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Site Selection and Assessment for a Nuclear Storage Facility*

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Abstract

We investigate the structure and accuracy of the decision-making process associated with the task of finding an optimal location for stored nuclear materials with the time period ranging from 25 to 50 years. Using a well-documented facility design, benefit hierarchy is set up for different sites to rank a given site with respect to different options. Criteria included in the benefit hierarchy involve safeguards standards, technical viability, environmental effects, economics, political impact, and public acceptance. The problem we face here is the multi-criterion decision making. Two known approaches are investigated: analytic hierarchy process (AHP) of Saaty, and fuzzy logic approach of Yager. Whereas the AHP methodology requires a pairwise comparison of criteria and pairwise comparison of alternatives, in Yager's approach each alternative is considered independently, thus allowing one to extend the analysis without performing time-consuming computation.

Introduction

Classical decision making generally deals with a set of alternatives comprising the decision space, a set of states of nature comprising the state space, a relation indicating the state of outcome to be expected from each alternative action, and finally a utility or objective function, which orders these outcomes according to their desirability.[1] In the popular Analytic Hierarchy Model (AHP) of Saaty,[2] one merely distinguishes the set of alternatives and the set of criteria. A decision is said to be made under conditions of certainty when the outcome of each action can be determined and ordered precisely. On the other hand, if a decision is made under conditions of risk, then the only available knowledge concerning the outcome states is their probability distribution. When knowledge of the probabilities of the outcome states is unknown, decisions must be made under conditions of uncertainty. In this case, fuzzy decision theories may be used to accommodate vagueness.

Starting with the pioneering paper of Bellman and Zadeh,[3] fuzzy decision analysis has been an object of intensive research.[4-6] The method of Yager[7] provides a specific algorithm to handle multi-objective decision making.

The goal of this paper is to apply the fuzzy logic approach of Yager[7] and the AHP methodology to the problem of site selection for a nuclear storage facility. The criteria we use for selection are borrowed from the Predecisional Draft report published by the U.S. Department of Energy, Office of Fissile Materials Disposition.[8] The screening criteria for all surplus plutonium disposition options listed in this report are resistance to retrieval, extraction, and reuse by host nation; technical viability; environmental, safety and health compliance; cost effectiveness; timeliness; fostering of progress and cooperation with Russia and other countries; and public and institutional acceptance. Additional benefits, such as the ability to leverage government investments for disposition of surplus materials, are not considered in this study. Since our investigation is only preliminary, we do not find it appropriate to consider realistic facilities as possible alternatives. Instead, we form a list of seven different facilities, differing in their ranking with respect to the assumed criteria. In our study, we consider an interim storage of fissile materials, with a time scale between 25 and 50 years.

Yager's Method

Multi-objective decision problems commonly require the choice of one element from a set X of possible alternatives, given a finite collection of criteria or objectives. When X is finite, two significant problems arise: evaluating how well each alternative satisfies the various objectives and combining the objectives to form an overall objective or decision function from which the

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best alternative is to be selected. In the final stage, a computer program selects best decision (assessment), including importances associated with the individual alternatives.

In the method of Bellman and Zadeh,[3] if one wishes to accommodate constraints and goals into a fuzzy model of decisions, both constraints *C* and goals *G* are treated as fuzzy sets characterized by their respective membership functions. A fuzzy decision *D* may then be defined as the choice that satisfies both the goals and the constraints. In terms of the logical *and* operator, we can model the fuzzy decision as an intersection of fuzzy sets *G* and *C*, specified by the minimum membership function. With Yager's method, the decision maker provides ordinal information about the preferences and the importance of individual objectives.

To apply the method to selection of the storage facility, we first list the criteria and their priorities. We have supplemented this list with the complement of the priority vector, as indicated in Table 1.

TABLE 1
Criteria of Their Priorities

Criteria	Priority (P)	1 - P
Resistance to Theft and Diversion	1.0	0.0
Technical Viability	0.8	0.2
ES&H Compliance	0.7	0.3
Cost Effectiveness	0.6	0.4
Timeliness	0.5	0.5
Progress and Cooperation with Russia	0.3	0.7
Public and Institutional Acceptance	0.2	0.8

The next step is to select the options (Facilities A through G) and the preference scale, listed in Table 2.

TABLE 2
Preference Scale

Attribute	Acronym	Numerical Equivalent
Outstanding	Sup	1.0
Very Good	VG	0.8
Average	Avg	0.5
Fairly Good	Fair	0.3
Poor	Poor	0.0

As in any multi-criteria decision process, it is necessary to rate each option for each criteria according to the preference scale. We use the assessment in Table 3.

