

# Cost-Effectiveness Analysis of Transportation Strategies for Nuclear Waste Repository Sites

JASON C. YU and CHARLES A. JUDD

## ABSTRACT

Because of the complexity involved in the evaluation of transportation strategies for nuclear wastes, a cost-effectiveness methodology is presented in this study for use in ranking the potential nuclear waste repository sites in the United States from the transportation perspective. In addition, some historical data are presented to help clarify the issue of safety in nuclear waste transportation. The basic features of the cost-effectiveness model are well-suited for the analysis of the issues addressed in this study. Based on available data, the results of two model applications indicate that the best nuclear waste repository location in the United States among five potential sites would be the Gulf Interior region in Mississippi, with a railroad connection to and from the points of waste production, and that the optimal local transportation corridor for the Gibson Dome site in Utah would be through the Colorado Canyon. It should be noted that the basic intent of this study was to illustrate how a cost-effectiveness model may be applied to resolving transportation-related issues in nuclear waste repository site selection. The tentative solutions recommended by this study need to be validated by further analysis, and to be based on a more complete data set.

One of the major issues that faces the United States today is the use of nuclear materials. With respect to public safety and health hazards, this issue becomes particularly critical when the transportation and disposal of high-level nuclear waste is required. The transportation and disposal of nuclear wastes is not only of national concern, but is of keen interest at local and state levels as well. For instance, the state of Utah has been chosen as one of the possible locations for a nuclear repository. The public seems to form its opinion without placing the issue in proper perspective, which causes undue confusion in our society. The decisions that need to be made when choosing a site for a nuclear waste repository are complex; there exist a wide range of consequences for the neighboring area. These include direct or objective impacts such as the cost and safety of transporting nuclear wastes, as well as indirect or subjective impacts, such as socioeconomic and environmental effects on the community. Therefore, the ranking of alternative nuclear waste repository sites from the transportation standpoint is a challenging task in which a variety of interests must be weighed among all parties involved. The purpose of the selection process, which involves weighing objective versus subjective factors, is to provide the public with the greatest net benefit. For coping with the complexity of the task, research is needed to develop an effective tool for use in the public decision-making process. This tool could be used to select the optimal transportation strategies under various situations. Many past studies have dealt with transportation planning methods for cost-benefit and alternative analyses. However, there are no known methodologies especially developed to evaluate and to set priorities for transportation alternatives of nuclear waste materials.

Presented first in this paper are some background data on the issue of nuclear waste transportation. Then, a cost-effectiveness model is introduced for the evaluation of alternative methods of nuclear

waste transportation. Following this, the model is applied to two separate issues, one at the national level and the other at the state level. It is hoped that the information presented in this paper will be useful to the planning, programming, and project development personnel of the transportation and energy agencies. In the area of planning, the concept presented here should assist the planner in sketch planning or preliminary feasibility studies to determine whether further planning or development efforts are worthwhile for any given nuclear waste repository site. In programming, the model for ranking a set of transportation strategies should have high utility. Finally, project development staff should find the approach instrumental in the assessment of environmental impacts and other project-supporting documents, and in the design of the transportation project itself.

It should be stressed that the model application is presented for illustrative purposes, and is not meant to provide a definitive ranking of sites. In particular, a firm conclusion would require more information on projected spent-fuel shipments and associated technical data, and greater attention to the process of establishing relative weights for the various subjective factors. However, for the purpose of this study, application of the model to a restricted data set is able to fully demonstrate the potential power and range of the proposed methodology.

## TRANSPORTATION OF NUCLEAR MATERIALS

A brief exposition of current methods of transporting nuclear material will enable a deeper understanding of subsequent sections. Nuclear material is one of many classes of officially designated hazardous materials. A hazardous material is defined, both by statute (the Hazardous Materials Transportation Act) and by regulation (Code of Federal Regulations,

No. 49, section 171.8), to be those materials or substances in a form or quantity that has been found to pose unreasonable risks to health and safety or property in commerce. There are approximately 2,400 materials so designated (1). There are insufficient data from which to derive verifiable figures on the amount of hazardous materials that are transported; the most commonly reported estimate by the U.S. Department of Transportation is that there are about 4 billion tons shipped each year (2). Of this amount, approximately 30 percent is transported by truck and about 70 percent by rail (3). Table 1 lists different types of hazardous substances that are shipped in the United States.

TABLE 1 Hazardous Materials Shipped in the United States (1)

Substance	Percentage of Shipments
Gasoline and jet fuels—flammable liquid	56
Distillate fuel oil—combustible liquid	34
Anhydrous ammonia—nonflammable gas	4
LPG—flammable gas	2
Paints and allied products	2
Industrial gases	1
Other	1

Of the more than 100 million shipments per year of hazardous materials in the United States only 3 percent or some 3 million packages contain radioactive materials (4). The material of perhaps most frequent public concern (and the material under the most restrictive regulatory and safety guidelines) is spent reactor fuel (i.e., high-level waste). The few hundred shipments a year of spent fuel constitutes only a tiny fraction of the annual shipments of radioactive materials currently taking place (5).

