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A Study on the Development of Intelligent Decision Systems Using Influence Diagram

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Abstract

Intelligent Decision System supports the decision analysis process in the managerial problems with decision analytic knowledge as well as domain specific knowledge. Influence Diagram has been one of the major knowledge representation in the intelligent decision system. In the development of intelligent decision system, knowledge acquisition is also known to be difficult. This paper suggests a developing tool using an influence diagram and Verbal Protocol Analysis which faciliates knowledge acquision for intelligent decision system. An environmental decision making problem is used as an illustrative example and validation of the suggested developing tool is discussed. The suggested tool is very flexible to be expanded or applied to similar problems.

1.INTRODUCTION

Everyone faces the challenge of making good decisions. Decision making is complicated by competing alternatives, conflicting objectives, and uncertain consequences. Uncertainty, in particular, makes decision making difficult, whether it concerns the profitability of a new product or the health risk of toxic chemical testing. Decision Theory allows us to make statements about what alternatives are and how the outcomes of each alternative are valued related to one another. Decision Analysis (DA) is an engineering discipline that tells how to apply decision theoretic principles to real problems in a tractable manner [6,7,25]. In spite of the major improvements in DA, the complex and evolutionary nature of the formulating process has limited its widespread use. The amount of effort, money, and time

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spent formulating a decision problem into a decision model is very burdensome. Another problem of DA is that it is usually difficult to apply the knowledge or information obtained while formulating one decision problem into other similar problems. These difficulties are considered to be a bottleneck to the widespread use of DA [23]. Since the early 1980s when several knowledge-based systems proved to be successful, there have been some approaches to apply knowledge-based systems to DA [1,4,9,11,23]. Knowledge-based systems that implements the decision analysis are referred to as Decision Analysis Expert Systems [7], Intelligent Decision Systems [3,4,15], or Knowledge-Based Decision Systems [1,11,12]. The common properties of these systems are they provide their users with a substantial amount of domain-specific knowledge and normative power of decision analysis. In this paper, Intelligent Decision System (IDS) is used as a representative. An IDS constitutes a means by which decision makers can exploit the normative power of DA in a relatively simple and inexpensive way.

In the development of IDS, there is no general agreement on the basic methodologies and appropriateness of the representation scheme. It is, however, widely recognized that influence diagrams are used to represent domain knowledge, uncertainty and preferences of decision makers [3,4,11,24,27]. Decision Class Analysis (DCA) suggested by Holtzman [3,4] is used as a basic concept combining DA and knowledge-based systems, even though it has some ambiguity [1,4,12,13,14,22]. Based on DCA, a set of decisions having some degree of similarity among them is treated as a single unit. Compared to knowledge-based systems, IDS has some additional difficulties in the development stage. Among them, designing a decision class and knowledge engineering are major difficulties. Designing a decision class is regarded as an art, and it is usually decided subjectively by system developer(s) with the help of decision makers or domain experts [4]. Knowledge engineering is the process by which expert knowledge is obtained, represented, refined, codified and installed in knowledge-base [30].

In spite of its conceptual usefulness, it is very hard to find a research on the development of an IDS. In 1985, Holtzman suggested a conceptual structure of IDS [3,4]. He implemented *Rachel*, an IDS for infertile couples using rule-typed knowledge. *Rachel* is a dialogue-based consulting system added some decision analytic knowledge. It is hard to see *Rachel* as an IDS. Howard introduces an IDS as a supervisor system of the decision analysis process [7]. He thought an IDS would not provide a direct recommendation, but rather building and evaluating a decision model that is custom-fitted to the decision maker. Kim et al. [1,9,10,11, 12,22] have tried to develop an IDS for a managerial problem domain using diverse knowledge types - frame, rule and neural network. The main criticism of these approaches are that although they are appropriate to a small size decision class, they may not be suitable to a real world problems. The author found that the model-based approach alone is hard to be applied to a real world problems. This research summarizes the following decision making process (i. e., decision analysis process) of IDS, based on previous researches:

1. Define a class of decisions by system developers or decision analysts.
2. One decision problem is selected to be modeled and solved by decision analysts with the help of decision makers and domain experts.
3. The domain knowledge and decision-analytic knowledge obtained from step 2 are stored in a knowledge base or model base.
4. Another problem in a same class is modeled and solved by decision makers, and the knowledge base or model base is expanded.
5. When a new decision problem is encountered, it is decided what class can cover a new problem, and how to use an existing knowledge base or model base.

A research related on the above steps is mainly focused on step 2, i. e., to build a decision model for an individual decision problem. The interview process [4,11] and the goal-directed approach [4,11,21] are most frequently used to structure an influence diagram. But the interview process is a kind of conversation process interchanging domain-specific knowledge and decision-analytic knowledge between decision makers (with domain experts) and decision analysts. Text analysis procedure is introduced to model an influence diagram by McGovern et al. [15]. One of the main purpose of knowledge-based systems (including IDS) is to mimic or replace an expert [30]. But decision problems are difficult to be modeled by the knowledge from text. Most real world decision problems are hard to find in the text, so the knowledge should be obtained from experts of that area. Merkhofer suggested using an influence diagram to solve a Multiple Attribute Decision Making (MADM) problems [16,17].

In this research, an IDS developing tool is suggested for step 2, and part of step 1, step 4. The author's previous research is related with step 3 [1, 11, 12, 22]. Step 5 is left for the future research area. The underlying idea of suggested tool is to acquire a decision analytic knowledge, domain-specific knowledge, and preferences from experts using Verbal Protocol Analysis (VPA). From the extracted decision-analytic and domain-specific knowledge, an influence diagram is developed. The knowledge is used to build a decision model as well as to decide a decision making process for a specific individual decision problem. This decision model and decision making process is modified to be applied into another similar decision problem within a predefined decision class. This paper describes the developing tool with environmental decision problems of Minnesota (MN) state. Even though an IDS is not yet implemented, this developing tool itself is successfully applied to a real world problems with an ID developing software alone. After the tool is explained and educated to decision makers, they were asked to evaluate the tool. The comments and verbal evaluation of the tool is summarized in the discussion section. The tool is also helpful for the decision makers or decision analysts to define a class of decisions, even though it is regarded as a kind of art [3,4].

