriate for use in the early decision making stages of the planning process. There is greater uncertainty associated with the measurements of this technique than with others. Less uncertainty is preferred to more uncertainty in any decision-making context.

Spin-Offs

It is not difficult to imagine an endless string of permutations and combinations of the techniques presented in this chapter. In fact, the literature has no shortage of examples of combinations of different tools and techniques. To review or even mention a significant portion of them would keep this manual from ever reaching a conclusion. Consequently, the reader is offered two suggestions.

First, feel free to modify any of these techniques. There is nothing prescriptive about this manual. It does not say you must do this and can't do that. Innovate. Feel free to add instead of multiplying and multiply instead of adding, if it makes sense to do so. It makes sense to do so if you have a rational reason for doing so and if the technique and its results aid the decision process.

Second, make use of the bibliography. It provides an entrée to the literature for many different tastes.

RANKING INDEX

COMMENSURABLE METRIC, ORDINAL DATA, DIRECT WEIGHTS

Information requirements for a ranking index include:

- Commensurable Metric, Ordinal Data
- Direct Weights

There are any number of ranking index schemes. In fact the Corps analysis from which the case study was taken applied a variation of this technique. The basic elements of this technique are simple. The ranking index is intended to create a commensurable synthesized metric. That is, at the conclusion of the process, each plan is summarized by a single value, as with the weighted product techniques. With other techniques that value may be dollars or some other familiar unit; here it is simply an index. Usually the highest value of this index is considered the best choice.

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[26] Note the scale of the weights is arbitrary. In the preceding example, the least important criterion was given a weight of one, and every other criterion could be expressed relative to that least important criterion. Here weights are assigned on a 1 to 10 scale. The choice is largely arbitrary. Choose a method that is easy to use.

ORDINAL RANKING

The steps in the ordinal ranking are the same up to the creation of a decision matrix. In this technique, all the criteria measurements are converted to an ordinal scale using one of two common approaches shown in the "Ties in Ordinal Ranks" text box. The example in Table 39 uses the Kendall average.

The matrix in Table 39 can be synthesized in any number of ways. Equally weighted (tied) criteria can be added, or they can be combined via a weighted average. With the Kendall average, rankings are handled by giving the average of the rank it could have obtained if it had not been a tie. Thus, for criterion 1, Plans 4 and 6 tied for first with high scores of 5. The average of first and second places is 1.5, as shown in the text box. If there had been a clear third place, it would have been given a 3. The two plans tied for third, the potential third- and fourth-placed plans, were given a ranking of 3.5 each.

Ties in Ordinal Ranks

Suppose we have a situation in which we have the following matrix.

	Criterion 1	Criterion 2	Criterion 3
Plan 1	4	1	11
Plan 2	4	2	10
Plan 3	3	2	9
Plan 4	2	2	8
Plan 5	1	3	7

High values for criteria 1 and 3 are better; low values are preferred on criterion 2. We see ties in the first two criteria. If our goal is to develop ordinal ranks from these data, we have at least two options. The first is demonstrated below.

	Criterion 1	Criterion 2	Criterion 3
Plan 1	1	1	1
Plan 2	1	2	2
Plan 3	3	2	3
Plan 4	4	2	4
Plan 5	5	5	5

Find the most desired value (for criterion 1, the highest) and call it a 1. If there is more than one most desired value, call them each a 1. Then find the next most desired value and call it a 2 if there was only one alternative in the class preceding it. If there were multiple most desired values, count each one and give the next most desired value the next available absolute rank. In this case, Plan 3 has the second best score, but because two plans have the first best score Plan 3 takes the value 3.

Under criterion 2 there is one best score, but there are three second-best scores. Each plan is ranked 2. The remaining plan is not a 3 but a 5. The third criterion has no ties.

A second approach, rank averages, (Kendall 1970) is shown below.

	Criterion 1	Criterion 2	Criterion 3
Plan 1	1.5	1	1
Plan 2	1.5	3	2
Plan 3	3	3	3
Plan 4	4	3	4
Plan 5	5	5	5

Here ties are rated differently. The top two performing plans for criterion 1 are tied. If not tied, these would account for first and second place in the ranking. Hence, ((1+2)/2))=1.5, the rank for these first two. The next best rank is in the third position. For criterion 2, the first choice is unambiguous. The second position has a three-way tie. This would include positions two through 4, so we obtain the average rank as follows: ((2+3+4)/3))=3. The last position is clear.

TABLE 39: ORDINAL RANK DECISION MATRIX OF CASE STUDY USING KENDALL

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost
No-Action	9.5	10	9	11	11	1
Plan 1	9.5	6.5	9	8.5	10	2
Plan 2	6	10	2	4	9	3
Plan 3	9.5	1	2	8.5	8	4
Plan 4	1.5	3.5	9	4	4	5
Plan 5	3.5	10	9	4	4	6
Plan 6	1.5	3.5	9	4	4	7
Plan 7	6	6.5	2	4	4	8
Plan 8	6	2	5	10	4	9
Plan 9	3.5	6.5	5	4	4	10
Plan 10	9.5	6.5	5	4	4	11

BORDA’S SIMPLE METHOD

The simplest Borda[27] aggregation method has been around since 1781. It is used often and is widely used in sports. The basic notion is that if there are 11 (n) alternatives (10 plans plus the no-action plan) then the one that ranks first receives 11 (n) points. The eleventh-ranked alternative receives 1 (n - (n-1)) points. Ties are averaged in the Kendall fashion. This leads to the Borda coefficient matrix for the case study shown in Table 40. The progression to this matrix has been from raw scores, to the ordinal ranks of Table 39, to Borda coefficients. Once you are experienced with this technique, it is easy to jump directly to Borda coefficients.

The simplest approach is to add the Borda ranks, i.e., the points awarded based on ordinal rankings. Plan 4 ranks highest by this method. A complete ranking of alternatives is possible, although Plans 3 and 9 are tied. All criteria are considered equally important in this approach. The Borda method solves the ranking problem. It is purely ordinal method, so any cardinal data must first be converted to ordinal data, which involves the loss of some information. This simple Borda method, shown in Table 40, is an equally weighted criterion method of identifying a priority order of alternatives.

TABLE 40: BORDA COEFFICIENT DECISION MATRIX

	Technical Recognition	Acceptability	Effectiveness	Efficiency	Acres Restored	Cost	Score	Rank
No-Action	2.5	2	3	1	1	11	20.5	
Plan 1	2.5	5.5	3	3.5	2	10	26.5	10
Plan 2	6	2	10	8	3	9	38	6
Plan 3	2.5	11	10	3.5	4	8	39	4
Plan 4	10.5	8.5	3	8	8	7	45	1
Plan 5	8.5	2	3	8	8	6	35.5	8
Plan 6	10.5	8.5	3	8	8	5	43	2
Plan 7	6	5.5	10	8	8	4	41.5	3
Plan 8	6	10	7	2	8	3	36	7
Plan 9	8.5	5.5	7	8	8	2	39	4
Plan 10	2.5	5.5	7	8	8	1	32	9

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[27] French scientist Chevalier Jean-Charles Borda (1733-1799) proposed this method in a note in 1781.

UNEQUAL WEIGHTS

TABLE 41: UNEQUALLY WEIGHTED CRITERIA RANKING

	Recognition	Acceptability	Effectiveness	Efficiency	Restored	Cost	Score	Rank
No-Action	2.5	2	3	1	1	11	35.5	
Plan 1	2.5	5.5	3	3.5	2	10	46	10
Plan 2	6	2	10	8	3	9	55	8
Plan 3	2.5	11	10	3.5	4	8	66	4
Plan 4	10.5	8.5	3	8	8	7	76.5	1
Plan 5	8.5	2	3	8	8	6	59.5	7
Plan 6	10.5	8.5	3	8	8	5	72.5	2
Plan 7	6	5.5	10	8	8	4	67	3
Plan 8	6	10	7	2	8	3	65	5
Plan 9	8.5	5.5	7	8	8	2	62.5	6
Plan 10	2.5	5.5	7	8	8	1	54.5	9
Weight	1	2	1	1	3	2		

Suppose the criteria measurements in Table 40 are not all equally important. Further assume their relative weights have been determined by one of the approaches in Chapter III to be as follows. Technical recognition, effectiveness and efficiency are all equally important. Acres restored is three times more important than these and, cost and acceptability are twice as important. Thus, the weights for the columns in their order of presentation in Table 41 are 1, 2, 1, 1, 3 and 2. Multiplying each value in the criterion column by its criterion weight, we obtain the score and rank shown in Table 41.

Borda's simple method and the unequal weights method produce different rankings, but each leads to the same "winner." One powerful advantage of the unequal weights approach is that it can be used with any kind of criteria and data that can be expressed ordinally. It is a simple and transparent process that is easily replicated using the decision matrix and the decision maker's weights. A disadvantage is that converting cardinal data to ordinal data in essence throws away information. If that information is not essential to the decision, it makes no difference. At times the information

Enhanced Criteria-Based Ranking

The literature is full of alternative techniques for making multicriteria-based decisions. A handy technique has been described at length in "Risk and Uncertainty Analysis Procedures for the Evaluation of Environmental Outputs," IWR Report 97-R-7, August 1997, and is illustrated in pages 77-82 of that report. This enhanced criteria-based ranking adds a formal structure to a simple thought process. It can be applied interactively and quickly. The steps include:

1. Design criteria with ratings for a scenario.
2. Rate alternatives against criteria.
3. Compile all possible combinations of ratings by relative desirability.
4. Rank each alternative according to its relative desirability.
5. Evaluate reasonableness of rankings.
6. Add criteria if needed.
7. Compile new combined ratings.
8. Complete new ranking.

This technique coincidentally provides a good example of using scenarios to define criterion measurements.

might be important.[28] Another disadvantage, one common to most techniques, is that the result relies heavily on the subjective weights assigned to the criteria. If cost were considered ten times more important than anything else, to exaggerate the point, then Plan 1 would be the best option among the ten plans.

If the alternatives result from a good planning process, then we can be assured they are all satisfactory solutions to the underlying problems. If the identification of criteria results from an open discussion, the consideration of planning objectives and other attributes, then we can be assured these are the values upon which the decision will be based. If the analytical process that produces the measurements of the criteria is as scientific as possible, if it separates what we know from what we don't know, then the process is as science-based as is reasonable to expect.

We can tell stakeholders the criteria were all considered equally important or that one was three times as important as another. These judgments may not enjoy the unanimous support of all stakeholders, but the process of ranking the plans will be transparent. To learn more about the Borda method and similar ranking techniques like the Condorcet method and others, see chapter five of the excellent text by Pomerol and Barba-Romero 2000.

Multiple Attribute Utility Theory

Multiple attribute utility theory (MAUT) is based on a relatively simple idea. The fundamental axiom is that any decision maker is unconsciously or implicitly trying to maximize some function

$$U = U\,(g_1, g_2, \ldots, g_n)$$

where g_i, is the measure of attribute a_i that aggregates all the different points of view taken into account. If the decision maker is asked about her preferences, the answers will be coherent and consistent with that certain unknown function U. The key here is that more than one criterion affects the decision maker's utility. In a sense, the utility function is based on the criteria as a whole rather than on individual utilities. Having said that, convenient additive utility functions occur under certain assumptions. The analysts' role with these techniques is to try to discover the nature of that function, U, by asking the decision maker some well-chosen questions. This technique has been used widely in the United States and less so in Europe.

Two principal tasks emerge from this theory. One is to ascertain the properties that the decision maker's preferences must fulfill, so the properties can be reasonably represented by a function U with an analytical form, such as the additive, multiplicative, mixed and other forms. The other is to build such a function, identify its analytical form and estimate its parameters.

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[28] For example, in this current exercise, the no-action plan ranks first on the cost criterion at $0. In second place is Plan 1 at a cost of $5 million. There is then a jump of $27 million from second to third. If these increments matter, and with incremental cost analysis they may, this information is lost in the conversion to ordinal data. One solution would be to sharpen the choice of criterion, perhaps using an incremental cost measure, before converting to ordinal data. Another option is to employ a technique that works directly with cardinal values.

It is not possible to rigorously discuss MAUT in a manual like this. The subject is far too rich and requires more mathematics than is desired here. Consequently, those seeking additional information should see chapter four of Vincke (1992), chapter six of Pomerol and Barba-Romero (2000), Bunn (1984), or the seminal works of Fishburn (1970) and Keeney and Raiffa (1976). In fact it is not easy to find the right balance of detail in order to convey some understanding of this technique because it relies so heavily on a set of assumptions that can only be accurately expressed mathematically.

A simplification of the case study decision matrix is used in a somewhat detailed illustration of one specific MAUT technique. There are many other possibilities. It is not likely that many analysts will consider this a practical pencil and paper method. Consequently, the discussion here is to provide some introductory background to MAUT models for analysts who may at some point choose to use software developed for these approaches. PREFCALC was one of the first software packages developed for these techniques. UTA Plus[29] is a Windows application that uses an additive utility function similar to the example that will be illustrated.

To simplify the explanation of this MAUT technique, the original decision matrix has been simplified to a two-criteria problem as shown in Table 42. The technique is fully capable of being used with the complete set of criteria, but the example would quickly become intractable.

Although the use of mathematics will be minimized, it is not possible to proceed without describing the steps used in this example. These steps are demonstrated in the pages that follow.

TABLE 42: DECISION MATRIX FOR MAUT EXAMPLE

	Acres Restored	Cost
Plan 1	46	5.3
Plan 2	285.4	32.5
Plan 3	326.3	37.2
Plan 4	379.3	43.4
Plan 5	379.3	43.6
Plan 6	379.3	45.2
Plan 7	379.3	57.7
Plan 8	379.3	58.7
Plan 9	379.3	61.7
Plan 10	379.3	70.6

Step 1. Check whether criteria 1 and 2 are mutually utility independent (also known as coordinate-independence). If they are, go on to Step 2. If they are not, the multiattribute utility function technique must be used which is well beyond the scope of this manual.

Step 2. Check for additive independence. If mutual utility independence and additive independence hold, the utility function is a multilinear utility function.

Step 3. Assess $U_1(g_1)$ and $U_2(g_2)$.

Step 4. Determine the parameters, k_1, k_2, and whether there is additive independence, k_3, of the multilinear utility function.

Step 5. Check to see if the assessed utility function is consistent with the decision maker's preferences.

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[29] The Institute of Computing Science, Poznan University of Technology, Poland, developed this software. Information is available at: http://www.lamsade.dauphine.fr/english/software.html#uta+.

In this example, a_1 is the number of acres restored, and a_2 is cost of the project. The number of acres will be between 0 and 500, and the cost will be between \$0 and \$100 million. We begin by checking for mutual utility independence. It helps to think of the different levels of these two attributes as shown in Figure 6. This shows possible levels of each criterion, which are considered continuous. The points shown are only representative of the possible combinations of criteria.

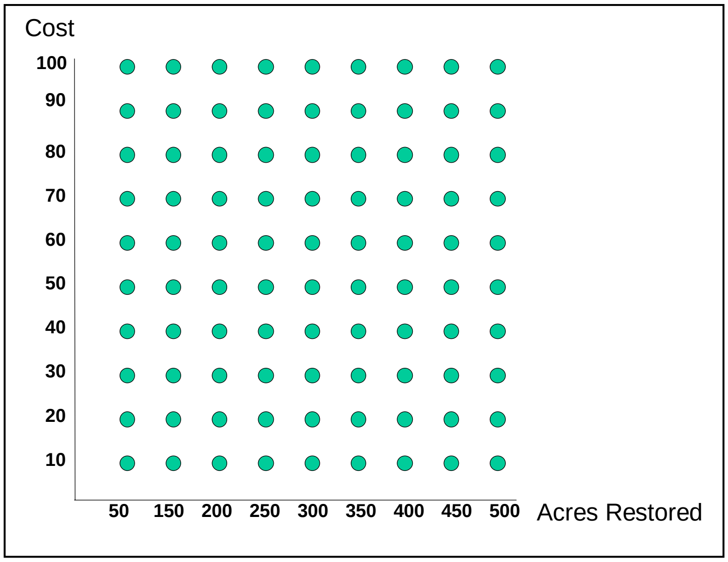

Figure 6: Possible Levels of Each Criterion

First, we want to know if acres restored is utility independent of cost. The decision maker is asked for the certainty equivalent of a 0.5 chance of the worst acres restored (0) and a 0.5 chance of the best acres restored (500), with a fixed and certain number of acres restored when cost is fixed at some level, say \$30 million.

Suppose the decision maker decides the certainty equivalent of this "lottery" is as follows: 0.5[0,30] + 0.5[500,30] = [185,30]. To explore this utility independence, we fix cost at some other level say \$55 million, and repeat the question. What level of acres restored with certainty is equivalent to 0.5[0,55] + 0.5[500,55]?

The decision maker's response should be close to [185, 55]. The process is repeated for other values, g_2, of cost. If the certainty equivalent of these repeated lotteries is close to [185, g_2], we assume acres restored is utility independent of cost.

The process is then repeated for cost and acres restored via a series of lotteries of the form 0.5[g_1, 0] + 0.5[g_1, 100] with various amounts of acres restored substituted for g_1. If the certainty equivalent cost value is close to constant for various levels of restored acres, then cost is utility independent of acres restored. If both pairs prove utility independent, then the criteria are mutually utility independent.

Step 2 is to check for additive independence. Additive independence holds if the decision maker is indifferent between 0.5[best value, best value] + 0.5[worst value, worst value] and 0.5[best value, worst value] + 0.5[worst value, best value]. For this example that means 0.5[500,0] + 0.5[0,100] = 0.5[500,100] + 0.5[0,0]. Granting that, in this example, that is a highly doubtful proposition, we proceed as if it is true in order to demonstrate the technique as simply as possible using our case study. This presumption of convenience allows us to write the utility function as follows:

$$U = U(g_1, g_2) = k_1\, U(g_1) + k_2\, U(g_2) + k_3\, U(g_1)U(g_2)$$

Additive independence renders $k_3 = 0$ and simplifies the example.

Step 3 requires us to assess $U_1(g_1)$ and $U_2(g_2)$. This is done by a separate process for assessing utility functions, of which there are a variety of methods (Vincke 1992, or more accessibly, Winston 1991). In brief, this method is based on ascertaining a series of certainty equivalents via lottery, as was done for the utility independence assessment: U(best value) = 1 and U(worst value) = 0. Costs are taken as a negative value so we can maximize utility.

The basic format is to ask the number of acres restored with certainty that makes the decision maker indifferent between 0.5[best value, g_2] + 0.5[worst value, g_2]. That is, we seek [value having utility = 0.5 on a (0,1) scale, g_2]. Then we seek [value having utility = 0.25 on a (0,1) scale, g_2], [value having utility = 0.75 on a (0,1) scale, g_2] and perhaps a few other intermediate values that enable us to establish utility functions as shown in Figures 7 and 8.

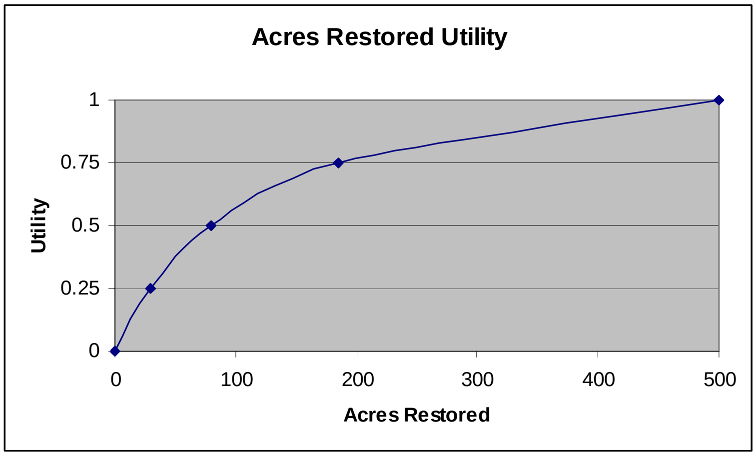

Figure 7: U (Acres Restored)

The points indicated on the curves indicate the minimum, maximum and quartiles for utility. These curves represent the decision maker's views of these two values.

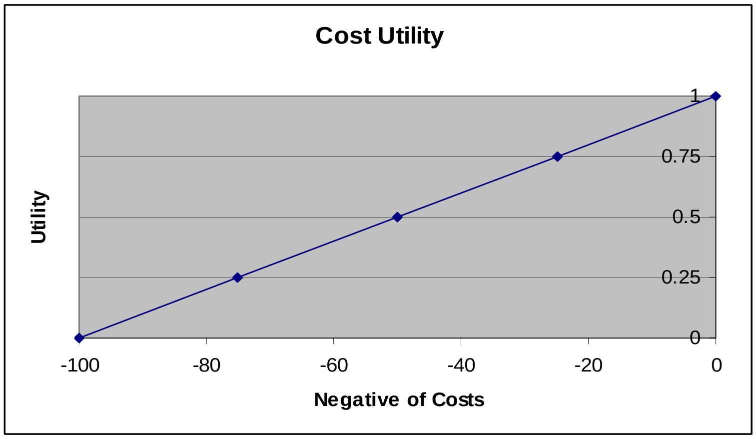

Figure 8: U (Cost)

To find the k values, we rescale the utility functions. To find k_1, we set U(best value of acres, worst value of costs) equal to k_1U(best value of acres, best value of costs) + (1 - k_1U(worst value of acres, worst value of costs). In numbers this becomes:

$$U(500,100) = k_1 U(500, 0) + (1 - k_1)U(0, 100)$$

Suppose the decision maker determines this value of $k_1 = 0.4$. That is if $k_1 = 0.4$, the decision maker is indifferent between the two choices above.