The safety record of hazardous materials transportation, on the whole, is fairly impressive. The total number of fatalities that result from hazardous materials transportation is very small relative to other transportation-related fatalities. For example, only 19 fatalities resulted from hazardous materials accidents in 1980 (with none attributable to the radioactive nature of the cargo), whereas in the same year 51,900 lives were claimed by highway accidents and 530 in railroad accidents. This is impressive considering that up to 15 percent of the trucks on the road are carrying hazardous materials (1). Furthermore, there is a significant difference in accident risk between transporting spent fuel and transporting other energy-related commodities. In terms of the statistical likelihood of fatalities, the shipment of gasoline, propane, and chlorine is from 300 to 30,000 times riskier than the shipment of all materials that are associated with the nuclear fuel cycle. An accident that involves a chlorine-carrying train resulted in 9 fatalities; in another case, a chlorine-shipment accident caused the evacuation of 250,000 people (6). Fires resulting from accidents that involved the transportation of gasoline on the nation's highways took 480 lives and injured another 3,500 between 1976 and 1980. In a similar vein, each year there are some 100 to 150 explosions and fires that cause approximately 2 dozen fatalities as a result of the transportation of natural gas through pipelines (7).

Of course, there is always the chance for the occurrence of the first nuclear spent-fuel accident, and the possibility that the accident would be major. However, with the extreme safety precautions that are taken in transporting radioactive spent fuel, these possibilities are relatively small. One

of the reasons for the relatively small chance of an accident is the design of the casks in which the nuclear wastes are encased. High-level nuclear wastes must be shipped in heavily shielded casks (Figure 1) on vehicles that conform to applicable federal regulations (8). A high-level waste shipping

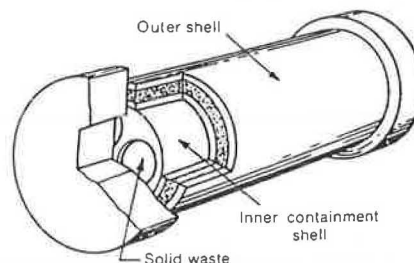


FIGURE 1 Shipping casks for nuclear wastes (8).

cask must be able to withstand severe simulated transportation accidents without losing its contents or shielding efficiency. Extensive testing of high-level nuclear waste casks that were conducted by the Transportation Technology Center of Sandia National Laboratories in New Mexico has shown that there would be no significant loss of contents or shielding if an accident did take place (5). Casks have undergone a rigorous series of crash and fire tests, which have been open to the public. In a typical test, a spent-fuel cask was mounted on a truck and crashed into a concrete wall at 60 mph. The same cask was crashed again at 80 mph. There was only superficial damage. In a third test, a locomotive crashed into a cask broadside. The 80-mph impact demolished the locomotive, but hardly dented the cask. A 150-ton railcar-cask assembly was crashed into a concrete barrier at over 80 mph, and then exposed to fire for more than 2 hr.

The results of these tests indicated that there would have been no radioactive hazard had the casks actually been loaded with spent fuel or solidified high-level waste. The casks also provide protection under normal traveling conditions. There is essentially no risk from the radiation exposure during the normal transportation of spent fuel. An individual who lives 90 ft from a highway where 250 spent-fuel shipments pass each year traveling at an average speed of 30 mph would receive a radiation dose some 9,000 times less than that received from natural sources—the sun, the earth, and radioactivity that occurs naturally in the human body. For comparison, the dose would be only slightly higher than that received from an ordinary smoke alarm in 1 year's time. Most smoke alarms contain a miniscule amount of radioactive material that is used to detect smoke (9).

#### A COST-EFFECTIVENESS MODEL

As indicated previously, transportation of nuclear wastes demands that the cost and efficiency of the transportation strategy itself, as well as the impacts of the strategy on the community, be fully considered and analyzed. Because of the complexity of the decision-making process, there is an immediate need for a comprehensive yet simple procedure for ranking alternative transportation strategies under a given environment, subject to policy and regulatory constraints. In this context, a cost-effectiveness decision model developed by Yu and

Pang (10) offers an excellent methodological framework to deal with the issue of transportation of nuclear waste. The following is a brief description of the model.

Yu and Pang's model was originally developed for ranking alternative strategies of transportation energy conservation, with the following objectives in mind:

1. To account for all relevant impacts of transportation strategies,
2. To consider both tangible and intangible impacts on a comparable scale,
3. To link the modeling framework to the actual public decision-making process,
4. To maximize the economic return from the expenditures invested, and
5. To be computer-based to facilitate actual applications of the model.