The main contributions of this research can be summarized as follows:

1. VPA is used to help decide the scope or boundary of the decision problems in designing a decision class. This analysis makes it easy to capture the knowledge from those of multiple decision makers or experts.
2. A decision class analysis is used to solve related decision problems with less effort and time. Their related information within a same decision class is represented as an influence diagram.
3. Most decision problems have multi-dimensional value structure [7,16,17]. Influence diagrams combined with Multi-Attribute Decision Making (MADM) methodology treat well the trade-off between conflicting objectives of hierarchical value structure.
4. The suggested developing tool is applied to a real world decision problems with decision makers of that problems, and is discussed with decision makers about usefulness, efficiency, internal validity, and reliability of the tool.

In section 2, the basic concepts of IDS such as influence diagrams, DCA, and knowledge engineering of IDS are provided. Section 3 provides an example of decision class, environmental decision problems of Minnesota. Section 4 describes about a developing tool for IDS using ID and VPA. The validation of the tool about the process, internal validity and reliability are discussed in section 5. Finally, section 6 contains conclusions and future research area.

2. Intelligent Decision System

2. 1. Influence Diagrams

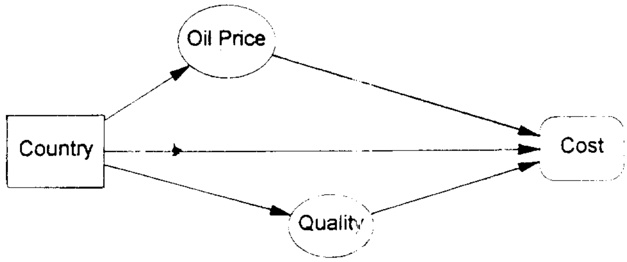
Influence diagrams were developed as a computer-aided modeling tool by Howard and Matheson [6]. The concept underlying influence diagrams is the representation of variables critical to the problem under consideration, and their interrelationships, in a graph-theoretic manner [24]. In contrast to other models, influence diagrams focus decision makers' attention on only those problem features that are most relevant to the focus being made. Excluding irrelevant information from an influence diagram can save decision makers' time and effort since there are fewer variables to be interpreted. If decision makers want to pay attention to a certain part more specifically, they can expand part of an influence diagram to a deeper level. The flexibility of influence diagrams makes it easy for decision makers to modify it and to store influence diagrams for the future use. An influence diagram is defined as a network consisting of a directed graph with no directed cycles, in which detailed data is stored in the nodes of the graph. The diagram consists of nodes and arcs (influences, or arrows) that represent decision basis [6,7]. Each node in the graph represents a variable in the model. This variable may be a constant, an uncertain quantity, a decision to be made, or a criteria value. The nodes can be viewed from three levels, the relational, functional and numerical levels [2,6, 15]. The relational level shows the major components, their types and interdependence. This makes the influence diagram to be suitable for the DCA. In short, a decision class is composed of some decision problems. Each decision problem can be represented by an individual influence diagram [2, 22]. Individual influence diagrams of a same decision class are almost identical in the relational level. They are different in the functional and (or) in the numerical level. This is further explained in the next section.

Once the problem has been modeled using an influence diagram, analyzing probabilistic relationships can be manipulated at the graph level of the diagram. Olmsted [20] proposed a computational architecture for automating influence diagrams along with rules specifying the topological transformations needed for his solving procedure. Shachter [26] developed a goal-directed algorithm based on these rules.

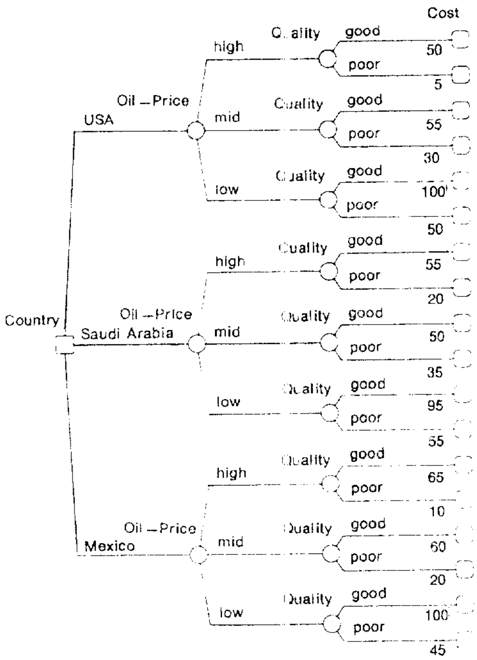
At first time, an influence diagram was used a supplementary tool of decision tree [6]. After Olmsted's and Shachter's algorithm, influence diagram alone has been used as a decision analysis tool. Please refer to Kim's and Holtzman's paper about the comparison between two models including several drawbacks of decision trees [4,11]. Figure 1, taken from Kim [11], shows an influence diagram and a decision tree, which represent a same problem.

In Figure 1(a), "Country" is a decision node. Decision nodes represent decision options that are available to decision maker(DM). It has branches to represent the possible options. Each chance node has an underlying probability distribution to quantify the uncertainty for the variable that node represents. Arcs into chance nodes represent information affecting the probability distribution for that node. Chance nodes are generally represented as a cycle or an oval. "Cost" is a value node, and it summarizes the preferences of the DM for the outcomes. A mathematical function (value function or utility function) associated with value node can be used for deriving a numeric value representing the trade-off among attributes of the problem.

Fig. 1 An Influence Diagram and a Decision Tree of a Same Problem



(a) influence diagram



(b) decision tree

Direct predecessor nodes of a value node indicate the attributes included in the evaluation of preferences.