To find k_2 we set U(worst value of acres, best value of costs) equal to k_1U(best value of acres, best value of costs) + (1 - k_1U(worst value of acres, worst value of costs). In numbers this becomes:

$$U(0,0) = k_2 U(500, 0) + (1 - k_2)U(0, 100)$$

Because we have presumed additive independence for this example, $k_2 = 0.6$ because $k_1 + k_2 + k_3 = 1$. We have $k_3 = 0$, so $k_1 + k_2 = 1$ in this example.

Now take Plan 1 with acres = 46 and cost = 5.3. We determine that $U_1(46) = 0.33$ and $U_2(5.3) = 0.947$ by interpolating between the points of Figures 7 and 8. Plugging the values into the multilinear equation as it has been simplified by additive independence we obtain:

$$U(46,5.3) = 0.4(.33) + 0.6(.947) = 0.1638$$

This is the decision maker's derived utility function based on mutual utility independence and additive independence. The utilities of all ten plans are shown in Table 43.

Because the decision matrix was simplified drastically to reduce the example to its bare bones, the ranking shows Plan 2 is best, followed by Plans 3 and 4, with Plans 1 and 5 tied, then Plans 6 through 10 in order. These results should not be compared to any others because they're based on a very different decision matrix.

This technique works with more criteria, but the comparisons become far more complex. For example, with three criteria, the decision maker has to compare triplets instead of pairs of values as was the case in this example. This technique is greatly aided by the use of computer software.

TABLE 43: MAUT EXAMPLE

	Acres Restored	Cost	U(Acres)	U(Costs)	Total Utility
Plan 1	46	5.3	0.330	0.947	0.700
Plan 2	285.4	32.5	0.830	0.675	0.737
Plan 3	326.3	37.2	0.862	0.628	0.722
Plan 4	379.3	43.4	0.904	0.566	0.701
Plan 5	379.3	43.6	0.904	0.564	0.700
Plan 6	379.3	45.2	0.904	0.548	0.690
Plan 7	379.3	57.7	0.904	0.423	0.615
Plan 8	379.3	58.7	0.904	0.413	0.609
Plan 9	379.3	61.7	0.904	0.383	0.591
Plan 10	379.3	70.6	0.904	0.294	0.538

Multicriteria Analysis Schools

Aggregation methods have been used most often on the U.S. side of the Atlantic. Hence, optimization and weighted products and multiattribute utility theory are often associated with the "American school" of multicriteria analysis. The outranking techniques pioneered in the 1960s by Roy and others have come to be identified as the "European school" of multicriteria analysis.

OUTRANKING METHODS

Outranking methods are all based on pairwise comparisons. A pairwise comparison requires one to compare alternatives systematically, criterion by criterion. This is quite unlike the techniques described to this point in the manual. The methods differ according to the way they are formalized, but there are common elements to any outranking method. At the broadest level are the construction of an outranking relationship and the exploiting of that relationship to obtain a synthesis of the information gathered.

Given a set of nondominated alternatives (plans), when one alternative (Plan A) is at least as good as another alternative (Plan B) for a majority of the criteria, and there exists no criterion for which the first alternative (Plan A) is substantially less good than the second alternative (Plan B), we can safely say the first alternative (Plan A) outranks the second alternative (Plan B). An example is offered to demonstrate this process in general terms.

Consider the decision matrix in Table 44, where weights have been assigned to each criterion as shown. The table shows the upper corner of the case study decision matrix. The decision matrix is cut drastically in size to make it easier for the reader to follow the calculations. For this section, assume Table 44 presents the entire decision matrix. There are three criteria and three plans for a total of nine data entries exclusive of the weights.

TABLE 44: DECISION MATRIX WITH WEIGHTS

	Technical Recognition	Acceptability	Effectiveness
Weights=>	1	3	1.5
Plan 1	1	2	1
Plan 2	2	1	5
Plan 3	1	5	5
Plan 4	5	3	1

The first step is to complete a pairwise comparison of all the alternative plans. For each pair of plans (A,B), we compute a concordance index. The concordance index is calculated by adding the weights of all criteria for which alternative A scores at least as well as alternative B. These values are then entered into a concordance matrix as shown in Table 45.

TABLE 45: CONCORDANCE MATRIX

	Plan 1	Plan 2	Plan 3	Plan 4
Plan 1	x	3	1	1.5
Plan 2	2.5	x	2.5	1.5
Plan 3	5.5	4.5	x	4.5
Plan 4	5.5	5.5	1	x

To understand the table, let's look first at the comparison of plans 2 and 3, then Plans 3 and 2, using Table 45. Plan 2 is as good or better than Plan 3 on technical recognition (1) and effectiveness (1.5). The weights sum to 2.5, the value found in row "Plan 2" and column "Plan 3" of Table 45. Plan 3 is as good or better than Plan 2 on acceptability (3) and effectiveness (1.5), for a sum of weights of 4.5.

The concordance matrix presents what we might call a rough draft of our preference structure, i.e., the outranking relationship. But it is not yet complete. All the same, in our rough draft, Plan 3 is preferred to Plan 2 because the concordance index (3,2) = 4.5 is greater than the concordance index (2,3) = 2.5.

Now we conceptually introduce some constraints into our thinking. Suppose, for example, we consider acceptability a very important criterion. In fact, it is so important that we will never allow A to outrank B if A has an acceptability criterion value of 1 or 2 while B has an acceptability criterion of 5. This is true without regard to the values of the other criteria. This is how we might define a discordance set for each criterion.

TABLE 46: DISCORDANCE MATRIX

	Plan 1	Plan 2	Plan 3	Plan 4
Plan 1	x	1	1	1
Plan 2	0.25	x	1	0.75
Plan 3	0	0.25	x	1
Plan 4	0	1	1	x

Rather than create a specific discordance set for each criterion, although that is certainly possible and permissible, some outranking methods define a general discordance set. The ELECTRE method, from **El**imination **E**t **C**hoix **T**raduisant la **Re**alité, defines a discordance function that we will use (Pomerol and Barba-Romero 2000, p. 186). The math is rather tedious, and although we avoid the use of mathematical equations, some may want to skip this section. You can do so without any significant loss of continuity with the remainder of the manual. The discordance matrix is Table 46.

To derive the discordance matrix, we begin by calculating the range for each criterion in Table 44. Then we select the largest of these intracriterion differences. By coincidence each criterion has an intracriterion range of 4. This will not always be the case.[30] The next step is to calculate a discordance coefficient for each pair of plans. Let us take Plans 1 and 2. The first task is to see for how many criteria Plan 2 strictly dominates Plan 1. The answers, using Table 44, are technical recognition and effectiveness. We now calculate the difference between those two criteria measurements. They are 1 and 4, respectively. Now choose the larger of the two, which would be the 4, and divide it by the maximum intracriterion range. That would be 4/4 = 1, the value in row "Plan 1" and column "Plan 2" of Table 46.

In a similar fashion, each cell value is calculated. One can appreciate that the magnitude of this task grows rapidly as the numbers of criteria and plans increases.

The next step will seem like black magic and perhaps must remain so for now. It involves setting a concordance threshold. The concordance threshold is set so that A is preferred to B only if that threshold is equaled or exceeded. This allows us to further restrict the structure of the concordance matrix in Table 45. In essence, this step enables us to specify what constitutes a significant difference in plans.

Suppose we set the concordance threshold to 4. Then we still prefer Plan 3 to Plan 2 because the concordance index for (3,2) > (2,3) and the concordance index of 4.5 for (3,2) exceeds our threshold of 4. But we can no longer say that Plan 1 is preferred to Plan 2. Before the threshold, the concordance index (1,2) was 3 and the concordance index for (2,1) was 2.5. Thus, Plan 1 was preferred to Plan 2. But with our index we have effectively said that the concordance is not significant enough.

Likewise, we set a discordance threshold that we must equal or remain below. Let us suppose a discordance threshold of 0.5. We use these two thresholds to define a preference matrix as shown in Table 47. The ones indicate pairings that meet both thresholds. The zeros indicate pairings that fail to meet one or both of the thresholds. The matrix shows that Plan 4 is preferred to Plan 1, Plan 3 is preferred to Plan 1, and Plan 3 is preferred to Plan 2.

TABLE 47: PREFERENCE MATRIX

	Plan 1	Plan 2	Plan 3	Plan 4
Plan 1	X	0	0	0
Plan 2	0	0	0	0
Plan 3	1	1	x	0
Plan 4	1	0	0	x

A simple graphic, as shown in Figure 9, often aids the results of this analysis.[31] This figure of the outranking relationship shows that Plans 1 and 2 are outranked, even if they were not dominated by any one plan. Thus, there would be little reason based on this outranking procedure to choose Plans 1 or 2. If they are selected, then clearly it was on the basis of information not included in the decision matrix.

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[30] Note that all criteria measurements must be converted to a similar scale for most applications of outranking methods. That is done in a variety of ways and depends on the method one is using. As we are making a generic presentation, we do not define any particular technique here as our data do not require doing so.

[31] The reader should not be mislead by the simplicity of this figure to believe that all such graphics will be as simple or as clear.

Notice the outranking relationship does not produce a clear answer here. That is often the case. Outranking methods can sometimes be intransitive as well. This method does not produce a definitive reason for choosing either Plan 3 or 4. It does, however, point the decision maker in their direction. Plans 3 and 4 cannot be directly related to one another based on this procedure.

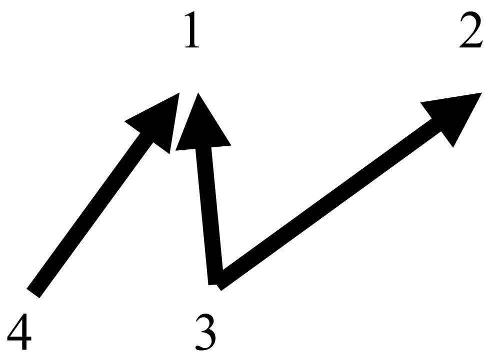

Figure 9: Graph of Outranking Relationship

The example was kept trivially simple so the process is easier to understand. More complex examples and real decisions invariably benefit from computer-aided outranking procedures, which are capable of doing far more than we have done here. For a more mathematical treatment of this approach, see the Pomerol and Barba-Romero (2000) text or any of the related references in the bibliography.

Additional use will be made of outranking procedures in one of the software applications in Chapter VIII. Outranking procedures are an important component of many decision support systems, and the overview to this technique is worthwhile background for the interested reader.

ANALYTICAL HIERARCHY PROCESS

It is impossible to provide a detailed description of the analytical hierarchy process in this manual. There is an extensive literature on the procedure. In general, the decision problem is represented as a hierarchy. At the top or vertex of the hierarchy is the main objective of the problem. In the current context, the objective would be to identify the best plan. The bottom vertices of the model would be the alternative plans. In between these two are the criteria upon which the identification will be based. A stylized hierarchy for the case study is shown in Figure 10.

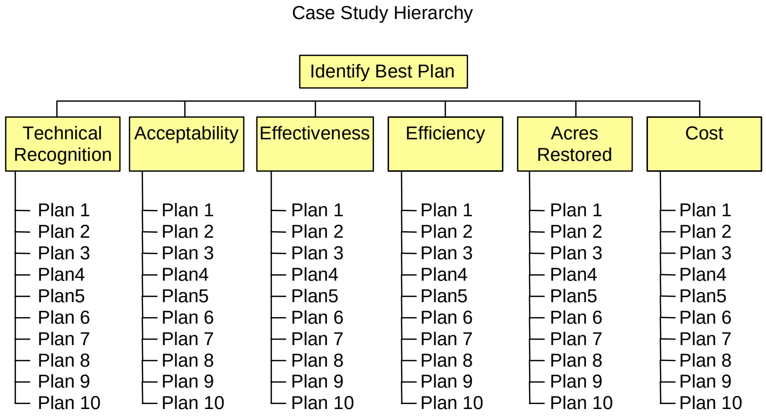

Figure 10: Hierarchical Model

At each level of the hierarchy, a pairwise comparison of the vertices is performed from the point of view of their contribution to each of the higher-level vertices to which they are linked. Thus, technical recognition is compared individually to each of the other criterion. The comparison goes basically like this: with respect to identifying the best plan, is technical recognition more important, equally important or less important than acceptability. The decision maker responds, and then technical recognition is compared to effectiveness, etc. Importance ratios are most often used for criteria. These are evaluated on a numerical scale that is built into the particular application. The comparison of criteria is complete when every possible pair of criteria has been considered. See the discussion of pairwise comparisons in Chapter III for an example of how this is done.

For each criterion, the plans are considered pairwise in a similar manner. Alternatives are often compared using data or preference ratios evaluated on a numerical scale within the method. Figure 10 shows how each plan is linked to the overall objective via each criterion. The mathematical technique based on the calculation of eigen values is similar to that shown in Chapter III. It is intended to produce a set of pairwise ratios that is closest to the decision maker's preferences. When each level of the hierarchy has been evaluated from the point of view of its contribution to the immediately higher level, the global contribution of each plan to the main objective is calculated by an aggregation of the weighted average type.

The calculation of the weights using eigenvectors has been demonstrated in Chapter III. A detailed example applying the analytical hierarchy process with commercial software is provided in the next chapter. Because it is unlikely that a Corps analyst will use this procedure without the assistance of commercial software, a detailed example is not provided here. The interested reader will find a carefully demonstrated example in Winston (1991).

SUMMARY: TAKE AWAY POINTS

1. Multicriteria methods do not yield objectively best solutions; such solutions do not exist.
2. Some seemingly intuitive methods for addressing trade-offs are flawed and may be harmful to the selection process.
3. Weighting, ranking and multiple attribute utility theory procedures are examples of aggregation techniques.
4. Weighting methods should use normalized decision matrices for noncommensurable criteria metrics. A raw data decision matrix is sufficient for commensurable criteria metrics.
5. Ranking indices are simple and useful techniques. They work well with ordinal data.
6. Extensive and sophisticated use of multiple-attribute utility theory has been made in decision-making applications and the literature.
7. Outranking techniques are based on pairwise comparisons.
8. The analytical hierarchy process is a popular technique based on pairwise comparison in a hierarchical model.

LOOK FORWARD

With some basic techniques for identifying the recommended plan in hand, it is timely to consider how these same techniques can be used in the evaluation step of the planning process. Although evaluation and comparison are ideally discrete steps, the real world of planners is rarely ideal. The next chapter considers the situation of an ecosystem restoration planning study in which the qualification of plans relies in whole or in part on cost effectiveness criteria. These qualifying criteria are often defined relative to other plans. Thus, evaluation and comparison can become intertwined. The techniques of the last few chapters are adapted for use in these situations in the next chapter.

VII. EVALUATION AND TRADE-OFFS

It is time to turn our attention to some practical planning situations that can profitably use some of the tools and techniques described in the previous chapters. The application in this chapter differs from that in the preceding chapters of selecting the recommended plan from among a set of alternatives. The decisions presented here are those that get you to the final set of alternatives. The distinction may be artificial, but it is a sharp distinction. Step four of the planning process is the evaluation step. Evaluation is described in the *Planning Manual* as essentially a qualification step.

Once a plan is formulated, the planning team looks at it to determine whether this specific plan, if implemented, would contribute enough to the planning objectives to solve the problems and achieve the opportunities sufficiently to deserve serious consideration as a viable solution. If it does, it qualifies for further consideration in the planning process. If it does not, then one of two things happens. If there is any way to modify this plan to make it qualify, the plan is reformulated. Otherwise, if the plan would not be an acceptable solution to the problems identified, the plan is eliminated from further consideration in the planning process. It fails to qualify for further consideration.

As the number of qualified plans grows to two and beyond, it becomes necessary to compare these plans to one another at some point. The qualification process means that any one of these plans would be an acceptable solution to the problems and opportunities faced. That is an important point to understand. To qualify for further consideration, each plan must be an acceptable and implementable alternative solution. The comparison process, step five in the planning process, considers all of the plans together in an effort to rank them from best to worst or to simply find the best of the lot.

In principle, these steps are distinct processes. In practice, they can blur together. This chapter examines this latter situation using an example that is believed to be reasonably representative of a recurring plan formulation situation encountered in ecosystem restoration projects and other projects that rely on cost effectiveness analysis and incremental cost analysis.

THE SITUATION

The *Planning Manual* suggests that planning begins with the identification of problems and opportunities. This is a clear statement of why planning is being done: to solve these problems and to realize these opportunities. Then planning objectives and constraints are identified. These articulate what must be done to solve the problems and realize the opportunities. The objectives and constraints define what successful plans must do. Plans are then formulated to achieve the objectives and to avoid violating the constraints. It makes sense, then, that the evaluation of plans be based at least in part on measuring a plan's contributions to the planning objectives. Then all qualifying plans would be compared, in part on the basis of their relative contributions to the planning objectives.

Planning objectives are not the only basis for qualifying plans. There are others. Economic efficiency, briefly defined here as taking only those actions in which the value of the outcomes exceeds the value of the resources used to realize those outcomes, is one of those criterion that always appears in one form or another. In traditional Civil Works projects, National Economic Development (NED) is a policy objective. In ecosystem restoration projects, a traditional NED analysis is not required because of the current theoretical controversies over the desirability and methods of estimating the values of ecosystem restoration outcomes. Reliable estimates of these project purpose benefits are not yet considered practical. Consequently, the inevitable economic criterion requires analysts to rely principally on the estimation of costs and the quantification of outcomes in non-monetary terms. The methods for doing this are called cost effectiveness analysis and incremental cost analysis (CEA/ICA) by Corps planners.

In order for a plan to qualify for further consideration, it must meet the somewhat subjective test of CEA/ICA qualification. This step is necessary regardless of a plan's contributions to planning objectives or other evaluation criteria. Because determining an acceptable incremental cost is a somewhat subjective process, it is often aided by comparison to the incremental costs of other plans. As a result, the qualification and comparison steps tend to bleed together at times.

The Institute for Water Resources has developed IWR Plan (http://www.pmcl.com/iwrplan/) as a decision support tool intended to aid CEA/ICA choices. This software currently supports analysis of plans that have one measure of environmental output and one measure of cost for each alternative plan. Corps planners are increasingly encountering situations in which multiple environmental outputs exist for each plan. It is to these situations that this chapter turns.

Consider the matrix of Table 48. It is a hypothetical example developed by Corps planners for this illustration. The discussion that follows relies on the three evaluation criteria presented in the table. Cost is one criterion and represents the cost of the project. Fish and ducks are arbitrary indications of different environmental values produced by a project. The numerical values are, likewise, purely arbitrary and simplified to aid the transparency of the discussion that follows.

TABLE 48: EVALUATION MATRIX

Plan	Cost	Fish	Ducks
A	100	10	5
B	100	5	10
C	150	10	10
D	150	10	15

The situation represented in Table 48 is expected to become more commonly encountered by Corps planners in the future. The context for this decision has been alluded to earlier. The first round of trade-off decisions usually occurs in the evaluation steps of the planning process. In this example, the trade-off is essentially between NED and National Ecosystem Restoration (NER), although it comes in the form of costs and environmental outputs. The specific focus of this example is on cost effectiveness trade-offs. Given the four plans A through D, which qualify for further consideration? And how can a planner trade off the different values in a reasonable way? The tools and techniques of the previous chapters will be used to demonstrate some ways to address this situation.

MAKING COST EFFECTIVENESS TRADE-OFFS

If there is a less costly way to achieve the same or more outputs, your action is not cost effective. The goal of this evaluation activity is to consider different methods that could be used, given the kinds of data in Table 48, to determine whether or not a plan is cost effective enough to be considered further in the planning process. In other words, which of the plans in Table 48 could be implemented?

An Important Caveat

The example presented in this chapter may not meet universal appeal as a realistic example. That is often the problem with reality; it is more complex than any simple example. The caveat here has to do with how qualification and comparison take place. The party line is that plans are evaluated on their own merits and that planning objectives should be part of that evaluation. If the plan under consideration would be a good and acceptable plan if implemented, it would qualify for further consideration. That means the plan is acceptable, efficient, effective and complete. That other plans may be more so is the point of the comparison step.

The example presented here differs somewhat in that it assumes that the efficiency and effectiveness criteria rely only on a comparison of the three criteria shown. Planning objectives are not used in this example. That is because there are situations where economics, as represented by project costs and environmental outputs, is a make-or-break criterion for a plan's efficiency and effectiveness. But when there are no explicit monetary measurements of project benefits, it can be argued that defining a plan's efficiency or effectiveness can only be done in a relative fashion.