The Yager method employs the implication operator in the form $p \rightarrow r$, where *p* is the priority vector and *r* is the set of alternatives under consideration. Using the *or* operator (V), the form of computation $(p') \vee r$ reduces the implication to two standard fuzzy set operations of negation and maximum. When we compute the intersection (expressed in terms of a minimum operation) of the fuzzy values for each of the criteria, we arrive at the conclusion that facilities *E* and *G* are the best sites for the interim storage; facilities *B*, *C*, and *D* are second to the best; while facilities *A* and *F* are the least desirable. These results are summarized in Table 4.

We note that, given the assumed ranking, we do not distinguish between facilities *E* and *G* when performing our selection; a refinement of the criteria, or a better data set, would lift this degeneracy. On the other hand, it is readily seen that, adding another facility, no additional comparison is involved. In other words, the computation proceeds for each alternative independent of the alternatives already present in the evaluation. This can be contrasted to the AHP method, to which we now turn.

TABLE 3 Ranking Facilities with Respect to Criteria						
Criteria	Fac. A	Fac. B	Fac. C	Fac. D	Fac. E	Fac. F
Resistance to Theft and Diversion	Sup	VG	Avg	Avg	VG	Avg
Technical Viability	VG	Avg	VG	Avg	Avg	Fair
ES&H Compliance	Fair	Avg	VG	VG	Avg	Avg
Cost Effectiveness	Poor	Fair	Fair	Fair	VG	Avg
Timeliness	Avg	Avg	Fair	Avg	Avg	VG
Progress and Cooperation with Russia	Avg	Avg	Avg	VG	Fair	Fair
Public and Institutional Acceptance	Fair	Avg	VG	Avg	Sup	Fair

TABLE 4 Results of the Selection Based on Yager's Method	
Facility	Priority Factor
E	0.5
G	0.5
B	0.4
C	0.4
D	0.4
A	0.3
F	0.3

Analytic Hierarchy Process

For the sake of comparison, we apply the AHP to the selection problem outlined in the previous section. AHP organizes the various factors of a problem into an upside-down tree structure. The tree branches down from the Goal, which is the root node. Intermediate levels represent Factors, or Criteria, of the problem. At the bottom of the tree are the leaves that represent the Alternatives of choice. In absolute comparisons, alternatives are compared with a standard that has been developed through experience; in relative comparisons, alternatives are compared in pairs according to a common attribute. The AHP has been used with both types of comparisons to derive a ratio scale of measurements.

We now apply the AHP to the problem of finding the optimal storage site using the same criteria that were considered in the Yager's method. The decision tree has two levels consisting of criteria and alternatives, as indicated in Fig. 1. The alternatives, shown explicitly for the time-effectiveness criterion, are repeated for all the criteria in the decision tree.

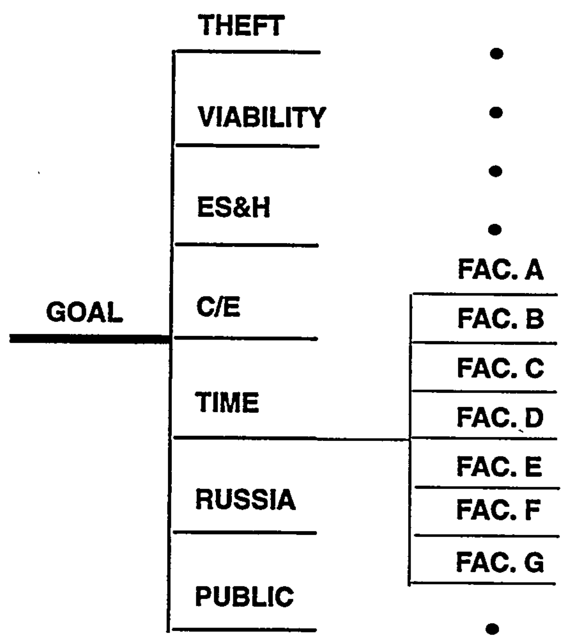

Fig. 1. Schematic diagram of criteria and options in the analytic hierarchy process.

The solution to the selection process is given in Table 5, which ranks the facilities according to the achieved goal, together with the numerical priority factors.

TABLE 5 Results of Selection Based on AHP	
Facility	Priority Factor
E	0.170
C	0.146
G	0.140
D	0.139
B	0.137
A	0.134
F	0.133

As in Yager's method, facility *E* attains the highest rank; however, facility *G*, which is second to best in the Yager method, has now rank three in the list. Similar to the other method, there is very little distinction between the ranks of facilities *G*, *D*, and *B*.

Conclusions

The significance of fuzzy logic in the decision-making process has been exemplified by the problem of site selection for a nuclear storage facility. We have used the criteria formulated by the DOE Office of Fissile Materials Disposition. To make the selection process more realistic, these criteria have to be supplemented by a realistic assessment of facilities with respect to the criteria. This assessment is likely to be supplied by a team of experts who would judge the facility compliance and potential to satisfy the criteria.

Though preliminary in scope, the current study addresses a lead role of the DOE for evaluating technical options and developing economic, schedule, and environmental analyses.

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