2.2. Decision Class Analysis

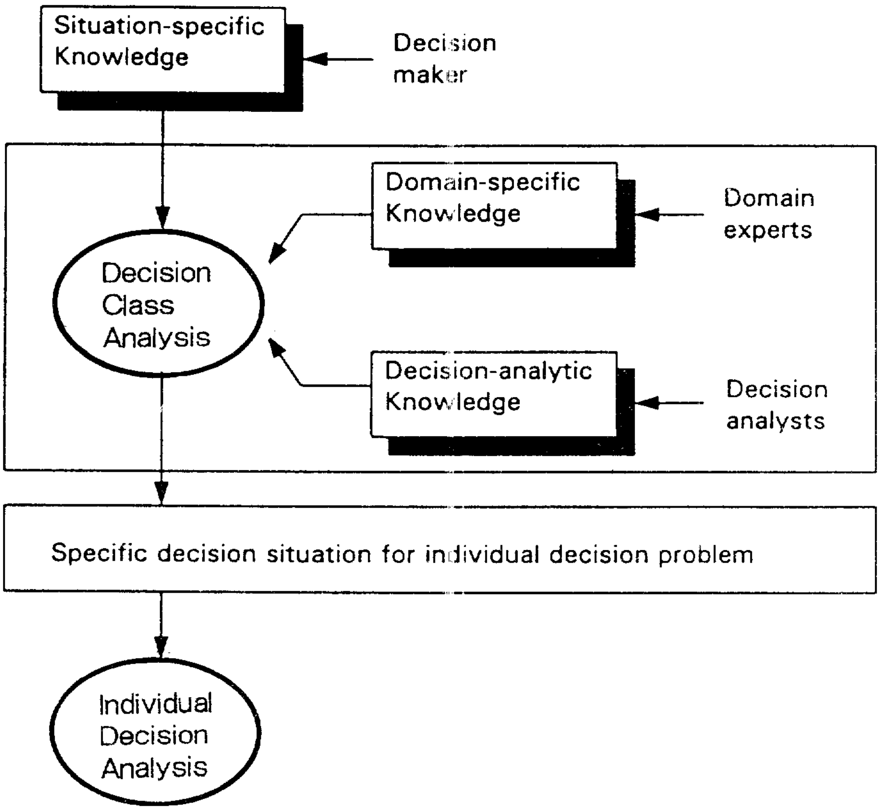
Decision making process can be viewed as three steps: formulation, evaluation and appraisal [4,7]. Among them, formulation (namely, development of a decision model such as an influence diagram) is known to be the most complicate and burdensome process, and the resulting model becomes applicable to only one specific decision problem [11,23]. The knowledge used and learned in modeling one decision problem is difficult to be applied to other similar problems.

To build a decision model, typically, domain experts provide domain-specific knowledge, while decision makers furnishes situation-specific knowledge (i.e., information about his or her circumstances and preferences) [2,4]. Domain-specific and situation-specific knowledge is required to be effectively combined to yield a formal model from which a recommendation can be inferred. In many difficult decisions, each knowledge source is ignorant of the others' knowledge. In fact, only a small portion of each participant's knowledge is needed for any specific decision. In its integrator role, DA focuses on acquiring knowledge from the decision participants, thus facilitating the development of a consistent decision model that properly represents the domain and situation of the decision problem. Influence diagram is a good decision model playing an integrator role, because it provides an effective communication language between the remote knowledge sources.

Holtzman [3] suggests decision class analysis which regards DA as an integrator of decision knowledge and treats a set of individual decisions having some degree of similarity as a single unit. He has referred this unit as a class of decisions and the corresponding analysis as a decision class analysis. Hence, the decision problems in a class share a common domain and also some common situation features.

Decision Class Analysis implies deliberately omitting knowledge pertaining to the decision situation. Hence, analyzing a class of decisions occurs at a higher level of abstraction than analyzing a single decision. An interesting way to think about analyzing a class of decisions is to view the collective analysis as a set of instructions for performing individual decision analysis. Thus, whereas the end result of an individual decision analysis is a decision, the result of a decision class analysis is an individual decision analysis [3,4,22]. Decision class analysis is performed by collecting the specific situation and analyzing the specific domain knowledge with decision-analytic knowledge. Figure 2 depicts the knowledge about decision class analysis.

Fig. 2 The Knowledge about Decision Class Analsis



2.3. Knowledge Engineering for IDS

IDS is suggested to enjoy the efficiency advantages of ES and the normative power of DA. The IDS is understood to be knowledgeable in the process of decision analysis, in what it means to formulate, evaluate, and appraise a decision problem, and in the content of the area in which a decision is made. IDS would have knowledge for the creation of decision models, knowledge for their evaluation and knowledge for explaining their implications [7,11].

The existing knowledge acquisition for the formulation of decision models consists of two stages. First, decision analysts or knowledge engineers conduct extensive interviews and discussions with domain experts in order to transfer the domain experts' mental image about the problem into the analyst's mind, where it will become the analysts' mental concept. The analyst then translates his/her mental concept into a formal representation, a decision model such as an influence diagram. *Rachel* is an IDS to diagnose infertility [4]. It contains rule-typed knowledge base about model building, probability distribution and preference knowledge. This system is regarded as a traditional knowledge-based system with some decision analytic knowledge, although it may not suitable for managerial decision problems. KIDS by Kim et al. is for strategic decision problems using HyperCard [1, 11]. It has a graphic user interface and knowledge base to structure an influence diagram. The main limitation of this system is its limited knowledge base capacity. McGoven et al. suggested the elicitation of decision structures through text analysis [9]. They emphasize that this approach is primarily exploratory with less well structured problems. They argue that when combined with natural language processing software, it will be possible to acquire knowledge of IDS. But the main source of knowledge of managerial problems usually comes from human experts, not from the text. So the knowledge base constructed from text analysis is usually out of date or not suitable in the manageable problems. In this paper, a Verbal Protocol Analysis is suggested to acquire knowledge from real world problems. VPA is suitable to acquire knowledge from many participants. VPA is explained in section 4.

As Owen has suggested, an influence diagram is suitable to be built by goal driven interactive processes [21]. If the goal is so complex that it is not easy to build an influence diagram, MADM becomes a useful tool. An influence diagram combined with MADM can treat well the relationship and trade-off of objectives.

3. Environmental Decision Problem: A Case Example

In recent years the Minnesota Natural Heritage and Nongame Research Program (MN NHNRP) has had to make decisions in a dilemma situation which often faces administrators and lawmakers throughout the world. This dilemma is how to balance endangered species protection with land development. The decision makers at the MN NHNRP perceived a need for guidelines to create a well-documented, defensible and explicit decision making process, and they requested assistance in developing an IDS to improve the current process.

3.1. The Decision Situation

The staff at the MN NHNRP decide whether to grant or deny a requested endangered species taking permit. Such a permit is issued by an authority at the Minnesota Department of Natural Resources (MN DNR) and allows its recipient to destroy the threatened or endangered species listed in it (MN Statute 84.0895). The final decision is based on recommendations made by the DNR NHNRP staff. Everyone involved in making the recommendations is referred to as *decision makers*, as alternatively as *staff members* or *specialists*. The need for a decision arises when it is clear that a project under Environmental Review (required by the MN Environmental Protection Act, MEPA) would cause the destruction of one plant or animal or a population of a species, classified as threatened or endangered under the Minnesota Endangered Species Act. In such cases, the taking permit is required to allow the project to proceed. An Environmental Review is required and is the formal governmental process used to determine whether to grant necessary permits based on consideration of ecological and social impacts. The law states that the permit may be issued if, "the social and economic benefits resulting from the [proposed project] outweigh the harm caused by it" (MN Statute 84.0895 Subd. 1 and 7(a)). Because the law is framed this way, it creates a decision situation which is a microcosm of the larger policy issue of balancing the need and desire for land development with the desire to preserve biodiversity. They encounter these decisions about two or three times a year. DNRs in other states also consider similar decisions. Some of the previous and current decision situations are summarized as following Table 1.