If a more thorough consideration of all the plans' effects was warranted, the example here would have to be expanded to include explicit consideration of planning objectives before a plan is eliminated from further consideration.

SIMPLE DECISION RULES

We begin by considering ways the plans of Table 48 might be considered on their own merits using the simple rules for decision making of Chapter IV. The examples that follow are each independent of one another. Arbitrary values are chosen to illustrate the application of the technique. No effort is made to assure that the techniques all lead to the same choice or that the required judgments are consistent with those made for other examples.

OPTIMIZATION

The most obvious optimization rule to apply to costs is cost minimization, but this does not take us far. Plans A and B minimize the costs, but they also offer less output. Maximizing the output is another option, but which output should be maximized when there are two of them? Aggregating the outputs receives a good deal of attention later in this chapter, so that discussion can be delayed until then. As it turns out, Plan D would maximize outputs. No plan produces more fish than Plan D, and none produces as many ducks. But these outputs come at a higher cost than other plans' outputs. The question is, are the outputs worth the extra costs? For example, Plan A has as much fish output as Plan D for $50 less. The question then becomes is it cost effective to pay $50 for 10 more units of ducks? That is but one of the trade-offs we could consider. Plan D could be compared to Plan B just as easily.

In general, optimization rules do not serve the qualification task of the evaluation step very well. Optimization implies a choice from among alternatives, and that is almost by definition antithetical to the notion of evaluation used here.

DOMINATION PROCEDURES

Like optimization, domination procedures require more than one alternative to have meaning. Thus, this procedure is only used in the twilit "real world" where evaluation and comparison have become intertwined. That said, if the set of criteria for this mixed breed of planning steps is complete, then it is always appropriate to use domination procedures. Whenever one plan dominates all others, it is safe to omit all others from further consideration. In a similar fashion, whenever one plan is dominated by another plan, it is safe to eliminate the dominated plan.

Table 48 presents an interesting situation. Consider each plan in a pairwise fashion: A–B, A–C, A–D, B–C, B–D and C–D. Plans A and B cost the same, but A does more for fish but less for ducks than B, so neither dominates. Plan A costs less than Plan C, but does less for ducks. Plan A costs less than Plan D, and again does less for ducks. So A neither dominates nor is dominated by any other plan.

Plan B costs less than Plan C, but does less for fish. Neither dominates. Plan B costs less than Plan D, but does less for fish and less for ducks. So Plan B neither dominates nor is dominated by another plan.

Plans B and C cost the same. They also do the same for fish. But Plan D does more for ducks than Plan C. Thus, Plan C is dominated by Plan D. As long as Plan D is an available choice, there is no reason to ever choose Plan C. Consequently, Plan C may be omitted from further consideration. Incidentally, Plan C was not dominated by the other plans; it is not necessary that a plan be dominated by all plans to eliminate it. Textbooks are rife with examples of intransitive preferences and other anomalies that can wreak havoc with domination rules, but because these situations seldom arise in a planning context, we do no more than say there are some situations where dominance procedures may not be appropriate.

CONJUNCTIVE PROCEDURES

In contrast to the first two simple decision rules, conjunctive procedures may be quite useful in evaluating plans like those shown in Table 48. With these procedures, minimum standards are set for each criterion. If the minimum standard is met for every criterion, the plan qualifies for further consideration.

In this example, a minimum standard for cost might be that the costs cannot exceed \$x, where x is determined by the planners. It may be an amount based on the local sponsor's willingness or ability to pay for a project. Alternatively, it may be a maximum expenditure allowed by policy for a particular program authority. The maximum cost represents a minimum standard for costs that must be met. How that standard is set is a matter of concern to the planners but not in the use of this procedure.

In a similar fashion, planners would establish minimum outputs of fish and ducks defined in some units meaningful to the planning process. If it is not yet already obvious, let's be clear. There is no miracle approach that will resolve the difficult necessity of making value judgments. These minimum standards do not often set themselves. But if standards are set and the reasons for the choice of those particular standards are made known, the decision process becomes more transparent and replicable, and is thus improved.

To complete this example, suppose the program authority under which this plan will be implemented has an expenditure limit of $125, which the partner does not want to exceed. Further suppose that marine biologists have assumed that if fish habitat is not improved by at least 10, there will be eventual extinction of a species. Wildlife biologists have opined that any improvement in duck habitat is good. So we now have minimum standards: no cost greater than $125, no fish output less than 10, and no duck output less than 1.

Plan A meets all three criteria and is qualified, meaning if Plan A is implemented, it would be better than no action. Plan B meets the cost and duck criteria but fails to meet the fish criterion, so it is eliminated from further consideration. Plans C and D can be eliminated for not meeting the cost criterion. Hence, based on this example, only Plan A would qualify for further consideration. It would be the planners' responsibility to explain why the minimum standards were set as they were. The choice of these standards should be based on sound science whenever possible. When science is an inappropriate basis of the standard policy, public sentiment or other reasons should be articulated.

DISJUNCTIVE PROCEDURES

In this technique a plan qualifies for further consideration if it equals or exceeds at least one criterion threshold. Once again planners must set a standard. This standard is a bit different, however, in that it is an inclusion standard, as opposed to the exclusion standards described for conjunctive procedures.

For example, suppose planners decided that any plan that cost $75 or less would be included. Any plan that increased fish output by 10 or duck output by 15 would also be included. In this case, Plan A qualifies because it meets the fish threshold. Plan B fails to meet any of the thresholds and is eliminated from further consideration. Plans C and D qualify on the fish criterion. Plan D would have also qualified on the duck criterion, but a plan need only qualify by meeting one of the minimum standards set by planners.

ELIMINATION BY ASPECTS

This procedure requires planners to prioritize the criteria or aspects of the plans from highest to lowest. Then a threshold for elimination is set for each aspect. With the rules so determined, executing the evaluation is simple.

Suppose fish output is judged to be most important, followed by cost and duck output. Let us borrow the elimination criteria from the conjunctive procedures above. These are no cost greater than $125, no fish output less than 10 and no duck output less than 1. To apply this procedure, we go to fish of 10 or more, and Plan B is eliminated. Now we go to costs no greater than $125, with Plans A, C and D remaining. Plans C and D are eliminated. Finally, we consider the ducks criterion of 1 or more, and no more plans can be eliminated.

The elimination by aspects need not yield the same result as the conjunctive procedures. They do here based on our reliance on the same thresholds and the requirement that all criteria be met for the conjunctive procedures.

LEXICOGRAPHIC RULES

In general, lexicographic rules would not be used to qualify plans. Lexicographic rules are most often used to obtain a complete ranking of the alternatives.

WEIGHTING METHODS

The above simple decision techniques are all workable for qualifying plans in the evaluation step with the noted exceptions. What they do not do is address the desire to consider the environmental outputs in an aggregate fashion. That is, they do not combine the fish and duck outputs.

EQUAL WEIGHTS

One of the more common ways for making qualification decisions would be by adding the environmental outputs and estimating the average unit cost of those outputs as shown in Table 49. This table shows the results of the most common weighting method. Both fish and duck outputs are assumed to be equally important, and summing them is equivalent to assigning each a weight of one.

TABLE 49: COMBINED ENVIRONMENTAL OUTPUTS

Plan	Cost	Environmental	$/Environmental Output
A	100	15	6.67
B	100	15	6.67
C	150	20	7.50
D	150	25	6.00

The last column in Table 49 has effectively aggregated all the information in the original table (Table 48) into a single variable, the average cost of an environmental output. It is now a simple matter, conceptually, to apply a threshold to these values to determine which plans qualify for further consideration. As a practical matter, determining what that threshold value is remains a difficult value judgment.

To minimize the appearance of arbitrariness in this process, it is best to identify the threshold values well before the evaluation analysis begins. For example, planners may have been inclined to think that anything more than $5 per unit of environmental output would be excessive before the evaluation. This would send planners back to the formulation table. A similar judgment would be far harder to make after planners have seen the values the plans yield. There would be a tendency to set a relative threshold rather than an absolute one. An absolute, predetermined threshold might be a more objective measure of what is or is not desirable. Once the values have been estimated, there is a tendency to want to define the better of the plans as acceptable while in fact they may not be in a more objective analysis. This could lead to a relative threshold set at, say, $7 per unit of environmental output.

Conversely, planners may have more objectively determined that anything less than $10 per unit of environmental output is acceptable. Once the results are known, there is again a tendency to want to establish a threshold that eliminates some but not all plans. This human tendency to winnow things out is not as sound a basis for qualifying plans as is a predetermination of the thresholds on as objective a basis as possible.

When environmental outputs are combined in this fashion, IWR Plan's cost effectiveness routine is an invaluable analytical tool for qualifying plans.

UNEQUAL WEIGHTS

A common difficulty with the equal weights approach is that the environmental outputs are not always of equal importance. It is not unusual to recognize that one kind of output is more important than another. The difficulty, as always, is in reaching some sort of consensus on how much more important one output is than another. There is no simple way around this. Someone must establish the relative weights of the different outputs to be combined. If the outputs are in common units, the raw data or normalized data can be used. If the outputs are in different units, say habitat units and acres restored, they must be normalized in one of the ways discussed in Chapter III or in some other acceptable fashion. Chapter III also discussed fixed point scoring, rating, ordinal ranking, graphical weighting and paired comparisons as tools that may be helpful in establishing the actual weights.

For the simplicity of the example, assume the units of output are the same. If you work with the same units, it is preferable to use weights that sum to one. This avoids adding a layer of complexity to understanding what your newly created units of measurement are. Thus, if fish are considered to be twice as important as ducks, fish receive a weight of 0.67 while ducks receive a weight of 0.33. The revised values are shown in the Table 50.

TABLE 50:
COMBINED ENVIRONMENTAL OUTPUTS UNEQUALLY WEIGHTED

Plan	Cost	Environmental	$/Environmental Output
A	100	8.35	11.98
B	100	6.68	14.97
C	150	10	15
D	150	11.7	12.82

The average costs are different and are no longer tied directly to the number of environmental units provided. The weighting process results in the creation of a hypothetical unit of output. In this case, the units are output equivalents; each unit is equivalent in importance to 2/3 of a fish output and 1/3 of a duck output. This can become quite confusing when the original units are themselves hypothetical units like habitat units.

Notice that the average costs have changed noticeably. The reliance of weighted output measures on hypothetical equivalent units makes it more difficult to establish an objective threshold to analysis. This can be finessed by establishing a threshold value for fish output, and duck output, and then calculating an equivalent value using the weights established. For example, suppose fish outputs less than \$20 per unit were considered acceptable while duck outputs less than \$8 per unit were okay. The resultant threshold value would be (0.67 x \$20) + (0.33 x \$8) = \$16.04. With a threshold like this, all of the plans A through D would qualify.

If any number of different environmental outputs can be combined like this, then IWR Plan can be a useful decision support tool. What is essential to understand, is that there is no magic bullet for determining the relative values of the environmental output. Determination of those weights is essentially a political process, in that it depends on individual or group process value judgments.

MORE COMPLEX METHODS

Although the more complex methods may be better suited to the final selection choice (the magnitude of the effort is more commensurable with the importance of the decision), they can be used for the qualifying steps as well as the final selection.

The methods are the same as those presented in Chapters VI and VII. They begin with the creation of a decision matrix and proceed through the weighting, synthesis and decision steps of the model presented in Chapter III. There is no reason why those methods could not be applied in this decision framework. Thresholds for qualification would have to be established because selecting a subset of qualifying alternatives from a larger set is a different problem than establishing a complete rank ordering or identifying the best plans.

COST EFFECTIVENESS TRADE-OFF RECOMMENDATIONS

The cost effectiveness trade-off essential to the evaluation of plans is unique because the qualification and comparison steps become blurred and intermixed. Other than that, there is really no difference between this trade-off and the others discussed in this manual.

For qualifying plans, the general rule is to keep the process as simple as it can possibly be but no simpler. If the analysis can be done using some simple decision rules, use them. The gains in simplicity, transparency and reproducibility are likely to outweigh the discomfort that attends making value judgments.

Combine different environmental outputs whenever possible. If you have like units, use them. If the units differ, you will have to normalize them before combining them. Use equal weights unless you know the outputs are not equally weighted. If you do use weights, try to use weights that sum to one. Make sure you understand and can describe the resulting equivalent units of aggregate output. Only use the more complex methods if there is a specific reason why a simpler method will not work.

The simple rules can be used to qualify plans. They do not absolve planners from the need to make value judgments. That is the very nature of planning–say which alternatives are better and which is best, as well as why one says so. If thresholds can be set and if priorities can be established, it is possible to make the qualification trade-offs in this relative comparison context.

Plans that survive this process could proceed to the next planning step of comparison. In that step the comparison is no longer intended to help planners decide whether a plan is good enough to consider further or not. Here comparison is intended to select the best plan from among all the qualifying plans. It is presumed that this step is distinguished by reliance on a broader set of criteria.

SUMMARY: TAKE AWAY POINTS

1. Evaluation of plans qualifies them for further consideration in the plan comparison step.
2. Ideally, evaluation and comparison are distinct steps.
3. Qualifying ecosystem restoration plans on the basis of their efficiency and effectiveness often combines evaluation and comparison.
4. The simplest possible decision rules or weighting algorithms should be used to qualify plans whenever possible.
5. The methods of this manual are, in general, as applicable for qualification trade-offs as they are for the selection process.

LOOK FORWARD

Several of the techniques presented in this chapter and those preceding it are simple enough to be paper-and-pencil procedures. Others are more complex and mathematically sophisticated. It is likely that Corps analysts in need of more sophisticated multicriteria decision analysis will make use of one of the many commercially available software packages. Three very useful software applications are presented in the next chapter.

VIII. MULTICRITERIA DECISION MAKING SOFTWARE EXAMPLES

Commercial software packages supporting multicriteria decision making are readily available and extremely useful decision-making tools. The techniques used by these software packages are variations of the techniques presented in earlier chapters. For all but the simplest decision problems, it is expected that Corps planners will find it effective and efficient to use one or more of these commercially available software packages.

An effort was made in the preparation of this manual to identify the most useful freeware and commercially available software. This was done primarily through an Internet search and correspondence with major authors in the field of multicriteria decision making to identify those programs with the right mix of utility and user-friendliness.

Change is a constant in any technologically advanced endeavor, and the decision support software technology is no exception. Although there are many more than the three computer programs presented here, the others are not mentioned because they are supported by individuals and academic institutions, and their availability is not as predictable. The three programs discussed below were deemed the best of the lot by the author.

It is chancy business to offer an Internet address in a document that hopes to have some shelf life, but a few may be in order so that readers might monitor new developments in commercial software. Rather than offer individual addresses, several of which have changed during the preparation of this manual, it is suggested that the interested reader use the International Society on Multiple Criteria Decision Making, located at http://www.terry.uga.edu/mcdm/ at the time of this writing, as the first stop for current information on software and other multicriteria decision making related matters.

The programs selected for use were Decision Lab 2000,[32] Expert Choice Pro[33] and Criterium DecisionPlus.[34] Examination copies of the software were provided for use in the preparation of this manual. It is neither the purpose nor the intent of this chapter to provide instruction in the use of this software. The emphasis is more on the nature of the input requirements, the results and sensitivity analysis opportunities than on any other aspect of the software. The case study described in Chapter V was used with each program.

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[32] Decision Lab 2000 is a product of Visual Decision, Inc., 401 Saint-Claude Street, Montreal, QC, Canada H2Y 3B6.

[33] Expert Choice Pro is a product of Expert Choice, Inc., Decision Support Software, 5001 Baum Blvd., Suite 650, Pittsburgh, PA 15213.

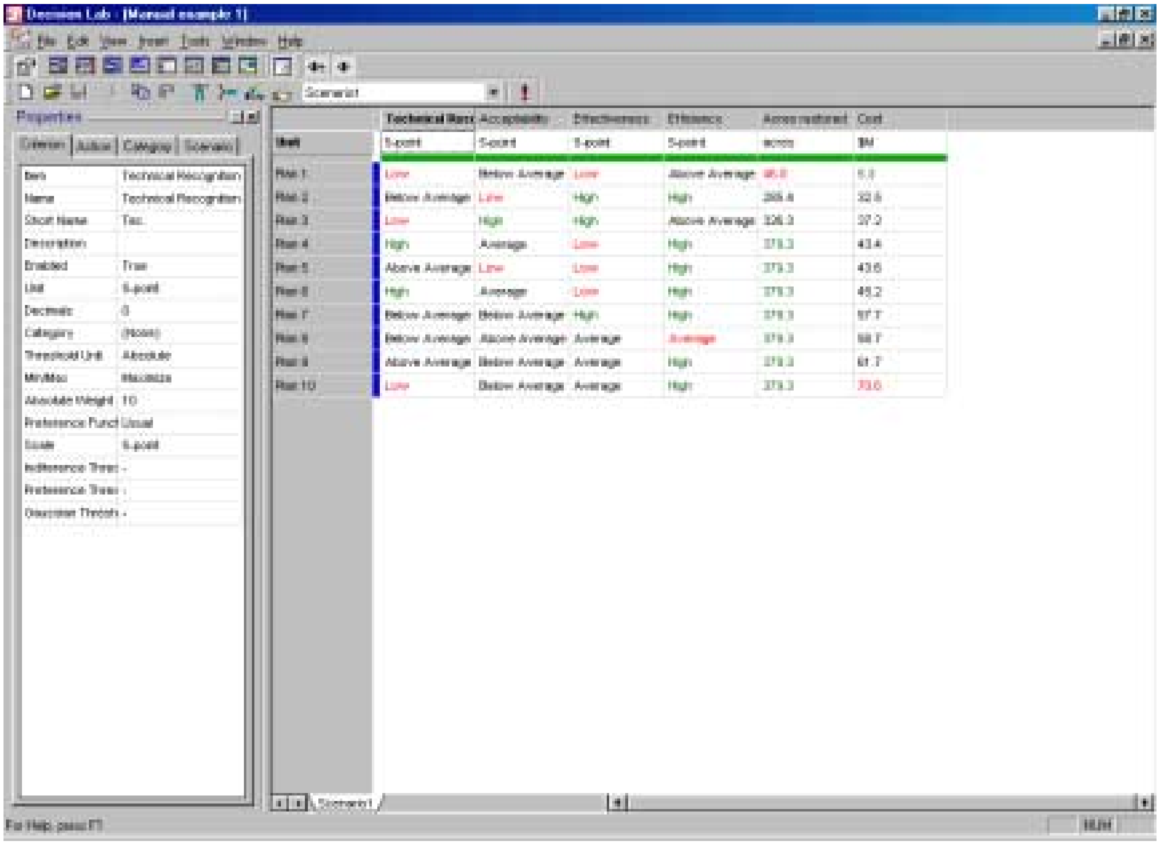
[34] Criterium DecisionPlus is a product of InfoHarvest Inc., PO Box 25155, Seattle, WA 98125-7150.

DECISION LAB 2000

Decision Lab 2000 is based on the PROMETHEE, **P**reference **R**anking **O**rganization **METH**od for **E**nrichment **E**valuations, and GAIA, **G**raphical **A**nalysis for **I**nteractive **A**ssistance, methods. The software requires a decision matrix similar to the one developed for the case study. The criteria are considered independently from their measurement units by way of choosing one of six different preference functions.[35] Priorities among criteria are defined by weights.

INPUT REQUIREMENTS

A decision matrix and decision maker's preferences are sufficient to build a decision model as shown in Figure 11.



Item	Technical Recognition
Name	Technical Recognition
Short Name	Tec
Description	
Enabled	True
Unit	5-point
Decimals	0
Category	(None)
Threshold Unit	Absolute
Min/Max	Maximize
Absolute Weight	10
Preference Funct	Usual
Scale	5-point
Indifference Thres	-
Preference Thres	-
Gaussian Thresh	-

	Technical Reco	Acceptability	Effectiveness	Efficiency	Acres restored	Cost
Unit	5-point	5-point	5-point	5-point	acres	$M
[illegible]	Low	Below Average	Low	Above Average	[illegible]	5.1
[illegible]	Below Average	Low	High	High	205.4	32.6
[illegible]	Low	High	High	Above Average	326.3	37.2
[illegible]	High	Average	Low	High	373.3	43.4
[illegible]	Above Average	Low	Low	High	373.3	43.6
[illegible]	High	Average	Low	High	373.3	45.2
[illegible]	Below Average	Below Average	High	High	373.3	57.7
[illegible]	Below Average	Above Average	Average	Average	373.3	58.7
[illegible]	Above Average	Below Average	Average	High	373.3	61.7
[illegible]	Low	Below Average	Average	High	373.3	70.6

Figure 11: Decision Matrix in Decision Lab 2000

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[35] There is a no-threshold or uniform-preference function, a U-shaped or V-shaped function, a level or step function, a linear function and a Gaussian function. These functions and the choice of threshold levels where appropriate enable the analyst to exercise considerable input into the nature of how the decision maker's preferences cover the range from minimum to maximum degree of preference.