Table 1. Three Situations Requiring Taking Permits

Projcet :	Considerations:
1. Landfill Expansion	Existing landfill expanded onto 63 acre site
The site contains:	17 acres of prairie, 20 acres of wetlands, 1 endangered and 1 threatened plant species
Crucial considerations:	The quality and rarity of the site, social pressures
2. Flood Control Project	Impounded a lake in order to dam an area to prevent flooding in downstream areas
The site contains:	A very rare MN endangered plant, the habitat in which this plant is found is also very rare
Crucial considerations:	Many pepole involved, large momentum of the project, the precedent the decision will set
3. Golf Course and Recreation Project	Build a large scale development and golf course next to existing ski resort area
The site contains:	3 endangered plant species, 2 threatened plant species, 1 plant of special concern
Crucial considerations:	Forest fragmentaiton and water quality (erosion, sedimentation, wetlands, impacts on aquatic habitats), a permit has never been granted for a development project.

3.2. A Landfill Example

The following example (first one in Table 1) illustrates the type of decision situation by which this research was originally motivated. In a project under Environmental Review, a landfill operator proposes to expand an existing landfill onto a 63 acre site which contains a 20 acre plot of the last remaining high quality prairie of its kind in the state. Although the prairie has no legal protection, the site contains very large and healthy populations of an endangered and a threatened plant species. In order for the project to proceed the proposer would need an endangered species taking permit issued by the DNR to destroy these populations. The plants are healthy, but even though the habitat is well suited to the plants needs, some specialist do not consider it to be high quality because it is surrounded by development on three sides and it is susceptible to invasion by exotic species. One population is of a very rare species: of the other species many healthy populations can be found in the State. Some of the NHNRP staff estimate that the populations could survive indefinitely if the proposed project is not authorized. Others, however, suspect that the populations would not survive longer than 15 years even without the proposed landfill expansion. If the project does proceed, it is certain that the populations will be destroyed. A moratorium prevents constructing new landfills near the high garbage producing metropolitan area, and some statistics indicate that within five years existing landfill sites will not be able to accept additional waste. Thus, if no additional landfill space is created, all new waste would be hauled at least fifty additional miles, increasing disposal costs. The project proposer might sue the DNR if the permit is not issued. If the permit is issued, it is possible that environmental groups would sue the DNR for not complying with its mandate under the Minnesota Endangered Species Act. The DNR's limited budget makes it reluctant to spend large sums in a legal battle, but not unwilling to do so in order to defend its decisions.

3.3. Properties of Current Decision Situation

The decision situations described in this paper is about to assist in deciding between two possible, yet mutually exclusive courses of action, both resulting in a win-lose situation. Periodically the MN DNR Natural Heritage and Nongame Research Program encounters situations which are similar but vary in the location, project type, and the number and type of species threatened (Table 1 depicts three of these decision situations). In previously encountered cases, the decision making process occurred on a basis of heuristic knowledge. The decision makers did not always follow an explicit set of criteria. They have their own criteria, which are slightly different from person to person. This made it difficult to consider the multiple criteria effectively and efficiently, and to defend the process. Some decision makers also did not have an explicit approach for assessing the relative importance of various factors, or evaluating trade-off. Many NHNRP staff members were involved in developing the recommendations to the final decision making authority. It had not been entirely determined how the different staffs' opinions should be treated. Ultimately this will be determined by the supervisors. The final decision may be made without a direct, well explained recommendation from the NHNRP. The final decision makers could also choose to ignore recommendations from the staffs though this is very unlikely. To summarize, the following assertions about the properties of the decision situation can be made:

1. The decision of what to recommend to the commissioner is made by many specialists i. e., experts who may consider trade-off between viability and importance of the population and social and economic benefits of granting a permit.
2. The major uncertainty is the survival of the population on site, nearby regions, and in the entire State, both if the permit is granted or is denied.
3. Decisions of this type are made periodically, and the final decisions depend on the circumstances of and information on a particular site and project, though the factors considered remain fairly constant.
4. Information gained through the problem solving process and about the species can be stored in a knowledge base or model base, and knowledge of the problem solving may be accumulated and used for other similar problems.

In conclusion, the general decision situation shown at Table 1 is thought as one class of decisions characterized by conflicting objectives, competing goals and alternatives, uncertain consequences and involvement of many decision makers. These conditions indicate that the permit decision is precisely the type of situation in which an IDS would be helpful.

4. Development of an IDS

4.1. The Verbal Protocol Analysis

After designing a class of decisions, the next step is developing a knowledge representation for the defined decision class. To do so, it is very essential gaining a clear understanding of the current decision situation and decision making process. The experts (some of the DM are experts and the others are novices) currently use some heuristic knowledge or rules in making their decisions. Even if they can not always make a best decision, their knowledge obtained by solving many similar but diverse problems over many years can be a good starting point. It is, therefore, important to obtain current heuristic knowledge from the experts (even if it may be partial and may not be consistent throughout the decision making process).

Verbal protocols are verbal reports obtained from experts who have been instructed to "think out loud" while solving problems. Experts are requested to express their thoughts step-by-step while solving the decision problems presented. The guidelines of VPA given to experts are in Appendix 1. The VPA is frequently used to obtain information regarding a subject's thoughts while focused on a problem-solving task (but not on their interpretation of these thoughts) [2,18]. This method is frequently used to gather information about the cognitive processes of a subject. System developers (the author, in this research) analyze the verbal protocol obtained from the recording machine. In such cases the data are "encoded". Encoding is the process for translating raw protocols to a form suitable for analysis by the various models being tested. In this paper, the data were encoded mainly to seek answers to the following questions:

1. What is the decision problem at hand?
2. What is being decided?
3. What are the objectives which need to be achieved through the decision?
4. What information is needed (and is it obtainable) as one proceeds?
5. What and where are the main uncertainties and risk factors?
6. What is the approach used in weighing the issues in relation to each other?

The respondents were asked to talk into a tape recorder while solving the decision problem. The decision problem used in this case differs from tasks typically used in VPA because the subjects cannot entirely solve the task at hand since its solution depends on interaction with other sources. The respondents could, however, arrive at their own conclusions without difficulty. Following are some quotes from the tape recordings which illustrate how a verbal protocol provides information (The number of each sentence represents sequences of each sentence by author's encoding scheme):

For example, one decision maker said:
03 This is an extremely high quality site and it is the habitat of two threatened plant species both of which have very well established and viable populations at this site. and this project would not simply take part of the prairie and a few of the plants, but would destroy

all of the plants and all the habitat.