The columns and rows are identical to the raw case study data in the decision matrix before normalization. The 5-point numerical scale has been transformed to the verbal scale shown in Figure 11. On the left is some information about the technical recognition criterion. It is entered as a 5-point scale, is a criterion to be maximized and has been assigned a weight of 10 points. Preferences are expressed in the usual way, using no threshold. Lest the point be lost on the reader, note that the analyst inputs the relative weight of each criterion as a number of points.

The quantitative data requirements for the decision matrix do not differ at all from the kinds of information routinely produced during the planning process. These inputs are identical to those used for any other decision matrix. The model shown was built within minutes of loading the software. Printed documentation, 66 pages, is to the point and useful. No doubt some users will want more documentation, but the tutorial is more than sufficient for analysts with some understanding of multicriteria decision making to begin using the software quickly.

RANKINGS

There are two basic ranking results available from Decision Lab 2000. The first, PROMETHEE 1 partial rankings, is shown in Figure 12 below.

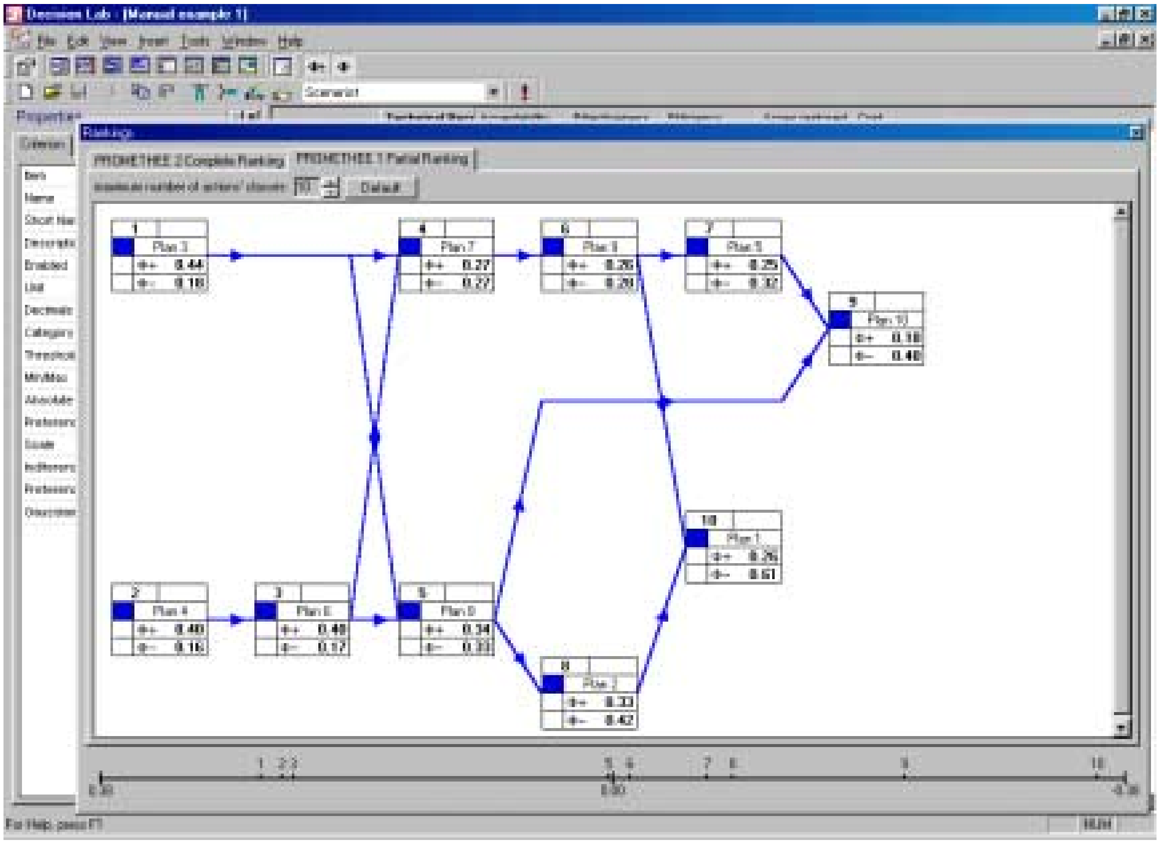

Figure 12: PROMETHEE 1 Partial Ranking

Plan 3 is found at site 1, as seen by the 1 in the upper left corner of the box in the upper left part of the screen. The line to Plan 4 at site 2 shows that Plan 3 outranks Plan 4. Plan 4 outranks Plan 6. The line from Plan 6 to Plan 7, at site 4, shows by transitivity that Plan 3 outranks Plan 7. Plan 7 in turn outranks Plan 9, and so on. An arrow from one plan toward another shows the ranking order. The arrow points toward the outranked alternative.

The site number is not the rank of a plan. The partial ranking is based only on strongly established preferences. Consequently, not all plans can be compared to one another. For example, Figure 12 shows no arrows between Plans 3 and 4. These two are incomparable. That means it is not possible to say that one is better than the other. But it is possible to follow the arrows and see that together they outrank all the other plans. Highlighting incomparable alternatives is a useful feature of this process because these alternatives usually have quite different profiles, as will be seen shortly.

Figure 13 shows a complete ranking. That means all the plans are ranked from best to worst. This ranking leaves no incomparable pairs of plans. This complete ranking is simpler and, to many, more satisfying, but it is based on less reliable preferences than the partial ranking is.

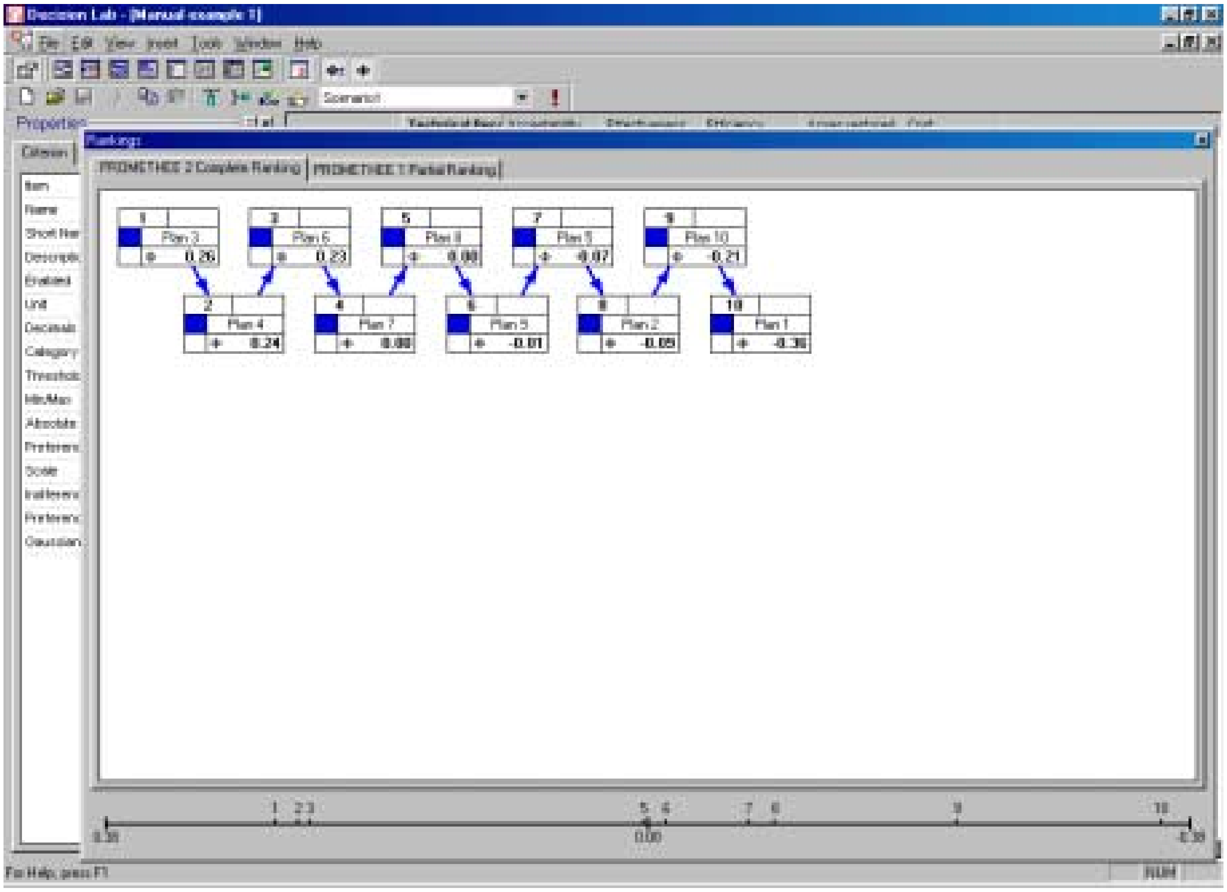

Figure 13: PROMETHEE Partial Rankings

The complete ranking shows Plan 3 outranks Plan 4, followed by Plans 6, 7, 8, 9, 5, 2, 10 and 1. The Φ value is a rating for the plan. Larger values are more preferred. With the partial rating, a larger Φ+ and a smaller Φ- are preferred.

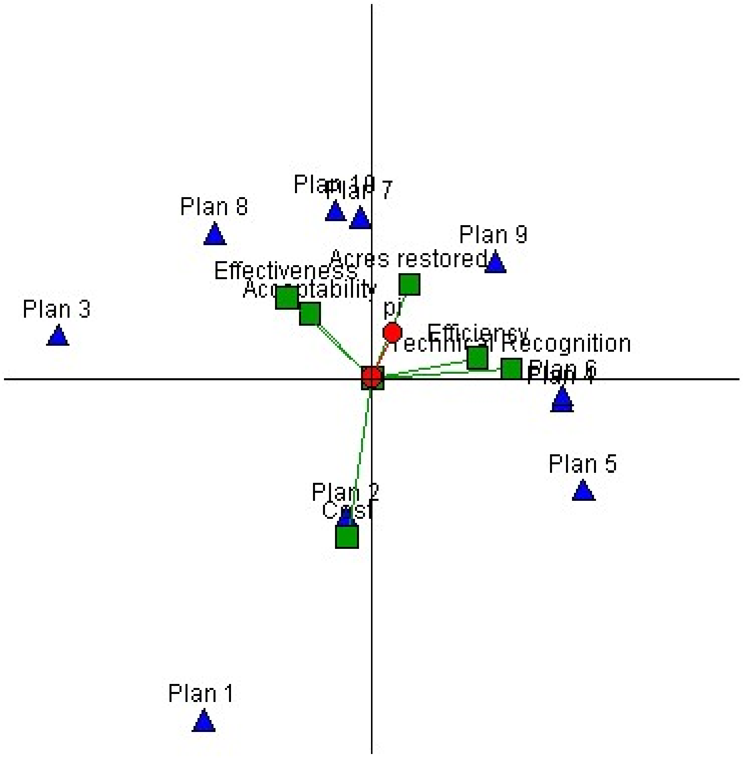

Figure 14: GAIA Plane

Following this initial review of the results, we turn to the GAIA plane seen in Figure 14. This is a comprehensive graphical image of the decision problem. The larger axes are for defining four quadrants to make comparison easier. Each criterion is shown as an axis pointing to a square. The orientation of the axes indicates which criteria are in agreement with each other and which are conflicting. Criteria in agreement are similarly oriented, and those in conflict point in opposite directions. Hence, cost and acres restored are diametrically opposed, as we might expect. Efficiency and technical recognition are in general agreement, as are effectiveness and acceptability.[36]

The position of the plans, displayed as triangles, show the strengths and weaknesses of each plan. The farther a plan is located in the direction of a criterion, the better it is on that criterion. Thus, Plan 1 is best on cost, followed by Plan 2. Plan 3 is worst on technical recognition and efficiency, and so it continues. The pi axis is shown as a circle in the upper right quadrant. It identifies the kind of compromise solution that corresponds to the weights of the criteria. Change the weights, and this axis will change. The delta value for this graph is 62.37 percent. It measures the quality of the GAIA plane. Rankings with values below 60 percent should be analyzed with great care. Values above 75 percent are considered high.

ANALYSIS OF RESULTS

It is important to be able to analyze these results to see if they are affected by slight variations in the decision maker's preference structure, weights, preference functions, thresholds and such. Figure 15 presents an "action profile."

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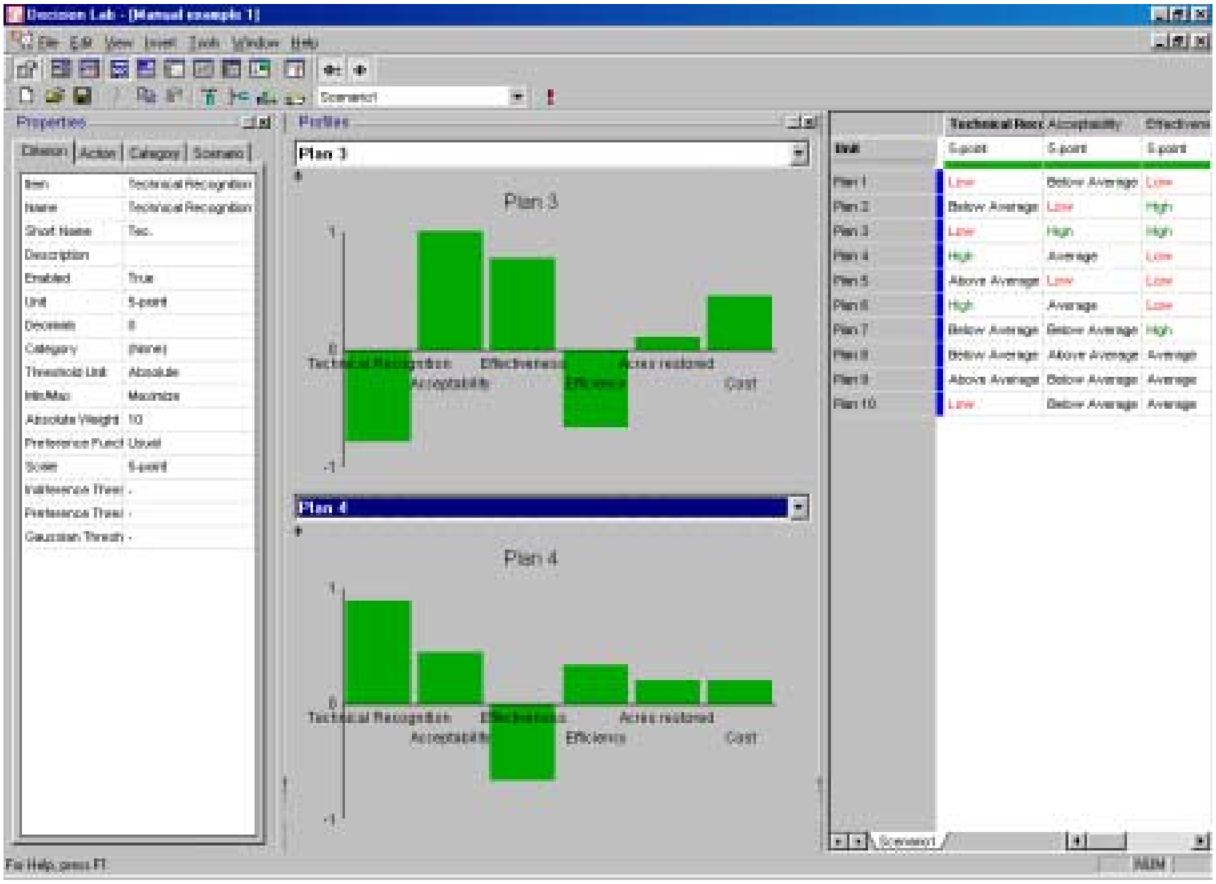
[36] Lest too much be made of these relationships, the reader is cautioned to remember the plans in the case study reflect a mix of real and synthetic data.



Item	Technical Recognition
Name	Technical Recognition
Short Name	Tec.
Description	
Enabled	True
Unit	5-point
Decimals	0
Category	(None)
Threshold Unit	Absolute
Min/Max	Maximize
Absolute Weight	10
Preference Funct	Usual
Scale	5-point
Indifference Thres	-
Preference Thres	-
Gaussian Thresh	-

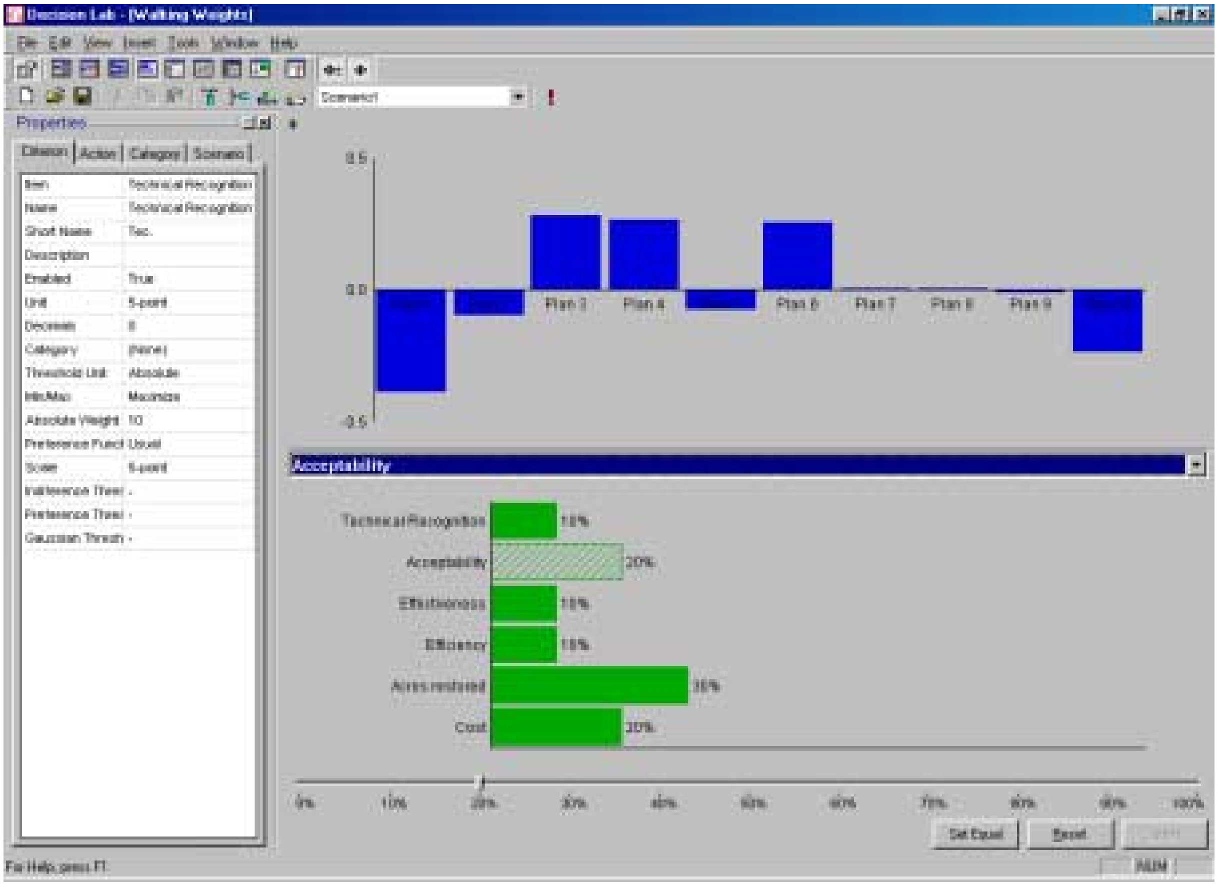
	Technical Reco	Acceptability	Effectivene
Unit	5-point	5-point	5-point
Plan 1	Low	Below Average	Low
Plan 2	Below Average	Low	High
Plan 3	Low	High	High
Plan 4	High	Average	Low
Plan 5	Above Average	Low	Low
Plan 6	High	Average	Low
Plan 7	Below Average	Below Average	High
Plan 8	Below Average	Above Average	Average
Plan 9	Above Average	Below Average	Average
Plan 10	Low	Below Average	Average

Figure 15: Action Profile Comparison of Plans 3 and 4

Values above the line indicate good performance for a criterion, and bars below the line indicate weaknesses. This graphic comparison makes the trade-offs between plans visually explicit. Plan 3 performs poorly on technical recognition and efficiency; Plan 4 is weak on effectiveness. The relative strengths and weaknesses make the magnitude of the trade-off more intuitive.

A feature called walking weights allows the analyst to see how the ranking would change if the importance of a given criterion is altered. An example is provided in Figure 16. The top half of the graph shows the Φ values for the plans. The bottom half shows the relative weights of the criteria. Acceptability is the criterion for which we test sensitivity.

By sliding the indicator at the bottom of the screen, one can vary the importance of acceptability and the other weights in a prorated fashion to see how the Φ values of the plans and their relative ranking would be affected.



Item	Technical Recognition
Name	Technical Recognition
Short Name	Tec.
Description	
Enabled	True
Unit	5-point
Decimals	0
Category	(None)
Threshold Unit	Absolute
Min/Max	Maximize
Absolute Weight	10
Preference Funct	Usual
Scale	5-point
Indifference Thres	-
Preference Thres	-
Gaussian Thresh	-

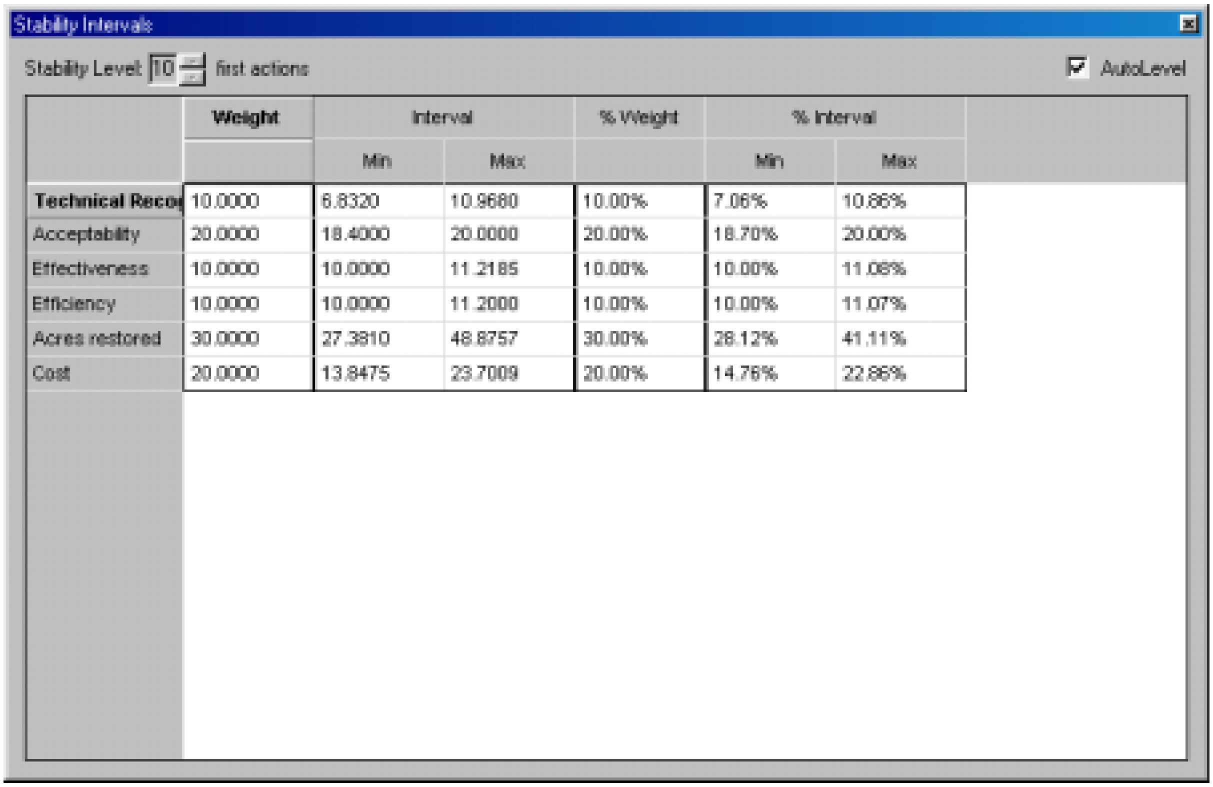
Figure 16: Walking Weights

A useful feature of this sensitivity analysis is called the weight stability intervals. These are shown in Figure 17. This table shows the bounds within which the weights of a criterion can be varied without affecting the complete ranking, provided that the other rankings are not altered. Weights are established by assignment; thus, this is a stability interval, all other things equal.

The weight of acres restored could go as low as 27.38 points or as high as 48.88 points. It is currently 30 points, and if the other weights are not changed, the complete ranking would remain unaffected. When there are known discrepancies about the importance of a criterion, this provides a quantitative measure of how much a weight can be varied before a change occurs. To examine the significance of weights that exceed the stability interval, one would have to change the weights and do more analysis.

This review of Decision Lab 2000 is little more than a cursory introduction to its capability. The software does much more than discussed here.

A useful feature is the ability to define indifference and preference thresholds. The analyst could, for example, set the indifference threshold to $5 million to indicate that if the costs of two plans vary by $5 million or less, this is not a significant difference. This is the largest negligible value for a difference between criterion measurements. The preference threshold is the smallest value the decision maker considers decisive in comparing two plans. A lower value



	Weight	Interval		% Weight	% Interval	
		Min	Max		Min	Max
Technical Reco	10.0000	6.8320	10.9680	10.00%	7.06%	10.86%
Acceptability	20.0000	18.4000	20.0000	20.00%	18.70%	20.00%
Effectiveness	10.0000	10.0000	11.2185	10.00%	10.00%	11.08%
Efficiency	10.0000	10.0000	11.2000	10.00%	10.00%	11.07%
Acres restored	30.0000	27.3810	48.8757	30.00%	28.12%	41.11%
Cost	20.0000	13.8475	23.7009	20.00%	14.76%	22.86%

Figure 17: Weight Stability Intervals

that the preference threshold induces some hesitation in decision making. Hence, if the preference threshold for cost is set at $10 million, the two values together mean that a cost difference of $5 million or less is insignificant. Cost differences over $10 million lead to decisive preferences and values between $5 and 10 million induce some weakness in the preference, depending on where the cost lies between these two thresholds.

Decision Lab 2000 has a useful ability to group criteria into categories. So, if there were several environmental criteria and several economics criteria, they could be bundled into a single environmental criterion category or a single economics category. Decision Lab 2000 also has the capability to define, save and compare different scenarios so multiple decision makers can use it simultaneously.

EXPERT CHOICE PRO

Expert Choice Pro is based on the analytic hierarchy process (AHP), a methodology for decision making described in Chapter VI. Users define a hierarchy for their decision problem by defining a goal, criteria to consider in achieving that goal and a set of alternatives for evaluation. The decision maker then provides pairwise judgments on the elements of the model within each level of the hierarchy in terms of their contribution to the next highest level of the hierarchy.

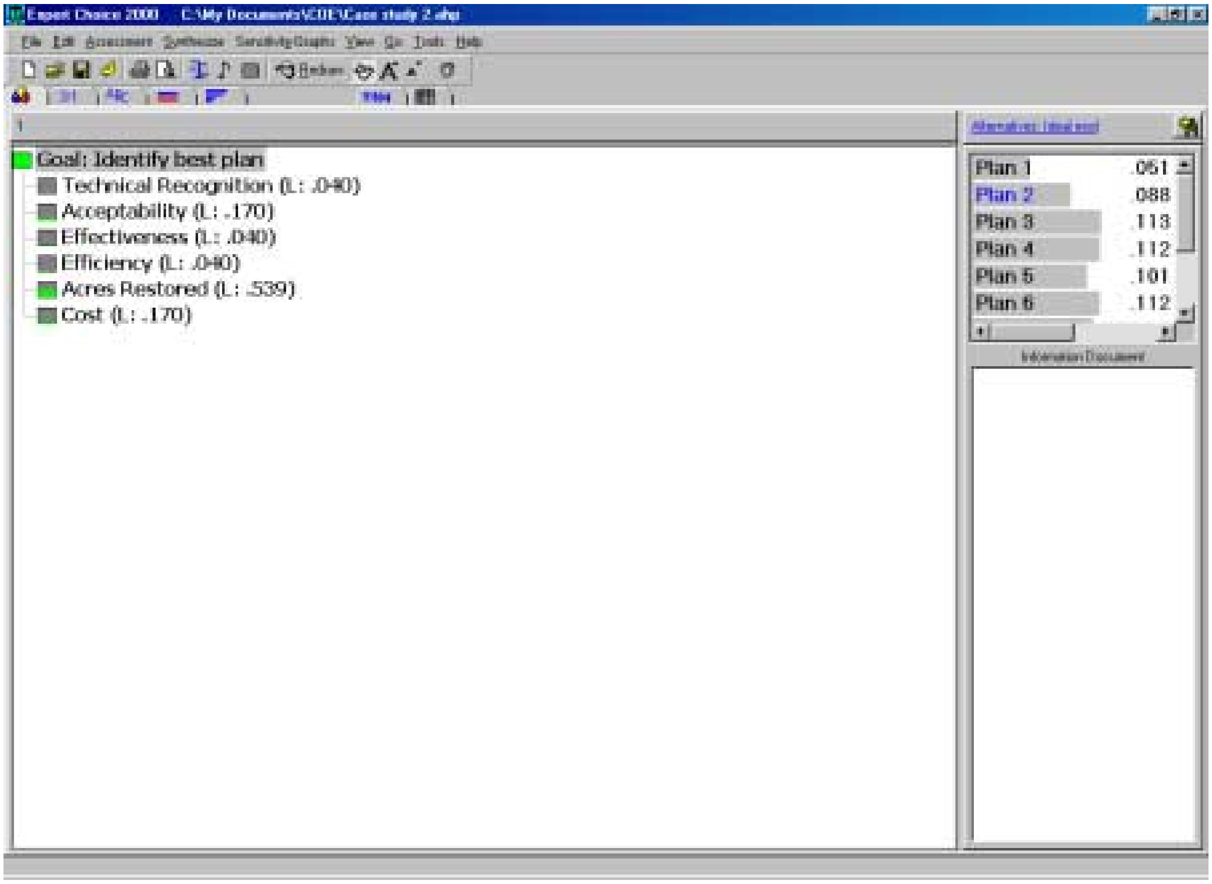
INPUTS

A decision matrix and the decision maker's preferences are sufficient to build a decision model with Expert Choice Pro. Building the hierarchy is very simple. Figure 18 shows the basic model construction screen.

A goal is specified, and then each criterion is entered beneath the goal on the screen shown in Figure 18. The numbers following the criteria show the relative importance of the criteria, calculated after the pairwise comparisons of the criteria were completed. On the upper right, some of the ten alternative plans can be seen.

Figure 19 provides an example of the numerical method of entering judgments about the relative importance of the various criteria. Using the pairwise method, the decision maker does not have to explicitly state the weights of the various criteria. It is only necessary that the decision maker make consistent and meaningful comparisons when taking the criteria two at a time. This is Expert Choice Pro's strength and its weakness.

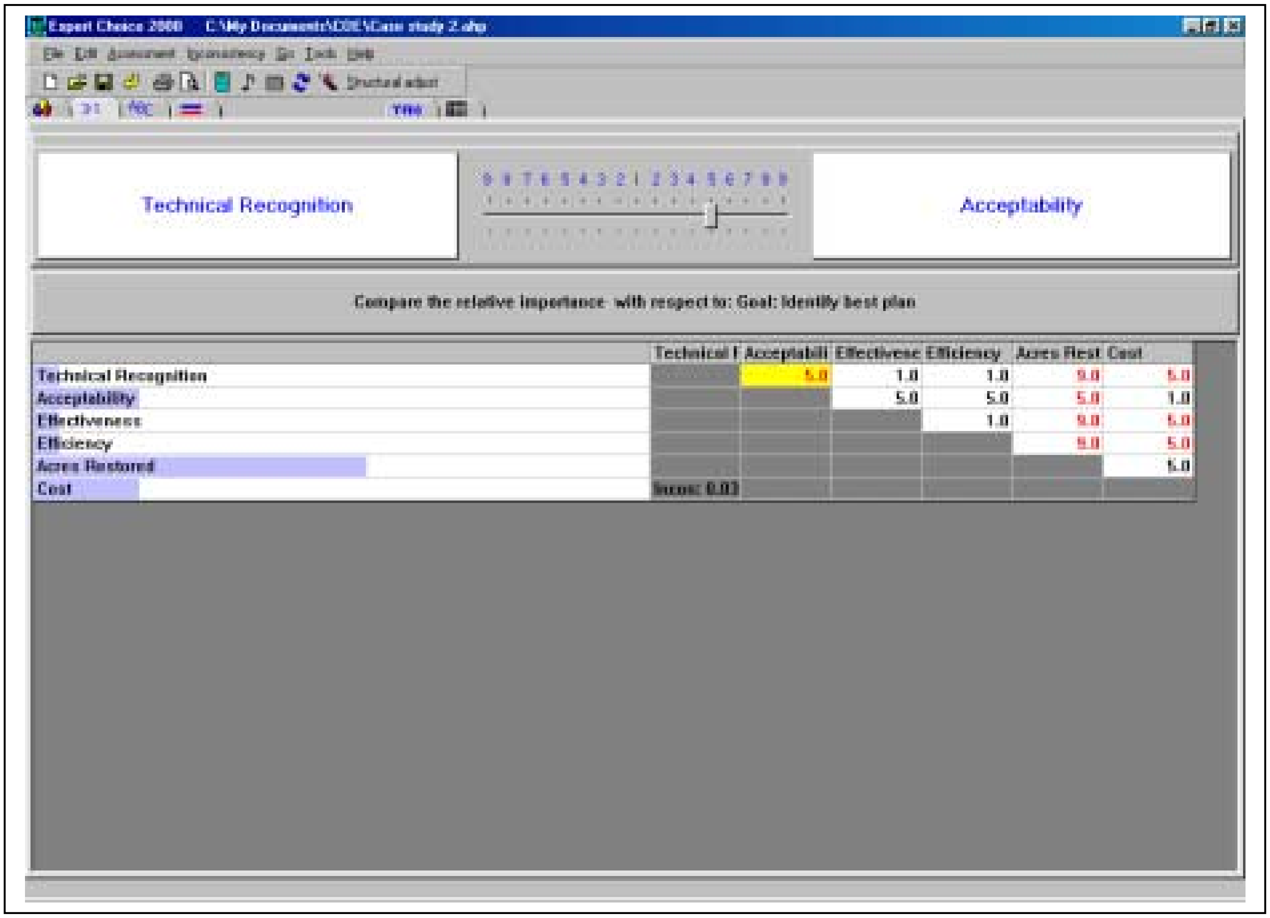
Note that the six criteria result in the need for 15 comparisons. The highlighted cell shows that acceptability is more important than technical recognition with respect to the goal of



Goal: Identify best plan
- Technical Recognition (L: .040)
- Acceptability (L: .170)
- Effectiveness (L: .040)
- Efficiency (L: .040)
- Acres Restored (L: .539)
- Cost (L: .170)

Plan 1	.061
Plan 2	.088
Plan 3	.113
Plan 4	.112
Plan 5	.101
Plan 6	.112

Figure 18: Expert Choice Hierarchy



Technical Recognition

Acceptability

Compare the relative importance with respect to: Goal: Identify best plan

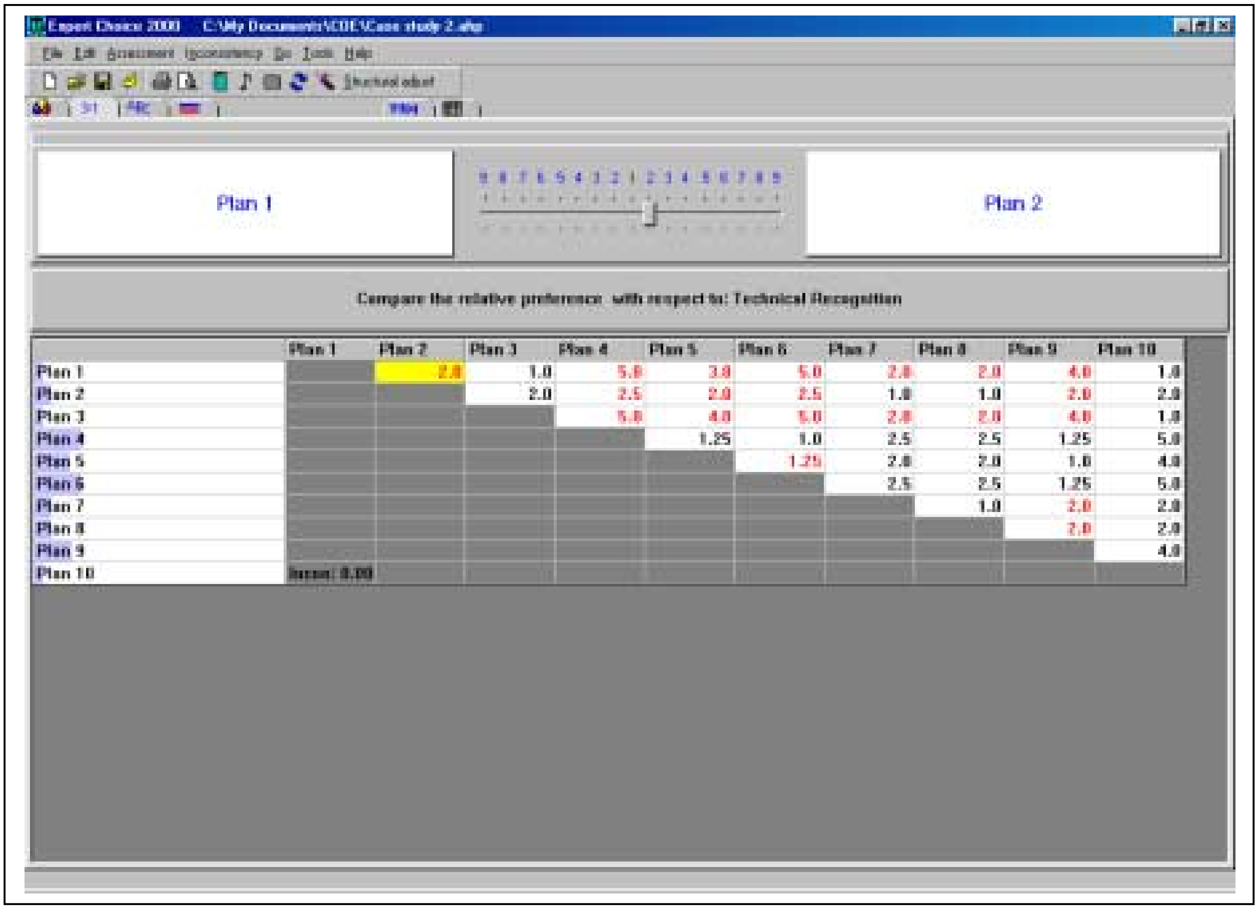
	Technical I	Acceptabili	Effectivene	Efficiency	Acres Rest	Cost
Technical Recognition		5.0	1.0	1.0	9.0	5.0
Acceptability			5.0	5.0	5.0	1.0
Effectiveness				1.0	9.0	5.0
Efficiency					9.0	5.0
Acres Restored						5.0
Cost	Incon: 0.03					

Figure 19: Pairwise Comparison of Criteria

identifying the best plan. The strength of that relationship is expressed on a scale from one to nine. This decision maker considered the difference a 5 on that scale. Red values indicate the column criterion is more important than the row criterion. Black numbers indicate the opposite. The numbers are presumed to convey only some internal consistency when entered by an individual; they have no other meaning.

Once the pairwise comparisons have been entered, the criterion measurement data must be entered. This can be handled in a number of ways in Expert Choice Pro. One strength of Expert Choice Pro is that it functions nicely in a data-poor environment. For example, you only need an opinion about which plan is preferred when provided with a choice of two plans for any given criterion. Thus, this software works well with nothing more than alternatives, criteria and the decision maker's opinions. It would also handle the raw data of our decision matrix as well as the normalized decision matrix. This is clearly a strength.

On the other hand, it is necessary to make many comparisons when the pairwise comparison technique is used. Figure 20 shows the results of a pairwise comparison of the relative contributions that various plans make to attainment of the technical recognition criterion. Forty-five comparisons had to be made for each of six criteria, for a total of 285 pairwise comparisons when the 15 comparisons for the criteria are compared. It is reasonable to wonder



Compare the relative preference with respect to: Technical Recognition

	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan 9	Plan 10
Plan 1		2.0	1.0	5.0	3.0	5.0	2.0	2.0	4.0	1.0
Plan 2			2.0	2.5	2.0	2.5	1.0	1.0	2.0	2.0
Plan 3				5.0	4.0	5.0	2.0	2.0	4.0	1.0
Plan 4					1.25	1.0	2.5	2.5	1.25	5.0
Plan 5						1.25	2.0	2.0	1.0	4.0
Plan 6							2.5	2.5	1.25	5.0
Plan 7								1.0	2.0	2.0
Plan 8									2.0	2.0
Plan 9										4.0
Plan 10	Incon: 0.00									

Figure 20: Pairwise Comparisons for a Criterion

whether it is possible for a decision maker to offer this many meaningful comparisons. But when the plans' contributions to criteria are measured, it is easier to develop an analytical approach to calculating these weights. For example, Plan 1 scored a 1, and Plan 2 scored a 2 for this criterion. The value in row "Plan 1" and column "Plan 2" is a 2, reflecting the fact that Plan 2 is more important than Plan 1 by the ratio of 2/1. The values in this table are simply the ratios of the values.