06 Um··· the main uncertainties and risk factors··· one big uncertainty is what the long term viability of the prairie and the species on this site would be if the project doesn't go forward. Another uncertainty is what sort of mitigation to ask for, how to go about determining what the appropriate mitigation is and how to successfully negotiate with the project proposer to get it.

For example, another decision maker said:

23··· my approach in weighing the different issues in relations to one another is to look at the significance of the plant species on the site and the prairie in the context of the state as a whole.

27··· so, my first reaction is just to say no··· ah, however, certainly there has to be considered [sic] there is a need for more [landfill space]··· it would be economically and politically wiser to simply expand the current landfill into this area than it would be to site an entirely new landfill somewhere else··· opening landfills are [sic] very, very difficult.

The knowledge obtained from VPA is a mixture of domain specific knowledge, decision analytic knowledge, and preference of experts. It is the role of system developer(s) to classify the knowledge and to build a model and procedure based on it. Some of the knowledge by VPA are listed as follows:

1. It seems that decision makers extract major uncertain factors first, and then other related factors step by step.
2. Decision makers consider several objectives and related factors of each objective, and synthesize the relationships among objectives using trade-off.
3. Main decision is made by several decision makers considering the tradeoffs between viability of that instance of that species, social and economic benefit.
4. The major uncertainty of project which should be considered by DNR is the probability of existence of species on site or MN given permit of project.
5. Another uncertainty is the comparison of viability of the population on site given the proposal is permitted and denied.

Based on VPA, system developers should think of suitable methodologies. We reached to the following conclusions:

1. Decision and other uncertain variable are related each other, so influence diagram becomes a suitable representation.
2. Value structure is a multi-attribute structure, so ID combined with MADM is useful.
3. After designing an abstract-leveled ID based on VPA, it can be expanded with detailed

decision specific knowledge from the interview with the experts.

4.2. Building an Influence Diagram from VPA

Multiple attribute decision making is well suited for comparing options against multiple objectives. Competing objectives, such as "to maintain biodiversity of MN and its social benefits" and "to increase economic and other social benefits," are common in environmental problems. MADM establish attributes for measuring the degree to which identified objectives are achieved. Next it quantifies uncertainty in attributes to calculate decision strategies that maximize expected value (or utilities) and performing sensitivity analysis.

The following steps can be used to develop an initial simplified influence diagram:

Step 1: Isolate objectives from verbal protocols.

- Biodiversity in state (To maintain Biodiversity of MN)
- Benefit (To increase the social benefit of MN resident)
- DNR (To abide by practical considerations)

Step 2: Isolate decision elements from verbal protocols.

- Permit Decision
- Viability in State
- Viability of the population on site
- Lawsuit
- Result of suit

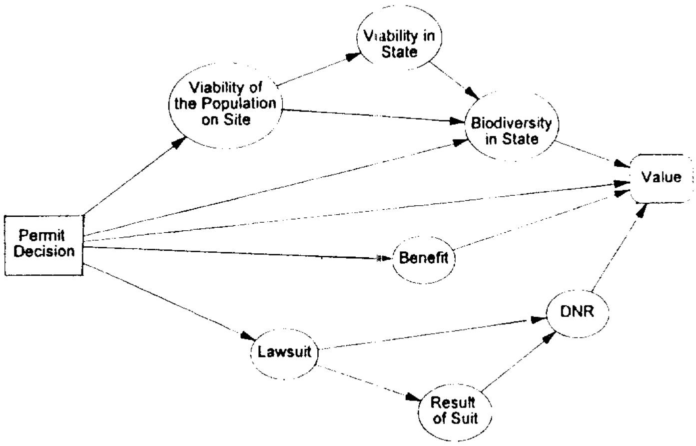
Step 3: Establish relationships between elements from verbal protocols. The relationships between elements are listed in pairs.

- Permit Decision influences Benefit
- Permit Decision influences Viability of the population on site
- Lawsuit influences Result of Suit

...

Step 4: Draw influence diagram. Each node is examined and its type is determined: decision, chance, and value node. The following initial simplified influence diagram like Figure 3 is constructed.

Fig. 3 Simplified Influence Diagram of Endangered Species Taking Permit Problem



4.3. Expansion Procedure of a Simplified Influence Diagram

The major uncertainties of this problem (see Figure 3) may be represented as the following inference problem types: the probability of "viability of the species on site given that proposal permit" and the probaility of "viability of the species on site given that proposal denial". Because these probabilities is not easy to elicit directly, this node is expanded into a more detailed diagram through the interview process with DMs. Figure 4 represents such an expanded partial diagram.

Fig. 4 Expansion of One Chance Node

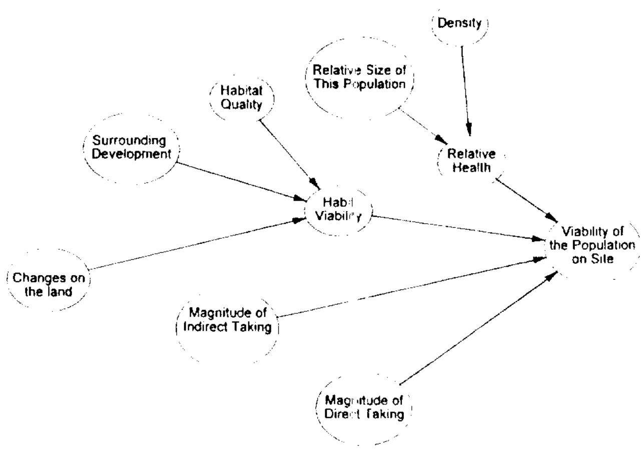
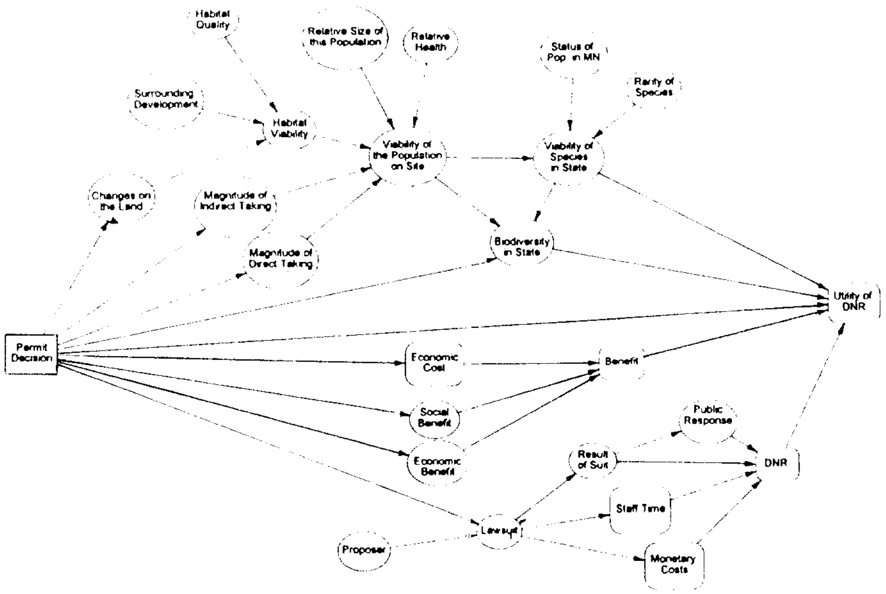