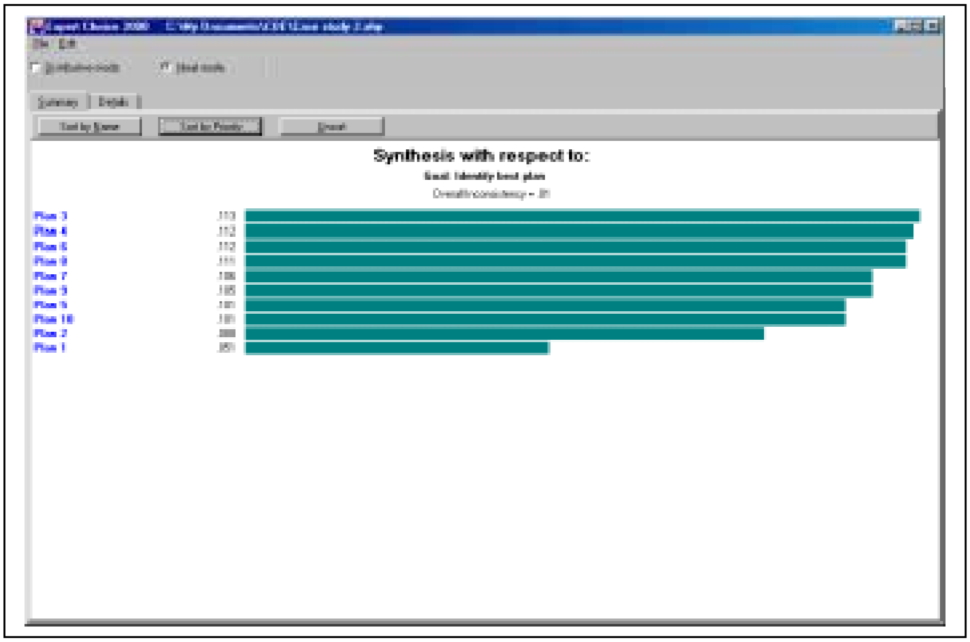
Group Applications

Each of the software programs discussed in this chapter can be used for decision making by an individual or a group. See the users' manual for details on those applications.

Expert Choice Pro calculated the bottom diagonal of the matrix in Figure 20. The analyst calculated the rest of the matrix.

RANKINGS

The results of the AHP analysis are shown in Figures 21 and 22. The composite numerical scores and a visualization of them is the standard first report. As Figures 21 and 22 show, Plan 3 is marginally better than Plans 4 and 6.



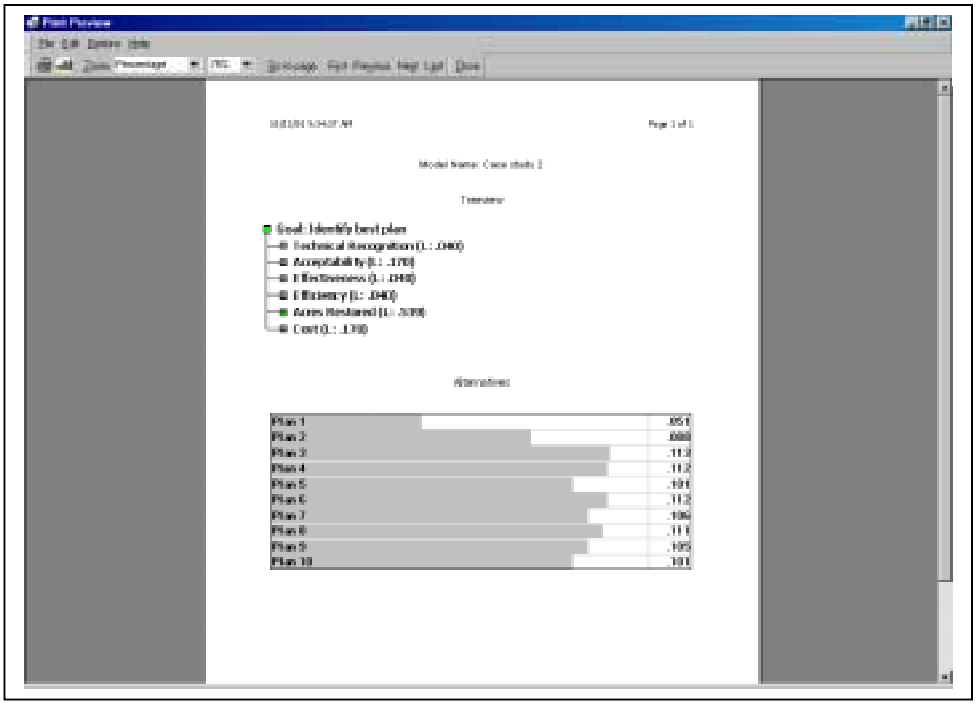
Synthesis with respect to:

Goal: Identify best plan

Overall Inconsistency = .01

Plan 3	.113
Plan 4	.112
Plan 6	.112
Plan 8	.111
Plan 7	.106
Plan 9	.105
Plan 5	.101
Plan 10	.101
Plan 2	.088
Plan 1	.051

Figure 21: AHP Results



Page 1 of 1

Model Name: Case study 2

Treeview

Goal: Identify best plan
- Technical Recognition (L: .040)
- Acceptability (L: .170)
- Effectiveness (L: .040)
- Efficiency (L: .040)
- Acres Restored (L: .539)
- Cost (L: .170)

Alternatives

Plan 1	.051
Plan 2	.088
Plan 3	.113
Plan 4	.112
Plan 5	.101
Plan 6	.112
Plan 7	.106
Plan 8	.111
Plan 9	.105
Plan 10	.101

Figure 22: Standard Report of Results

One of Expert Choice Pro's standard assessment reports is shown in Figure 22. This figure shows the numerical weights of the criteria as well as the composite score of the alternatives. The winning margin for Plan 3 is razor thin with this technique as it has been with several others. Bearing in mind the synthetic nature of the data, not too much should be made of this point in these examples.

Once the decision matrix is completed, building the hierarchical model is trivially simple. Entering data is more challenging because of the various options available and the potential for entering many pairwise judgments.

ANALYSIS OF RESULTS

It is clearly in this arena that commercial software offers analysts and decision makers the most value added from their products. The full value of the features can only be appreciated by using the software in a real decision context. Expert Choice Pro offers four of the richest graphic analysis techniques imaginable.

Figure 23 presents one of these. Printed versions of this manual that lack color capability will leave the reader at a substantial disadvantage, for colors are used effectively to convey information in this and other graphics.

In Figure 23, the criteria are shown on the horizontal axis. The relative importance of the criteria, based on the decision maker's pairwise judgments, is shown by the height of the bar. On the far right is a ranking of the plans. Plan 3 in bright green is ranked first, and Plan 1 in blue is last.

At each criterion there is a vertical line. A colored line representing one of the ten plans crosses each of these vertical lines. In this example, several lines are printed directly over one another, yielding fewer than ten distinct lines at most criteria. At the cost criterion, the blue line representing Plan 1 spikes very high. This means that Plan 1 is rated significantly higher than any other plan on this criterion by virtue of its $5 million cost. The red line of Plan 2 and the green line of Plan 3 are the next two highest-ranking plans for this criterion. You can read the overall ranking of the plans or the ranking of the plans for any one criterion from this graphic. Lines that move from one criterion to the next by intersecting indicate direct trade-offs among plans for those adjacent criteria.

The real value of this graphic lies in its interactivity. The analyst can click on and grab any one of the criterion bars and raise or lower it to observe the effect of a changed decision maker preference concerning a criterion on the overall ranking of the plans. Notice that acres restored is the most important criterion in Figure 23. Suppose a stakeholder disagreed and felt acres restored was less important. To illustrate such an interactive analysis, compare Figure 23 to Figure 24, where the relative weight of cost has been greatly increased. There are a few changes in the overall rank, but Plan 3 remains the best choice.

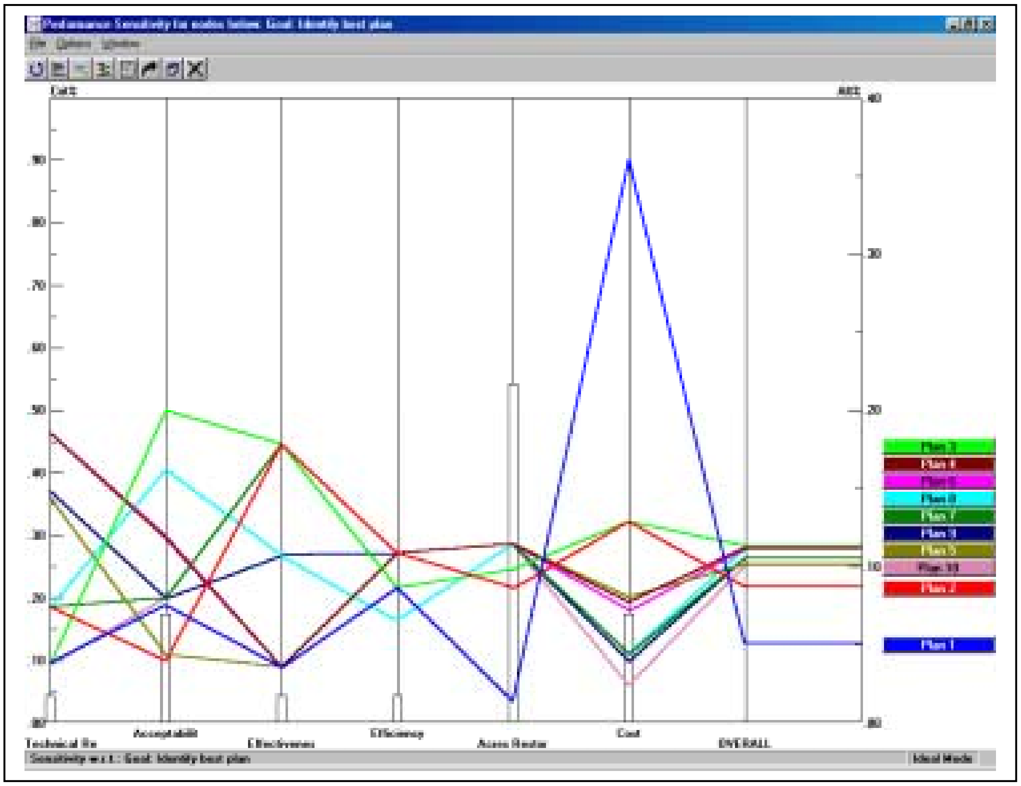


Figure 23: Performance Sensitivity

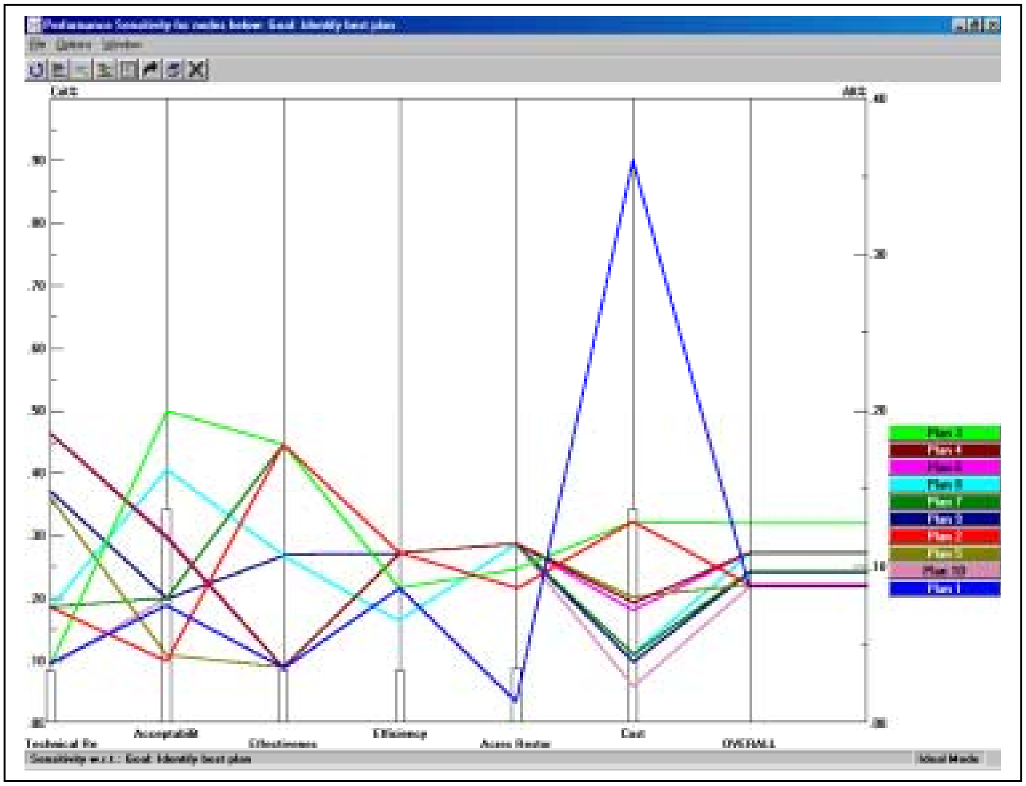


Figure 24: Performance Sensitivity with Acres Restored Diminished

It is also possible to investigate trade-offs visually with the graphics. Figure 25 shows how the plans perform when we focus on the two criteria of acceptability and acres restored.

Figure 25 is divided into four quadrants. The upper right and lower left quadrants show plans with a direct relationship for these two criteria. Plans 4, 6 and 8 have more of both acceptability and acres restored compared to the other plans. Plans 5 and 7 tend to do better on acres and worse on acceptability, indicating the direct trade-off involved in the choice of either of these two plans.

The graphics produced by Expert Choice Pro are challenging, but that is only because they are far richer in terms of data than most of us are used to seeing. The small circles on the projection line show the relative strength of the alternative over all criteria. Thus, Plan 3 has its small circle most advanced on the line. The larger green circle for Plan 3 shows its standing based on these two criteria only. It is farther to the left and hence does not score as well on these two criteria alone.

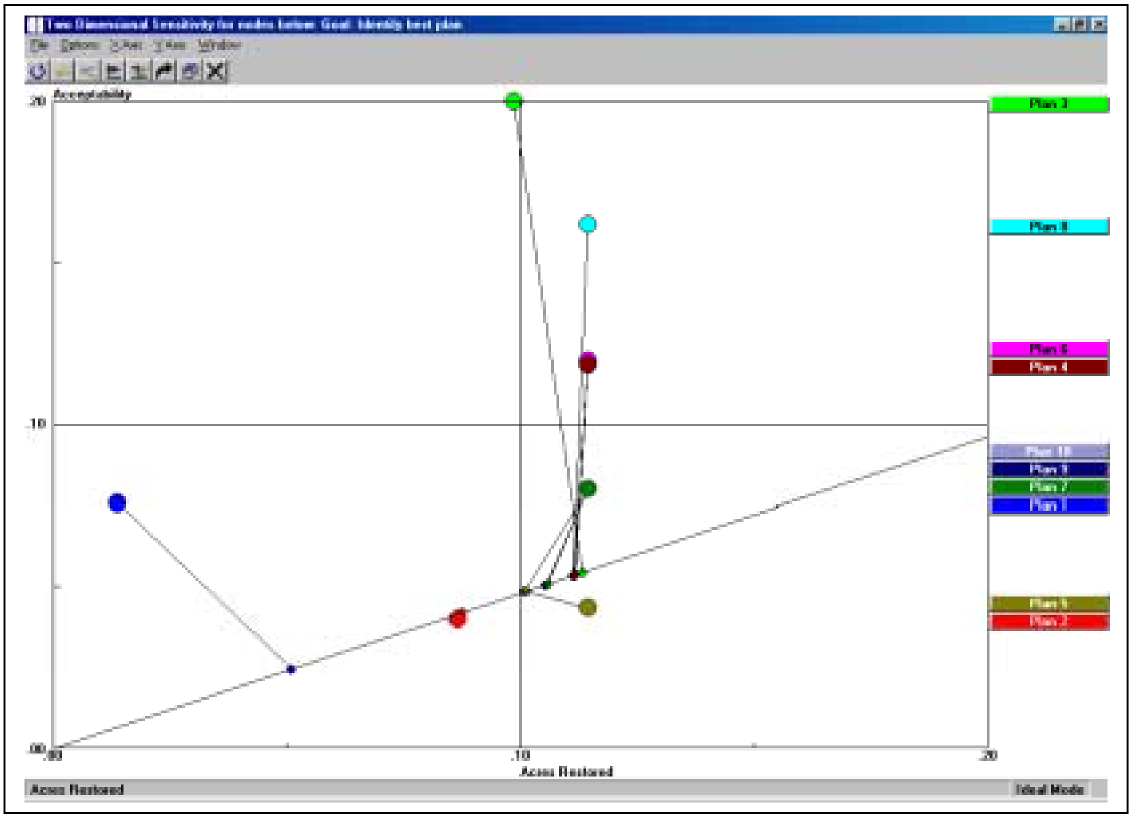


Figure 25: 2D Chart

A comparison of individual plans is also possible with Expert Choice Pro. Figure 26 provides a comparison of Plans 3 and 4. They both scored very closely on the overall ranking. This figure makes the direct trade-offs involved in choosing one over the other very apparent.

Plan 3 contributes more to the criteria of acceptability, effectiveness and cost while contributing less to technical recognition, efficiency and acres restored. The overall edge for

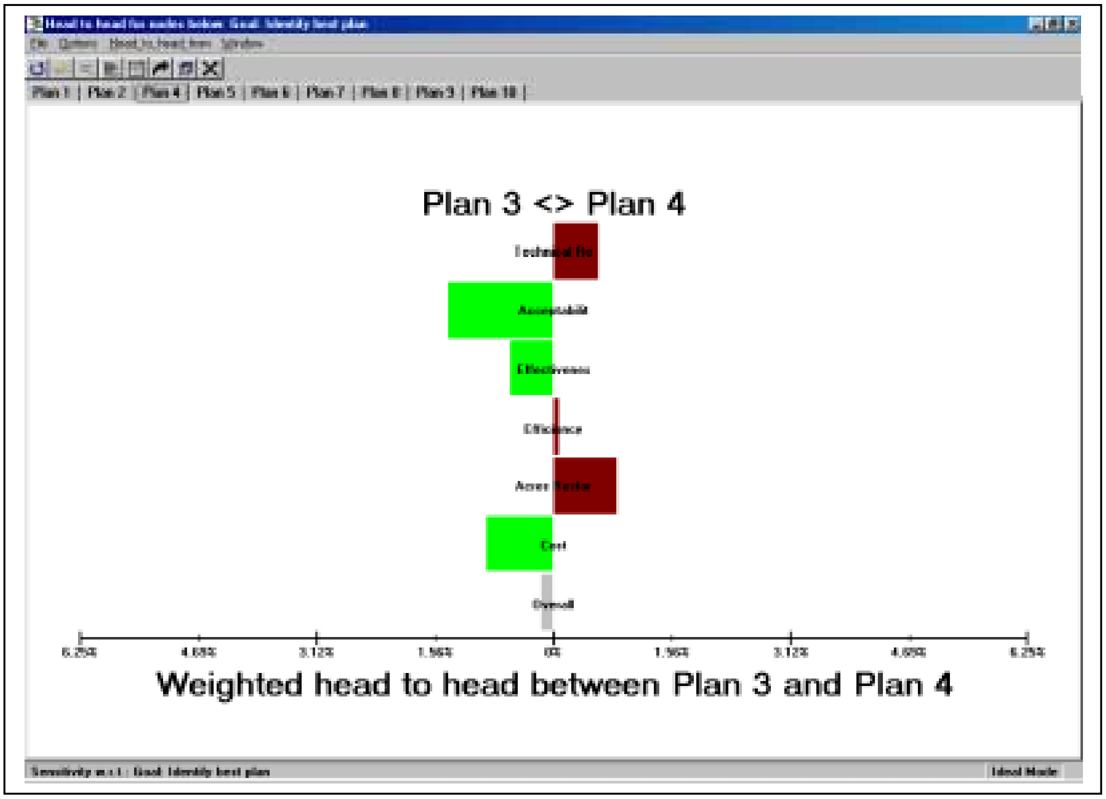


Figure 26: Head-to-Head Comparison

Plan 3 is shown to be rather small. This is an extremely useful graphic because it enables the decision maker to compare any two plans directly to see what is gained and what is lost by going for one plan rather than another.

Another interactive graphing option is also available with Export Choice Pro. The graphic opportunities enable the analyst or decision maker to interactively analyze the results of the ranking. They are perhaps Expert Choice Pro's strongest point. The richness of these graphic tools is not immediately obvious, and it takes some effort to learn how to interpret and use the information in these graphic tools. It is effort that is well rewarded.

CRITERIUM DECISIONPLUS

Criterium DecisionPlus provides the capability to use the AHP or Simple Multiattribute Rating Technique (SMART) to assist the decision process. SMART originates from the MAUT approach of the last chapter. The user defines a hierarchical model based on the decision matrix. This can be done via a brainstorming feature for those not so familiar with decision theory, or the model can be built directly from the decision matrix. Expert Choice Pro has a similar feature. As with the other programs, there is a great variety of option and choice in the way the data can be entered and the weights determined. Criterium DecisionPlus has the capacity to handle a model with seven levels, including the goal level and alternatives and five levels of criteria and sub-criteria. It can handle up to 200 alternatives.

INPUTS

A decision matrix and the decision maker's preferences are sufficient to build a decision model with Criterium DecisionPlus. Figure 27 shows the basic model structure.

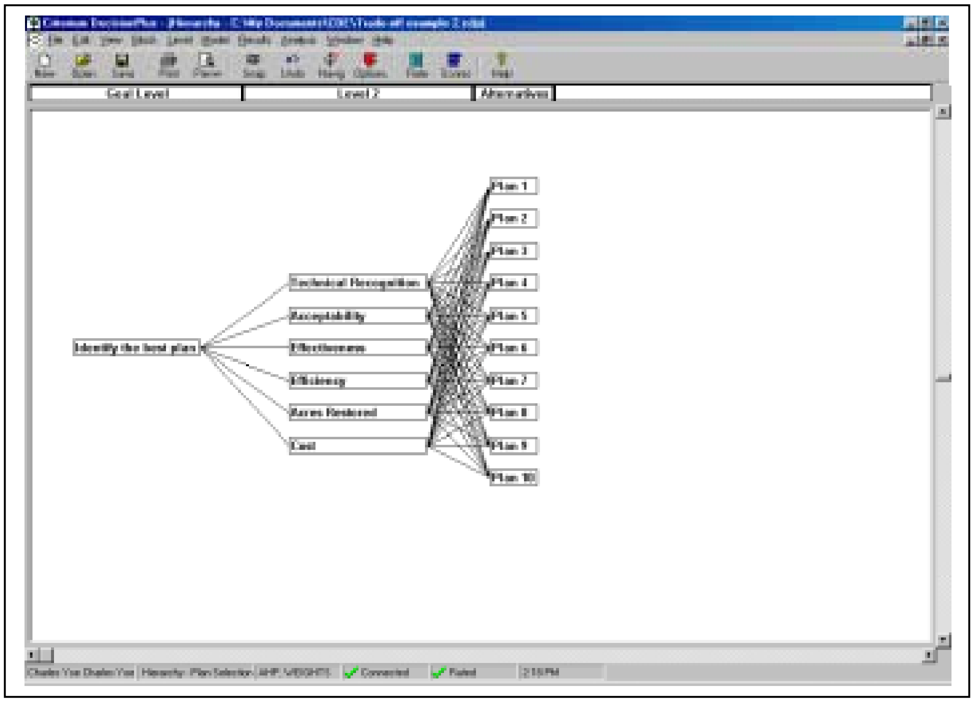
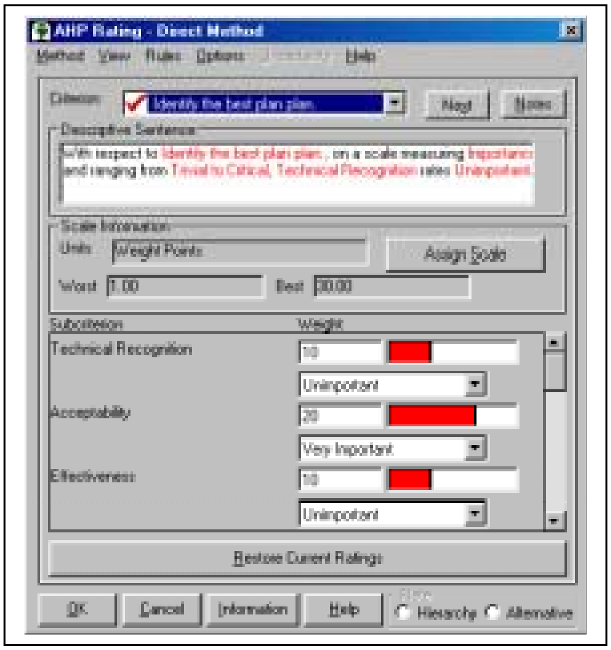


Figure 27: Criterium DecisionPlus Hierarchy Model

This model was built using the brainstorming feature. These intuitive and helpful features tend to slow you down once you have a basic understanding of the process. They remain helpful aids to the uninitiated, however.

The weights for the criteria are identical to those used for the other programs. They were entered directly as shown in Figure 28. The weights can be entered verbally, visually or numerically. The figure shows examples of each. Two criteria with weights of 10 are verbally classified as unimportant because the analyst set the potential weight scale from 0 to 30. Acceptability with a greater weight is very important as reflected by the larger bar. It is also possible to derive the weights from a full pairwise or partial pairwise comparison approach if desired.



Criterion: Identify the best plan plan.

Descriptive Sentence: With respect to Identify the best plan plan., on a scale measuring Importance and ranging from Trivial to Critical, Technical Recognition rates Unimportant.

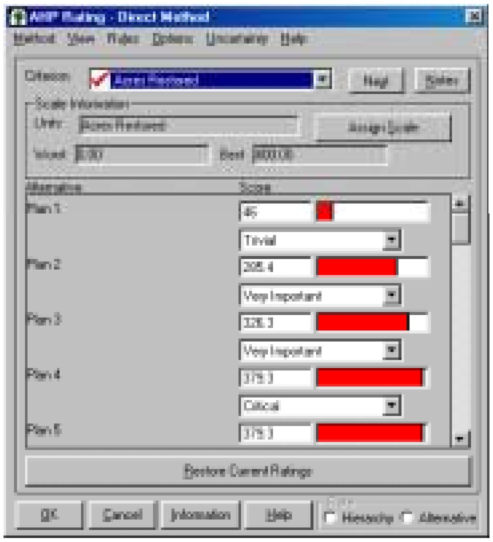
Units: Weight Points

Worst: 1.00 Best: 30.00

Subcriterion	Weight
Technical Recognition	10 Unimportant
Acceptability	20 Very Important
Effectiveness	10 Unimportant

Figure 28: Direct Entry of Weights

After entering the decision maker's criteria preferences in this manner and with only one level of criteria, the next step was to enter the decision matrix data directly. This task was considerably easier for a first time user than it was with Expert Choice Pro. The data were entered in a similar fashion, as shown in Figure 29.



Criterion: Acres Restored

Units: Acres Restored

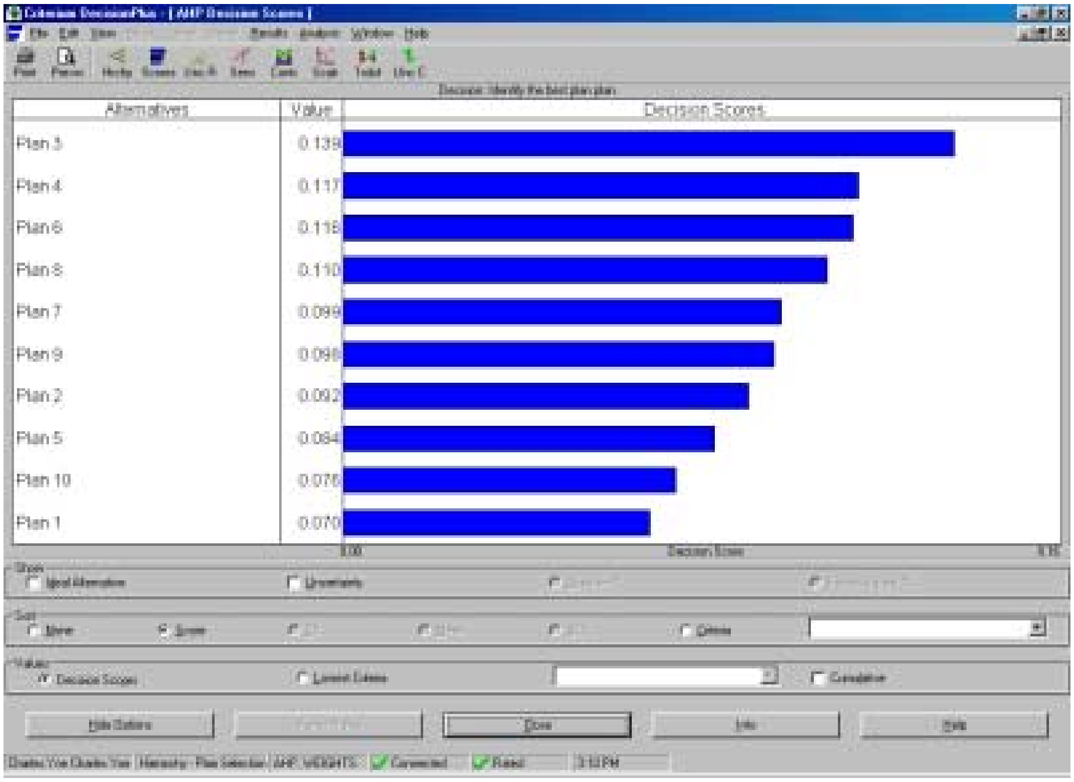
Alternative	Score	
Plan 1	46	Trivial
Plan 2	205.4	Very Important
Plan 3	326.3	Very Important
Plan 4	375.3	Critical
Plan 5	375.3	

Figure 29: Direct Data Entry

RANKING

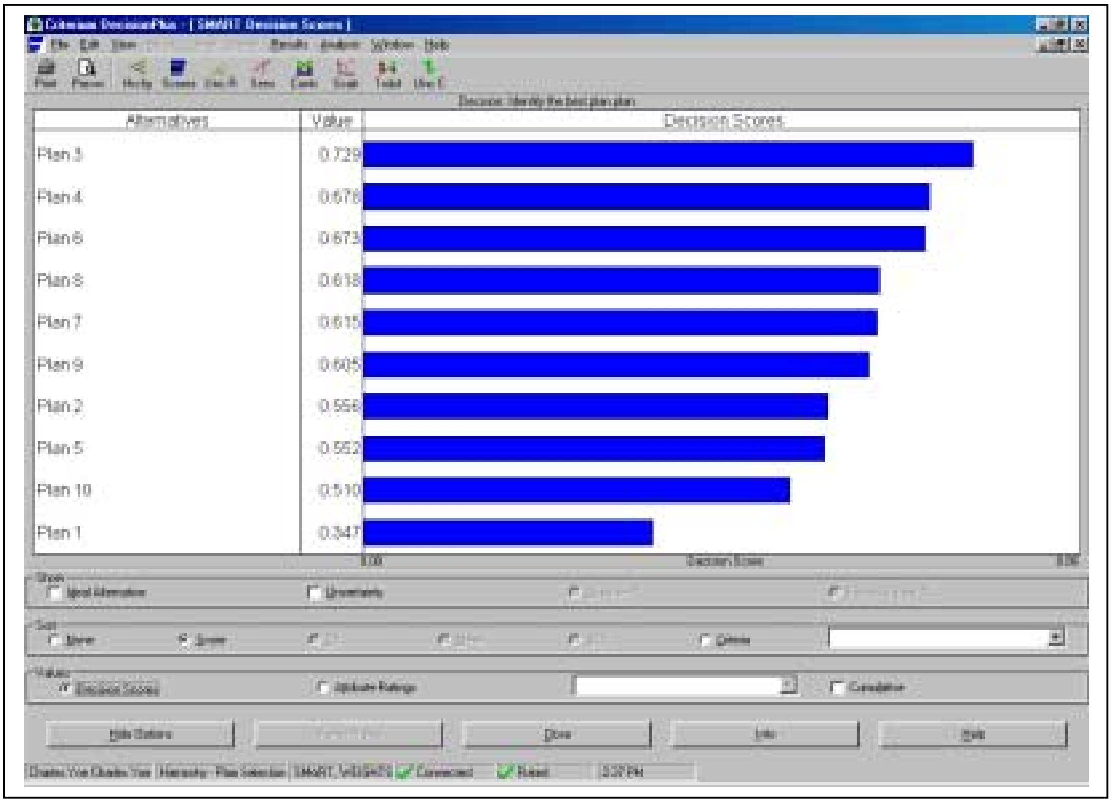
The analyses of alternative options include AHP and SMART. The hierarchy can be based on weights or trade-offs. The results of using AHP and weights for the initial analysis are shown in Figure 30. Plan 3 is first followed by Plan 4.

For comparison, the SMART analysis of alternatives was run. It produced the identical ranking seen in Figure 31. The identical ranking should be considered anecdotal evidence. As with the other programs, once the decision matrix has been completed, the model constructed and the data entered, analysis is trivially simple.



Alternatives	Value
Plan 3	0.139
Plan 4	0.117
Plan 6	0.116
Plan 8	0.110
Plan 7	0.099
Plan 9	0.098
Plan 2	0.092
Plan 5	0.084
Plan 10	0.076
Plan 1	0.070

Figure 30: Criterium DecisionPlus AHP Rankings



Alternatives	Value
Plan 3	0.729
Plan 4	0.678
Plan 6	0.673
Plan 8	0.618
Plan 7	0.615
Plan 9	0.605
Plan 2	0.556
Plan 5	0.552
Plan 10	0.510
Plan 1	0.347

Figure 31: SMART Ranking

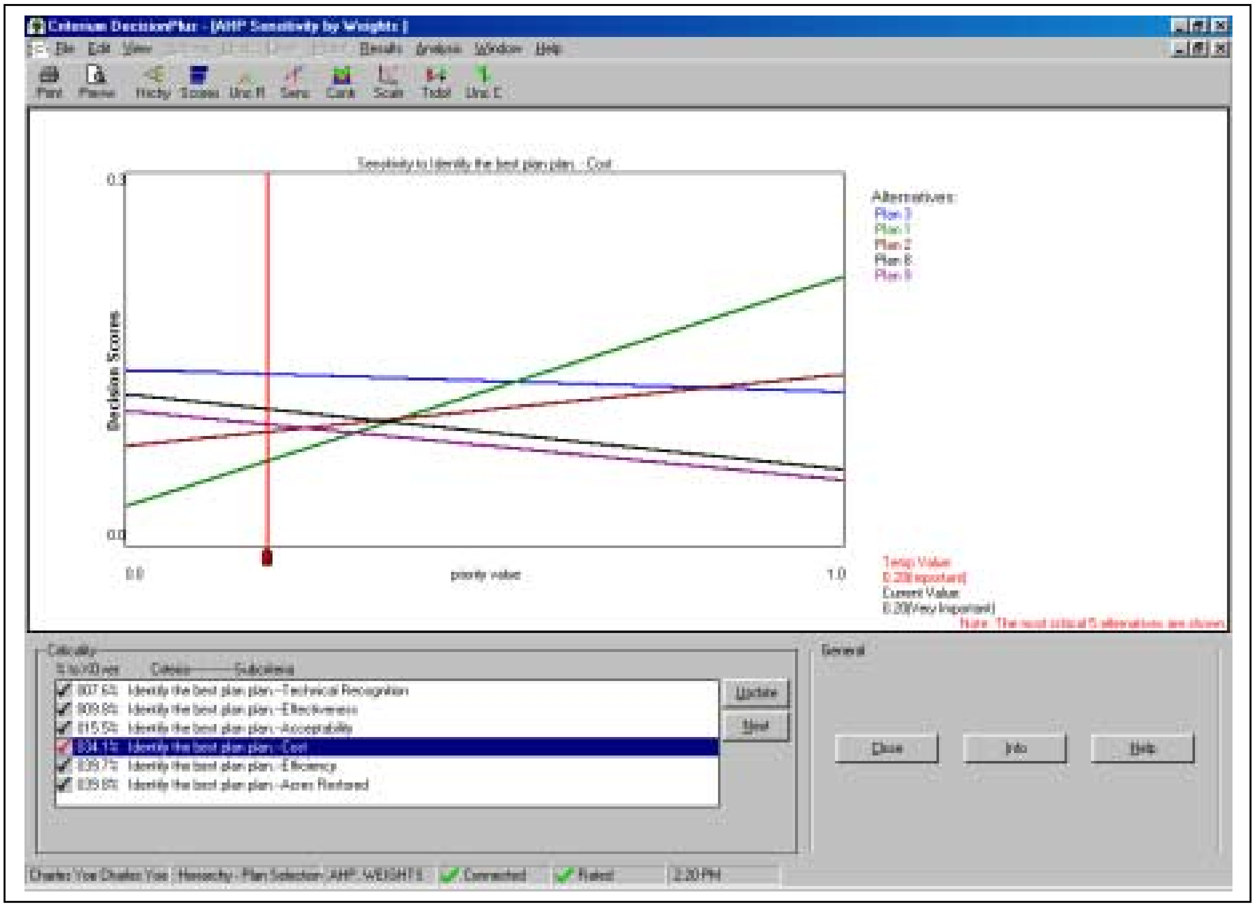
ANALYSIS OF RESULTS

Once again the value added of the commercial software is most evident in the options available for analyzing the results. Interactive and static sensitivity analysis options are available.

Criterium DecisionPlus provides a sensitivity analysis for the weights as shown in Figure 32. The analyst may select any of the decision criteria and graph them as shown. The decision score is measured on the vertical axis and the criterion weight is measured horizontally. Different colored lines are drawn for each of the top five ranking alternatives. The vertical line in the graph indicates the decision maker's currently identified weight for the cost criterion. The height of the plan lines at their intersection with the vertical line shows their decision score when the cost weight is as shown.

By dragging the tag at the bottom of the vertical line, the analyst can reposition the cost criterion weight anywhere on the scale from 0 to 1. Then, by examining the intersection of the plan lines with the vertical line at that position, one can see how the plans would be ranked if only the cost criterion is changed.

For example, if the cost criterion's weight were to increase from its current 0.2 to about 0.55, then Plan 1 would be identified as the most preferred plan, reflecting the new importance of



807.6% Identify the best plan plan - Technical Recognition
909.8% Identify the best plan plan - Effectiveness
815.5% Identify the best plan plan - Acceptability
834.1% Identify the best plan plan - Cost
839.7% Identify the best plan plan - Efficiency
839.8% Identify the best plan plan - Acres Restored

Charles Yoe Charles Yoe | Hierarchy - Plan Selection AHP WEIGHTS | ✓ Connected | ✓ Rated | 2:20 PM

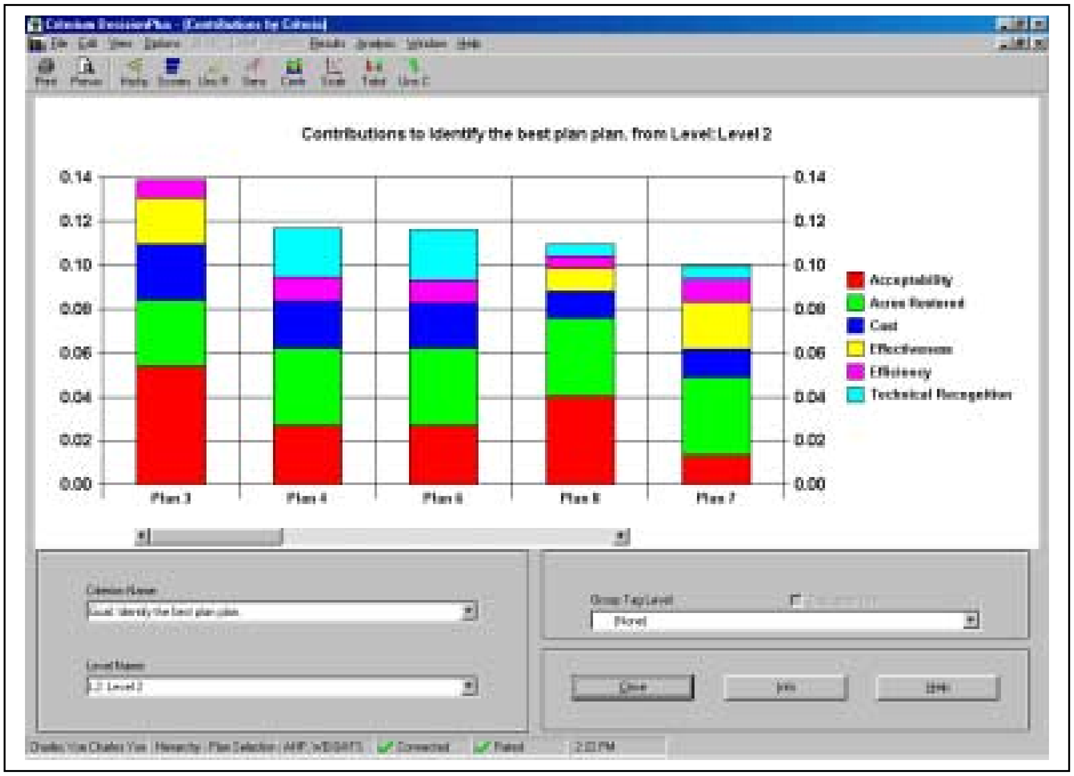
Figure 32: Sensitivity by Weights

costs. The interactive feature makes it easy to identify the points at which plan lines intersect, i.e., the weights at which the ranking of individual plans changes.

A second useful sensitivity analysis shows the contribution of each criterion to a plan's overall score. An example of this analysis is shown in Figure 33. Plan 3 has the highest overall score as indicated by overall bar height. It is apparent that Plan 3's acceptability score contributes more to its overall preference than any other criterion. Technical recognition contributes nothing to this plan's performance. A shift in preference from acceptability to technical recognition would likely dethrone Plan 3 from its number one post.

Direct trade-offs can be inferred from this graph. Think of the bars as the market basket of goods provided by each plan. The mix and magnitude of the plan effects is depicted by different-magnitude colored bars that comprise overall plan performance.