Figure 5 represents the final version of the influence diagram of the landfill project problem with some additional knowledge by experts. The main purpose of the interview is to obtain the exact knowledge of a probability distribution and preferences from DMs. But to fulfill such a purpose, a more detailed influence diagram is more helpful. So, building a final diagram currently occurs by obtaining all the knowledge. A major benefit of influence diagrams comes when it is time to analyze the model after building the model. Because an influence diagram is logically precise, there is no need to transform the diagram into a form appropriate for analysis. The same graphical representation that is so effective for modeling is also effective for analysis. Because transformations of influence diagrams correspond to applications of probability calculus, graphical techniques can be used to transform the diagrams to more convenient forms without getting bogged down in mathematical details. Please refer to Olmsted [20] and Shachter [26] regarding analysis by transformations.

Fig. 5 Expanded Influence Diagram of Endangered Species Taking Permit Problem



4.4. Analyzing the Influence Diagram

Once the ID in the relational level is completed from decision makers, decision makers enters their state assessments, probability assessments, preferences and weights, and then calculates the expected value (used to indicate the preferred alternative). The model is set up so that an individual or a group of decision makers begins by assuming that they grant or deny the permit (the decision node), then estimates the probability of certain events occurring (the chance nodes) and the state of certain relevant factors (the value nodes). The relative importance of various factors (the weight a factor receives) is also assessed. The most important information for this kind problems is a subjective probability of each event given each option is decided. But all the values of each event are not related with options directly. Instead they are related each other as a network form like Figure 3. Figure 6 shows the generic decision tree transformed from influence diagram shown in Figure 3. As we said before, it is very hard which node is conditional or not to a given node in the decision tree. For an example, "Biodiversity in state" seems to be dependent on all the preceding nodes if you just consider decision tree shown in Figure 6. However influence diagram shows that only "Permit decision", "Viability on site", and "Viability in state" nodes influence "Biodiversity in State".

Fig. 6 Generic Decision Tree

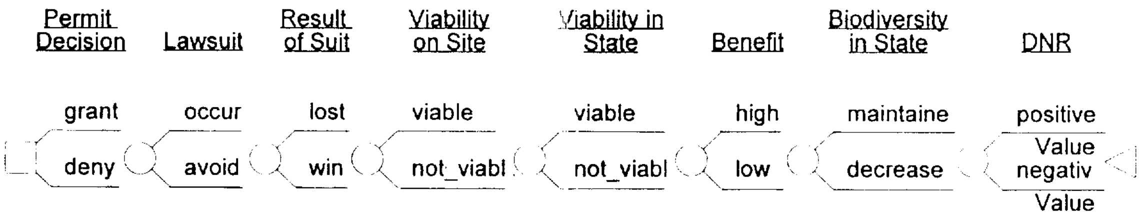
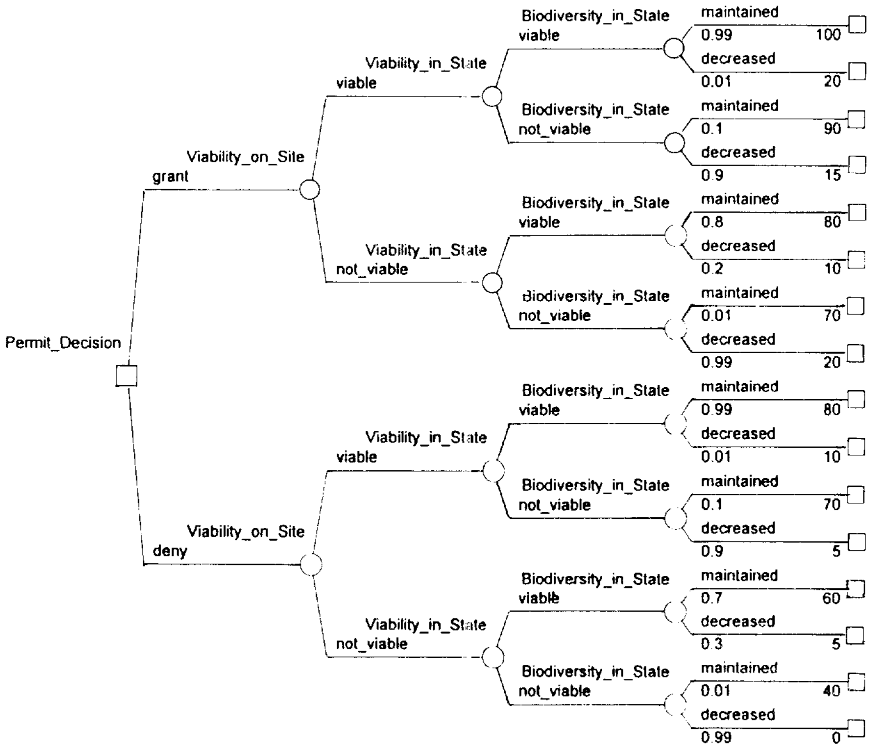


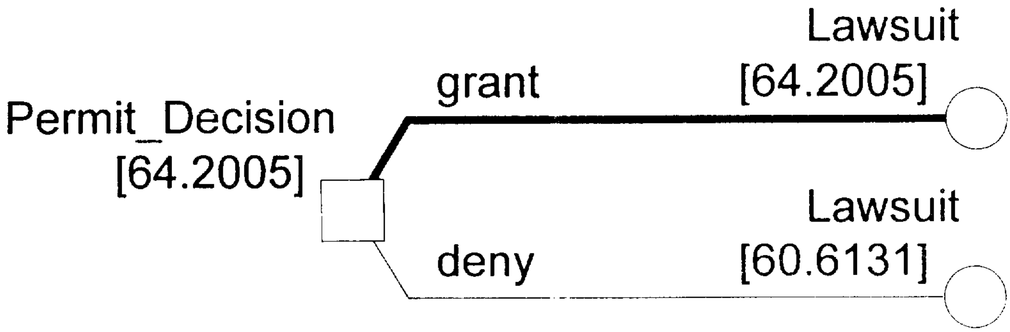
Figure 7 shows the assessments of values and probabilities for "Biodiversity in State". For purposes of testing the tool, estimates of subjective probabilities (how likely a decision maker thought an event was) and assessments of states were obtained through interviews with the decision makers using the influence diagram as a basis for discussion. These interviews were also used to develop the scales used to evaluate a variable or probability of an event. Thus, the scales were developed using the expertise of the Natural Heritage Program decision makers.

Fig. 7 Values and Probabilities for "Biodiversity in State"



The categories for social and economic benefits were developed with input from the commissioner's office, since it is this office which typically assesses these issues. When used by a group or by individuals, an expected value or "score" can be calculated for the alternatives of granting or denying the permit given the state and probability assessments. The values calculated by the model reflect how well a decision meets the goals given decision makers' inputs. Figure 8 shows the calculated results for the simplified influence diagram shown in Figure 3. The expected value of granting the permit is 64.2 while the expected value of denying the permit is about 60.6. Thus, the recommended course of action given the (combined) assessments of the two decision makers, would be to grant the permit because our criteria is to choose an alternative with maximum expected value. Please refer Shachter [26] about the optimizing algorithm of influence diagram.

Fig. 8 Expected values of Two Options



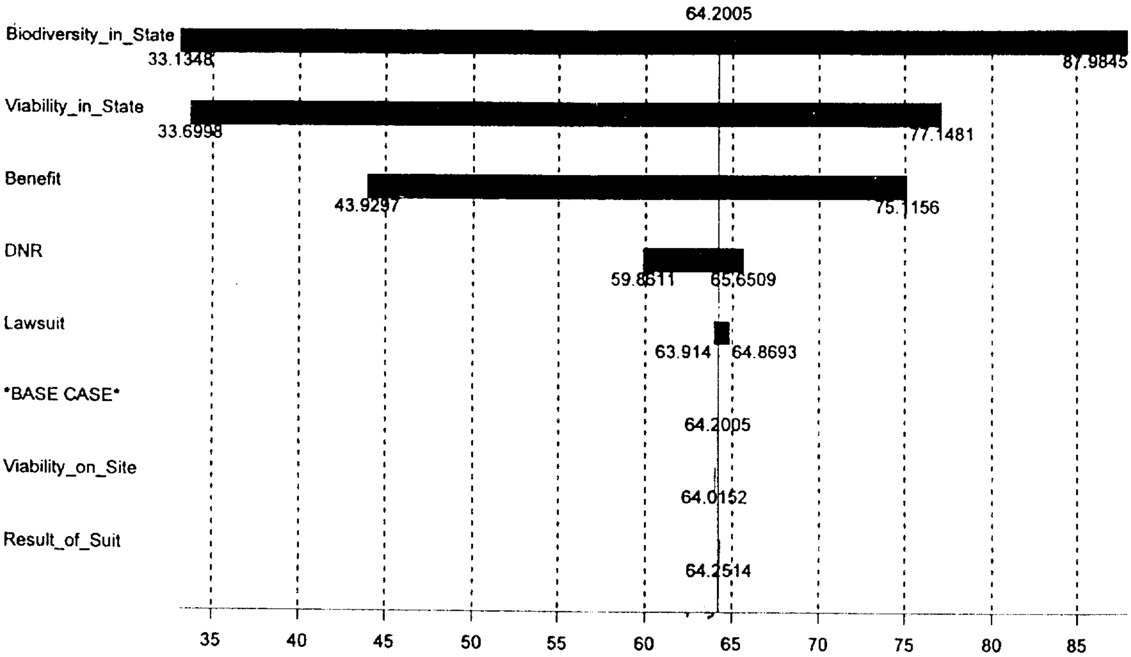
Once the expected value of each of the alternatives has been calculated, it is useful to assess the validity and robustness of these numbers with regard to what intuitively makes sense. If the results do not seem appropriate, it is advisable to re-assess the values and probabilities entered previously to determine if any of the estimates should be revised. Figure 9 shows deterministic sensitivity analysis for the case example. This shows "Biodiversity in state" and "Viability in state" is very sensitive. This means that if the values of "Biodiversity in state" and "Viability in state" are changed, the optimal decision may be changed [5,7]. Even though the "Viability on site" is a very important event, it looks to influence little to the decision, because the probabilities of that node is nearly deterministic. In this case decision makers may wish to use the more detailed influence diagram, like Figure 5, to gain greater understanding of the problem. This example demonstrates that some decisions may be nearly evenly balanced for each side. In such cases, the decision makers may find that either alternative is acceptable, and the analysis can help support this point.

4.5. Decision Class Analysis

The decision whether to grant an endangered species taking permit meets the criteria necessary for use of decision class analysis. The MN Natural Heritage Program must make this kind of decisions periodically. Analysis of three previous decisions (in Table 1), indicates that the situations are similar, varying primarily in the project type and location, and the number and type of species which would be affected.

"Burnsville Flood Control Project" and "Giants Ridge Project" can be modeled with ease from the decision model of "Landfill problem" like Figure 5. The models are relationally very similar because many variables are common between the problems of same decision class. But the functional level or the numerical level will be somewhat or very different. For example

Fig. 9. Deterministic Sensitivity Analysis for the Case Exampel



the options of decision node, possible state and probability of chance node and value equations are totally different from the "Landfill problem". And the knowledge about MN will be used without modification. Anyway, the whole descriptive model helps the DMs to see the problem in global sense, and provides guidelines to elicit a knowledge. The decision makers can solve the problems of a same class without the help of decision analysts or knowledge engineers.

4.6. Validation

To evaluate the suggested tool, the respondents were supposed to be asked to test it by using it to solve a decision problem. The decision problem used for this purpose was selected among those which they had not previously encountered. The problem was based on a problem decision makers in the Wisconsin DNR had solved a few years earlier. At first, it is intended for the groups are divided into two groups, one group is trained with this decision tool, and the other group is not. But the subject group is too small and they already have their own heuristic knowledge for the decision making. So the author just explained this decision tool and educated them. The decision makers were asked to evaluate the following three categories:

usefulness and efficiency of the process, internal validity, and reliability. The comments and verbal evaluation of this decision tool is summarized in the following discussion section.