Figure 34 is an example of a plot of each plan on a two-by-two comparison of the criteria. In the figure, acres restored is plotted against acceptability. It is obvious that there are only four levels of restored acreage and three of these are relatively tightly grouped. This graph makes it immediately obvious why Plan 1 continuously turns up as the least desirable plan. It also makes it clear that Plan 3's acceptability rating is what makes it most preferred.

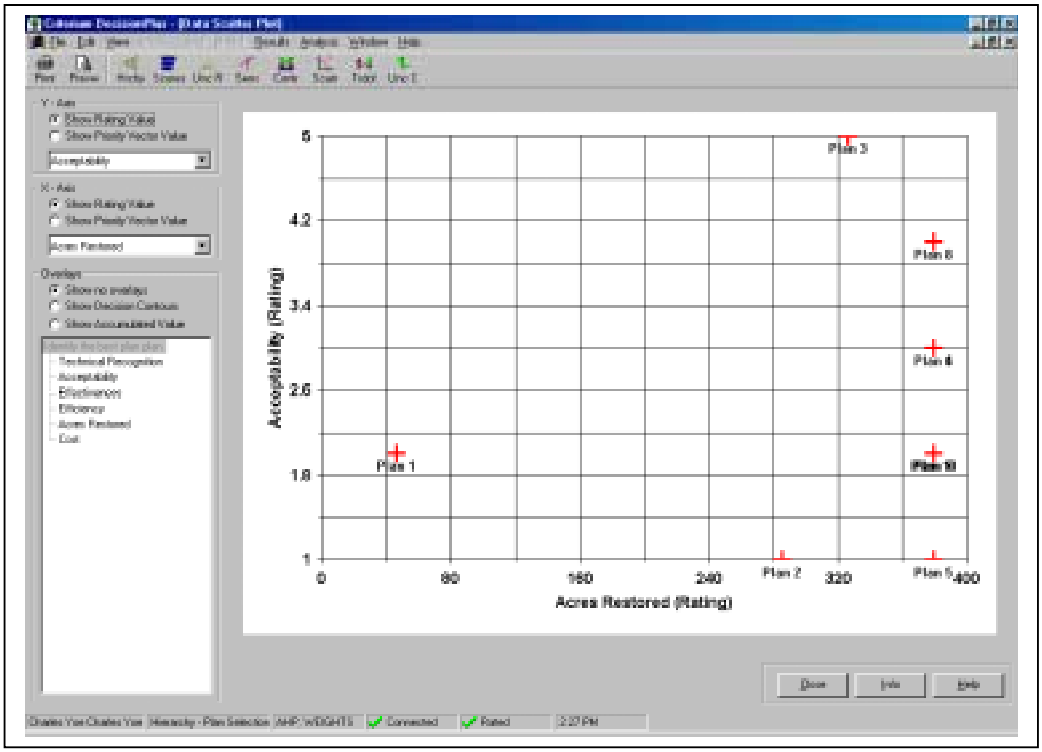


Criterion Name: Goal: Identify the best plan plan.

Level Name: L2: Level 2

Group Tag Level: (None)

Figure 33: Contributions by Criteria



Y - Axis
● Show Rating Value
○ Show Priority Vector Value
Acceptability

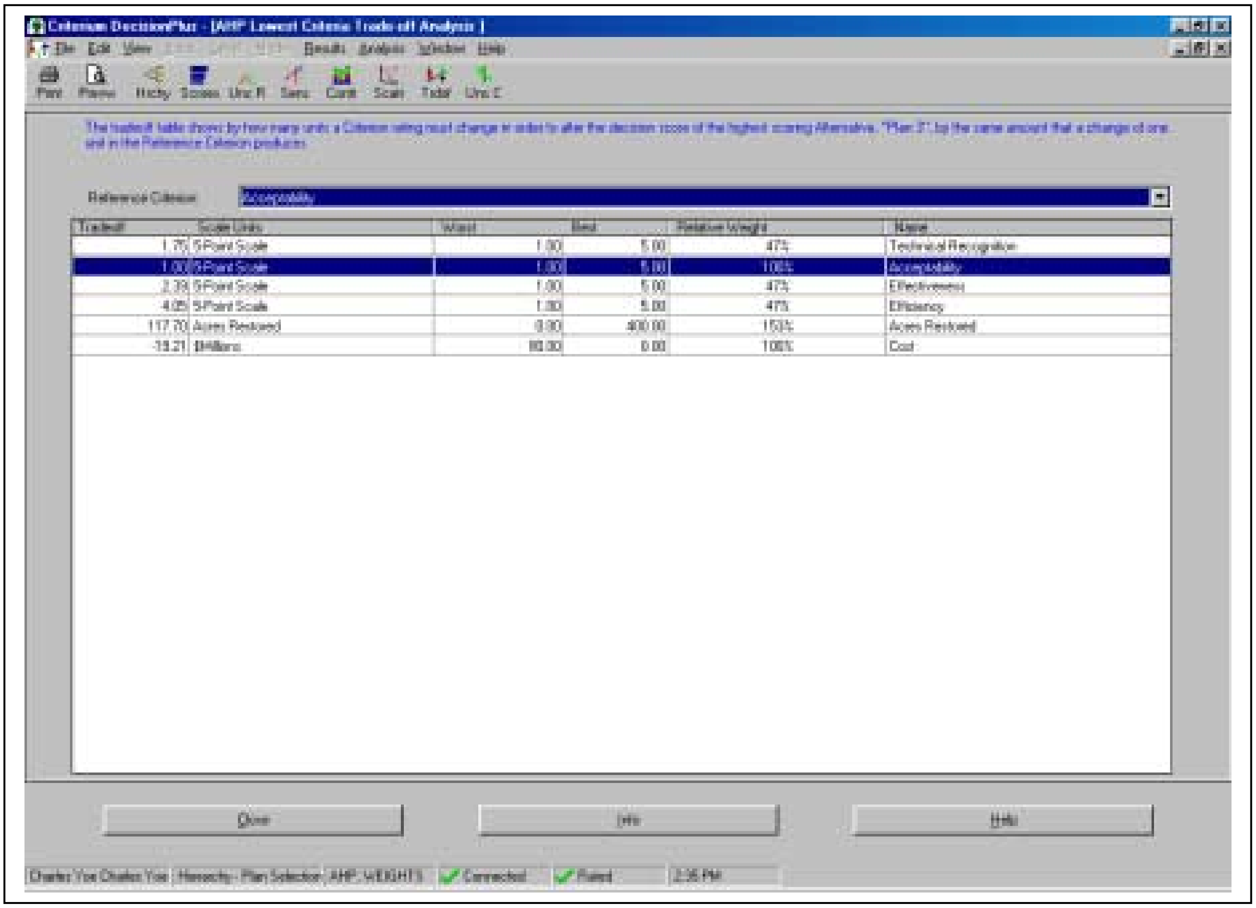
X - Axis
● Show Rating Value
○ Show Priority Vector Value
Acres Restored

Overlays
● Show no overlays
○ Show Decision Contours
○ Show Accumulated Value

Identify the best plan plan
- Technical Recognition
- Acceptability
- Effectiveness
- Efficiency
- Acres Restored
- Cost

Figure 34: Data Scatter Plot

A very interesting feature of Criterium DecisionPlus is shown in the Figure 35. The analyst can designate any of the criteria as the lowest trade-off analysis criterion. In this example acceptability has been chosen. If the acceptability rating of Plan 3 changed by one unit from a 5 to a 4, there would be an impact on its score and ranking. This particular analysis indicates that the same effect on Plan 3's ranking could occur if the cost of Plan 3 increased by $19.21 million, if technical recognition fell by 1.75 points (impossible since it is 1 now), effectiveness fell by 2.39 points, efficiency fell by 4.05 points (impossible since it is 4 now) or if the acres restored fell by 117.70 acres. A one-unit increase in acceptability is not possible; it is already at the maximum. But if an increase were possible, the trade-offs would be the same, only opposite in direction of change.



The tradeoff table shows by how many units a Criterion rating must change in order to alter the decision score of the highest scoring Alternative, "Plan 3", by the same amount that a change of one unit in the Reference Criterion produces.

Reference Criterion: Acceptability

Tradeoff	Scale Units	Worst	Best	Relative Weight	Name
1.75	5 Point Scale	1.00	5.00	47%	Technical Recognition
1.00	5 Point Scale	1.00	5.00	100%	Acceptability
2.39	5 Point Scale	1.00	5.00	47%	Effectiveness
4.05	5 Point Scale	1.00	5.00	47%	Efficiency
117.70	Acres Restored	0.00	400.00	153%	Acres Restored
-19.21	$Millions	80.00	0.00	100%	Cost

Charles Yoe Charles Yoe | Hierarchy - Plan Selection | AHP, WEIGHTS | ✓ Connected | ✓ Rated | 2:36 PM

Figure 35: Lowest Criteria Trade-off Analysis

COMMENTARY

It bears repeating that this discussion is neither a critique of the software nor a tutorial. It is simply a demonstration of the feasibility of using the programs to help solve the kinds of decision problems the Corps faces. These are three good decision support software packages.

Any one of them would be an excellent addition to the District's planning and decision-making toolbox.

With respect to their input requirements, it is important to note that the hardest part of any multicriteria analysis is developing a good decision matrix. The steps that lead up to this are a normal part of a good planning process. That makes the adoption of multicriteria decision-making tools to planning's decision-making a natural fit.

The decision matrix would be the same regardless of the software package chosen. So we are essentially talking about the ease with which the necessary information can be entered. The determination of weights, always one of the most critical parts of any multicriteria analysis, differs from one program to the other, and this may be one of the principal factors in choosing one technique over the other.

Decision Lab 2000 offers a synthesis of information using PROMETHE, an outranking procedure. This distinguishes it from the other two software packages, which both use AHP. Criterium DecisionPlus also offers SMART analysis of alternatives. Other software packages are available. The Decision Analysis Society maintained a list of MAUT and AHP software at the time this report was written at: http://faculty.fuqua.duke.edu/daweb/dasw1.htm.

SUMMARY: TAKE AWAY POINTS

1. Commercial software is an invaluable decision support aid and is highly recommended.

2. Any of the software presented in this chapter would be an excellent addition to the planner's toolbox.

3. Using more than one decision-support program can support the robustness of a decision.

LOOK FORWARD

The final chapter of this manual looks at the qualities of a good multicriteria decision-making tool. It compares the results of several of the techniques presented in earlier chapters and closes with a set of twelve guidelines to help the planner choose the right multicriteria decision-making technique for the right situation.

IX. WHAT MAKES A GOOD DECISION TOOL?

Now it is time to take stock of all that is in this manual. As much as some people value options, others disdain them. When there is a choice to make, there is always a chance you'll make the wrong choice. This is indeed a fitting conundrum for a manual about decision-making aids. The goals of this chapter are simple. It begins with a discussion of the desirable qualities of a decision support system. These qualities have been identified by the Corps technical support team for this project and by experience. The next section compares the rankings of several techniques used in this manual to examine how different or similar they are. The manual concludes with some guidance on which techniques to use and when to use them.

QUALITIES OF A GOOD TECHNIQUE

The planning for this manual involved a highly energetic exchange with the Corps technical review team for this research project. Their input is greatly appreciated, and we hope their wisdom is reflected in these pages. At times during that discussion, the scope of this manual threatened to equal or exceed the rich literature that exists on multicriteria decision making. At the end of that discussion, everyone was asked to list the most important qualities of a good decision making trade-off analysis technique. There were two unanimous responses, perhaps different sides of the same coin. The review team wanted practical and easy to use techniques.

To these two qualities we add a few more. A good technique is transparent. That means the analyst and decision maker can in effect say "this is what we did and this is why we did it." Although an interested party might disagree or might not understand all the technical details of the analysis, they will be able to understand what was done and why it was done. That transparency should extend to technical transparency, meaning that a suitably educated and experienced person should be able to examine and "see through" the calculation.

This practical, easy to use and transparent technique should be structured and organized. These seem to be simple components of a transparent approach. The results of the analysis, the process that produced them and the decision framework in which that work was embedded should be something that can be easily described and understood. This makes some techniques like multiattribute utility theory, less effective with stakeholders despite its many strengths.

A good technique has a process and follows it. The technique is commensurate with the importance of the analysis and the resources available to it. Simple problems and simple studies warrant simple techniques. Not every multicriteria decision technique has to be quantitative. Qualitative judgments will sometimes be appropriate for decision making.

The technique should be collaborative. It needs to involve others. Multicriteria decision making is driven by compromise rather than optimization. Compromise requires collaboration. Early and effective collaboration is best.

It needs to be comprehensive. You have seen how a change in weights or normalization technique can change the ranking of an array of plans. If an important point of view has been neglected, compromise is not going to be easy to obtain. The decision matrix should be based on a comprehensive view of the most important decision criteria.

The validity of the data is important. This transcends the decision process and is a truism for the entire planning process. Associated significant uncertainties in the decision matrix need to be addressed. This may be done through sensitivity analysis or by including an uncertainty criterion in the matrix itself.

The analysis has to be understandable. Interested people have to understand what you did. This is a first cousin of transparency. Some people will want to examine the process. For them, it must be transparent. Lost files, folders and arcane spreadsheet programming techniques do not meet this quality. There will be many other people who do not want to examine the result but who do want to understand it.

It has to be consistent. It is easy to make mistakes. The techniques are often difficult, but they are always tedious, and it is easy to make a mistake. It could be forgetting to use the reciprocal so you can maximize a criterion measurement planners want to minimize. Arithmetic mistakes are easy to make. It is not hard to misuse software.

The process needs to be flexible. If a new plan is formulated, you have to be able to include it. If the criteria change, the decision matrix should be easy to update. If new data or analyses generate changed criteria measurements, you need to be able to accommodate that. If someone has a better idea, it should not be precluded.

A good process is well documented. This is one significant advantage of software-based models, commercial and homemade. The models, their databases, scenarios and associated files do provide a modicum of documentation. But analysts should not overlook the need to keep a chronology of significant decisions and thoughts throughout the process. Lists are your friends. Keep them well and close at hand.

The assumptions used in the process should be clear. It is okay to say the weights were 10, 20, 30 and 10. There is a significant and important subjective part of this process. The justification need not be any more than a judgment call. What is not acceptable is an inability to identify the weights used or the people and processes used to determine them.

COMPARISON OF SELECTED TECHNIQUES

A number of techniques have been presented throughout this manual. There is a temptation in preparing a manual like this to provide an endless series of comparisons and sensitivity analyses. That would prevent this manual from ever reaching a conclusion.

Table 51 presents the rankings obtained by several of the techniques presented throughout this manual. Two caveats are in order. First, this case study was based on synthetic data. The examples in this manual are anecdotal, not conclusive. Second, although the criteria

TABLE 51: COMPARISON OF RANKINGS

	Weighted Product % Max.	Weighted Product % Range	Borda Unequal Weights	Decision Lab 2000	Expert Choice Pro	Criterium AHP	Criterium SMART	Borda Equal Weights	MAUT 2 Criteria
Plan 1	10	10	10	10	10	10	10	10	4
Plan 2	9	9	8	8	9	7	7	6	1
Plan 3	1	1	4	1	1	1	1	4	2
Plan 4	2	2	1	2	2	2	2	1	3
Plan 5	8	8	7	7	7	8	8	8	4
Plan 6	3	3	2	3	2	3	3	2	6
Plan 7	4	4	3	4	5	5	5	3	7
Plan 8	5	6	5	5	4	4	4	7	8
Plan 9	6	5	6	6	6	6	6	4	9
Plan 10	7	7	9	9	8	9	9	9	10

preference assumptions, i.e., the weights, used in the various techniques were very similar, they were not always identical.

There is an enormous literature supporting and critiquing these techniques. Every method found in the literature has strengths and weaknesses. They are often mathematical and complex in nature. This manual has purposely avoided a head on discussion of these issues.

The two shaded rankings at the end of the table are not considered comparable to the others by even the wildest stretch of the imagination. The first used equal weights for the criteria, the second used acres restored and cost as the only two criteria in the decision matrix.

The Borda ordinal ranking is the only technique that fails to return the same top two plans. That technique relies on a rather subjective assignment of ordinal rank and points for the rank. Plan 3 is first in six of the seven roughly comparable techniques; Plan 4 is second in these as well. Avoid the temptation to draw any global conclusions from these results. The one thing that can be said with absolute certainty is that different techniques produce different rankings even when working from the same data and weights. If a complete ranking of plans was the goal of this exercise, it would remain unresolved because the rankings do differ. These results provide a reasonably sound argument for Plan 3 as the best plan, regardless of the multicriteria decision model used to evaluate the decision matrix.

This analysis does not even begin to address the sensitivity of the rankings to different weights or criteria measurements. What we hope it does is point out the importance of not accepting the result of any one multicriteria analysis as a de facto decision. It is not, and we recommend as much sensitivity analysis as is necessary to provide a level of comfort with the results. In those instances where the differences cannot be resolved or smoothed by analysis of the results, the decision maker is back to square one, which says it is the decision maker's job to make the decision.

WHICH TECHNIQUE TO USE

There are hundreds of decisions made in the course of a typical planning investigation. Many of these are technical, task-oriented decisions most appropriately made by analysts with academic training and professional expertise. Some of these decisions rise to the level of routine scoping, screening, winnowing, discriminating, discerning, separating and qualifying on the way to developing a final array of alternative plans. These decisions can make good use of the techniques described in Chapters IV and VI. Particularly useful at this stage of the planning process are the conjunctive and disjunctive procedures.

Of keenest interest in this manual, however, are the decisions that involve direct or indirect trade-offs. While we focus on the choice of the recommended plan, the reader is reminded for the last time that these techniques may have considerable utility in earlier stages of decision making in the planning process.

The overarching rule to follow is to use what is useful. The overarching reminder is that you are making decisions when there is no objectively determined best answer and no objectively determined best multicriteria decision-making technique. This said, there follow a few simple guidelines you may find helpful. The guidelines are oriented toward the practical while mindful of the technical strengths and weaknesses of the results presented.

First, use a decision support framework to guide significant decision making in the planning process. There is a way to do good planning. The six-step planning process describes it. There is a way to make decisions. It is described in this manual by an eight-step decision support framework. Use it. Follow the steps. It gives you a way to think about making decisions. Having a systematic way to approach decision making within the planning process is an invaluable aid to good decision making. You should always know where you are in the decision-making process. The context for the remainder of the guidelines is that the larger planning process that engulfs this sixth-step decision has produced a good final decision matrix.

Second, if a dominant alternative exists, choose it. There is no need for a decision-making model or additional analysis when there is a plan that scores higher on at least one criterion and no lower on any other criteria than every other plan. A dominant plan wins. If it is not recommended, then you could not have had the actual, final decision matrix.

Third, optimize when you can. If it is possible to satisfactorily choose a plan based on the largest or smallest measurement on a single criterion, do so. These situations will be few and far between, but they may not yet have disappeared from the face of the earth.

Fourth, do not do silly things. There are more than a few examples of bad techniques in decisions makers' pasts. They range from arithmetic mistakes, such as were found with the case study for this manual,[37] to the use of weighted products with incommensurable metrics. Therefore, the advice is, maximize instead of minimize.

Fifth, use the simplest multicriteria analysis that meets your needs. Note that is simplicity, constrained by need.

Sixth, decide if you are going to use an aggregation technique or an outranking (pairwise comparison) technique. Use an aggregation technique for decisions that are less complex, less controversial and less subject to further scrutiny.

Seventh, when using an aggregation technique (weighted products, ordinal ranking, multiattribute utility theory), use a commensurable metric. If you have a convenient metric that appears in the raw data—such as dollars, habitat units, energy flows or any other meaningful metric—that can be used for all your criteria measurements, use it.

Eighth, when a raw data metric is not available, normalize your final decision matrix to get to a commensurable metric. Use the percentage of maximum technique unless you have a reason not to. Ordinal techniques are generally not as popular as weighted products.

Ninth, develop weights using one of the techniques described in this manual. Usually the decision makers level of comfort with the method is the best basis for choosing the technique.

Tenth, try a simple weighted product and see if it gives you information that helps you decide.

Eleventh, consider using commercial software for your analysis. It takes some time to learn, but it is very user friendly and is becoming more so. It enables you to do far more analysis of your results than you will be able to do on your own. Be aware that you will not likely understand what the software is doing to arrive at its results as well as you will understand what you have to do to arrive at your results if you do the analysis yourself. The need and ability to understand and explain what has been done to arrive at the answer may be enough to swing your choice of method in one direction rather than another. Use the software you best understand.

Twelfth, analyze your results. Test the sensitivity of key assumptions about weights and even techniques when you are doing the analysis yourself. Identify the trade-offs of the various choices and discuss them broadly.

SUMMARY: TAKE AWAY POINTS

1. There is a decision support framework for making the kinds of multiattribute decisions required to solve the wicked problems of the Corps planning process.

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[37] A five-point scale was used for several criteria measurements. The point values were simply added to rank the plans. This meant a high negative impact (say 5) was added to a high positive impact (say 4) to obtain a meaningless sum (the resulting 9).

2. That framework comprises eight steps: problems, alternatives, criteria, evaluation, decision matrix, weights, synthesis and decision.
3. Use the process.

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