5. Discussion

The developing tool and its result, the decision making process were usefully discussed from the perspective of the goals it was to accomplish, from the methods used to accomplish them and the assumptions underlying these methods. The goals to be accomplished, listed in the design criteria, fall into three general areas in which the model was intended to be useful: 1) the process: did the developing tool clarify the decision making process for the DNR decision makers? 2) internal validity: can the tool contain the information DNR decision makers do and want to think about? 3) reliability: does using the decision process lead to the "best" possible decision?

5.1. The Process

In the sense that decision analysis is a tool to assist in the process of making a decision and thereby arrive at a better decision, it is worthwhile to explore if developing the tool itself accomplished this. Comments made by the decision makers during interviews, indicated that the process clearly helped the decision makers gain a sense of what they were considering, where the difficulties lie and how they could and might best approach the problem. It also gave the decision makers vocabulary for thinking about the decision making. The process of developing the tool caused several people to become more comfortable with seeing the decision making process as one involving trade-off between species preservation and land development. It remains to be seen how useful the tool will be in the future for illuminating a new decision case.

As part of a discussion of what the tool can accomplish, it is important to point out the limits of the assistance decision making tools can provide. The current tool does not provide a formal way to reconcile disagreement over the differences in judgments or estimation of probability of events. This should be provided to develop an IDS.

5.2. Internal Validity: Satisfaction with the Process and Results

Internal validity in this discussion refers to whether or not the developed decision process reflects what the decision makers truly want to consider and their interpretation of the problems. The model was tested for internal validity first by going through the influence diagrams with the decision makers one-by-one to determine if they agreed with the representation, and to see how they would move or alter nodes and re-direct the influence arcs. This procedure allowed significant input into the design from those who have the most expertise and knowledge about how to solve the decision problems. This process also can transfer knowledge about how to think about representing the problem from the system developer to the decision makers. It also increases the likelihood that the model is consistent with the decision makers' world view.

Another issue with regard to whether the information used in the tool is the best information available, is the way the information was obtained. One problem with the way the VPA was used in this case is that the directions given to the decision makers describing the VPA and the decision task also described the information sought through this process. It is expected that the necessary information would be obtained even if it is not explicitly mentioned to the subjects. In fact, it is not a good idea to mention any information expected because the decision makers could tailor their responses around the researchers' expectations. This happened in two of the subjects' responses, and although the information was very useful, it was not pure VPA data.

5.3. Reliability

The reliability discussion addresses the question of whether using the tool will lead to the "best" possible decision resulting from both the process of analyzing the situation and the values calculated using MADA given the probabilities and the constraints and preferences of the decision makers. One aspect to consider, is whether or not use of the tool is even conducive to solving for the "best" alternative. Ideally, because it focuses attention on the decision making process, this tool could allow people to see viable new alternatives. When using the decision tool, there is a risk that using the model could limit, rather than enhance identifying alternatives because the analysis is pre-defined. It is important that decision makers maintain flexibility in their thought while using this model.

Another aspect to consider regarding whether the tool will point to the "best" alternative is whether the data used (probability and state assessments) are accurate. Subjective probabilities were obtained simply by VPA or asking each person interviewed to make a judgment, not by any more detailed (e. g. lottery or swing-weight) methods. This is in part because the probabilities assigned were for possibilities of something occurring, not preferences, and those interviewed were generally willing to provide probability estimates. The framework was not used to solve a specific problem to make a recommendation and therefore it was not crucial to obtain specific scores using a formal technique. The decision makers were not trained in more formal probability elicitation techniques because this would have required more time and more expertise than was feasible. Given that the main purpose of the framework was to provide a basis for discussion, it is questionable how necessary it would be to obtain very precise inputs.

A problem concerns obtaining consistent responses from one decision maker over the course of working on several decision problems. This is primarily significant if the knowledge from solving a decision situation is stored using knowledge base or model base, because it could lead to a distorted knowledge base or model base. The problem is amplified when modifications of the model are necessary for a new situation. An additional issue arising in this case is that of ensuring that the decision makers will have sufficient understanding of the modeling process to make the necessary changes. By the conclusion of the research, the decision makers had learned how to make the necessary changes.

6. Conclusion

This paper has presented a developing tool to develop an IDS for the real world problems. At a first step toward an IDS, a decision making process is developed which can be used to assist decision makers in the process of understanding and synthesizing their own preferences. The resulting process can be used without the assistance of a decision analyst. Because decisions in a class such as whether or not to grant an endangered species permit generally contain similar elements, it is possible to make use of previous structuring of the decision situation for similar future decisions. The influence diagram is an extremely effective way of representing the decision situation as well as revealing the assumptions in the representation. It is a useful way of getting feedback from the decision makers. It is useful to decision makers in clarifying the processes, cognitive and social (small group, bureaucratic, etc.) entailed in a class of decisions. Even though this developing tool and decision process is described for MN NHRP decision makers, basic ideas underlying decision tool can be used to other decision problems.

The main purpose of IDS is to mimic or replace a decision analysts. Even though it may be impossible, further research should be continued in the following area.

1. Management of the class of decisions: although a class is defined arbitrary, how to ex-

pand the class or how to measure the similarities between two problems in the same class would be defined.

2. How to store a class of decision problems in the knowledge base or model base?: influence diagram may represent an individual decision problem, but the relations between decision problems in the same class would be defined.
3. When a new decision problem is encountered, how to use an IDS?: they are to be defined what class can cover a new problem, and how to use an existing knowledge-base or model base.

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Appendix 1.

Verbal Process Protocol Guidelines:

1. Look carefully at the attached decision problem. You have encountered this decision problem previously, yet attempt to look at it as if you were looking at it for the first time.
2. Do not think through the problem fully and then begin recording your problem solving process. It is the process of structuring the problem, thus, the process of "thinking through the problem fully," which we wish to have recorded. Look at it once, and then express your thinking process precisely and step by step into the tape recorder. Please be as frank and thorough as possible.
3. The thinking process which is to be recorded begins when you first look at the problem, and ends once you have made your decision regarding the endangered species permit for a given problem.
4. The most important thing is that you express what you are thinking. What are you taking into consideration? How do these factors relate to each other? For the first problem, which you have previously encountered, it is important that you verbalize your thoughts as if you were considering the decision for the first time.
5. If you wish to make any other comments, please do so at the end of the verbal process protocol.