The foregoing features are all well suited for the consideration of nuclear-waste transportation alternatives. It is believed that the basic model with minor modifications should be useful in the evaluation and decision making on alternative methods for delivering nuclear wastes to possible repository sites.

The cost-effectiveness model quantifies objective and subjective impacts into dimensionless indices and includes decision weight factors for both. A composite measure of effectiveness (CMOE) is computed for the setting of strategic priorities. The model is mathematically expressed as

$$CMOE_i = W_O \cdot OIM_i + W_S \cdot SIM_i \quad (1)$$

where

$CMOE_i$  = composite measure of effectiveness of strategy  $i$ ,

$OIM_i$  = objective impact measure of strategy  $i$   
( $0 < OIM_i < 1$  and  $\sum_i OIM_i = 1$ ),

$SIM_i$  = subjective impact measure of strategy  $i$   
( $0 < SIM_i < 1$  and  $\sum_i SIM_i = 1$ ),

$W_O$  = objective impact decision weight  
( $0 < W_O < 1$ ), and

$W_S$  = subjective impact decision weight  
( $0 < W_S < 1$  and  $W_O + W_S = 1$ ).

The CMOE values are used as a basis for assessing the relative worth of a transportation strategy compared with all other strategies considered. Strategies with higher CMOE values are preferred over those with lower values.

All objective impacts are classified as being measurable in monetary terms. The life-cycle cost of each strategy is the basic element in the case of transportation of nuclear wastes. To ensure compatibility between objective and subjective impact measures, objective impact measures are converted to dimensionless indices. In deriving these indices, it is necessary to compute a monetary ratio for each strategy. These cost ratios are then normalized to obtain dimensionless indices (objective impact measure) for each strategy by the following equation:

$$OIM_i = OIC \cdot \left[ \sum_i (1/OIC_i) \right]^{-1} \quad (2)$$

where  $OIM_i$  is the objective impact cost for strategy  $i$ .

Subjective impacts are usually difficult or impossible to quantify in dollar terms. The subjective

impact measure for a given strategy  $i$  is a function of two quantities: (a) the relative weight of each subjective impact as compared with all of the subjective impacts, and (b) the relative weight of each strategy for a given subjective impact. The subjective impact measure of strategy  $i$  in the model is mathematically given as

$$SIM_i = \sum_k (SIW_k \cdot SW_{ik}) \quad (3)$$

where  $SIW_k$  is the weight of subjective impact  $k$  relative to all subjective impacts, and  $SW_{ik}$  is the weight of strategy  $i$  relative to all strategies for a given subjective impact  $k$ .

The individual subjective impact weights are determined from ratings through a decision-making body involved in nuclear waste projects. A member of a decision-making body may view one or more particular objectives as more important than others. The way for that member to express this is to attach weights to the different impacts. For each member, the sum of the weights assigned to all impacts considered may be a total of, for example, 100 points. The average rating of each subjective impact is then normalized to a number within a range of 0 to 1, which is comparable with the objective impact measure.

The subjective impacts of a specific transportation strategy vary in magnitude, intensity, scope, importance, and acceptability with each community. The strategy weights must be carefully established by the technical staff of the transportation agency so that the impact of given transportation alternatives for nuclear wastes can be assessed. This involves (a) assessing utility functions for individual subjective impacts, (b) predicting anticipated impact levels for each strategy and finding the corresponding utility associated with that level, and (c) estimating the scope of the strategy (i.e., the proportion of the population or area affected by the strategy). The value of an individual strategy weight is derived by the sum of the ratings for all transportation strategies with respect to each subjective impact.

The decision weights,  $W_O$  and  $W_S$ , measure the relative importance of objective impacts versus subjective impacts. The sum of both decision weights is equal to 1 (i.e.,  $W_O + W_S = 1$ ) and thus the value of each weight ranges between 0 and 1. The values of  $W_O$  and  $W_S$  are obtained from the decision-making body by using an approach similar to that used in determining the subjective impact weight. Each member assigns a value for  $W_O$  and  $W_S$ . The values of all members are then averaged to obtain the final value for the decision weights.

As indicated earlier, Yu and Pang's basic model and its application procedure were slightly modified to be more suitable for analyzing the transportation of nuclear wastes. The major area of modification is the determination of the objective impact measure. Instead of using the benefit-cost ratio as specified originally, only the cost-ratio factor was employed. This is because no tangible benefit related to the nuclear disposal transportation can be realized. The concept will be illustrated in the model application that is presented in the next section. To facilitate actual application, the model has been implemented as a computer package for a microcomputer.

#### ISSUES OF STUDY

The cost-effectiveness model was applied to two current issues associated with transportation alternatives for nuclear waste: (a) which of the five proposed nuclear repository sites in the United States

would be most desirable from a standpoint of transportation (while this issue is being considered, two transportation modes, rail and highway, are compared), and (b) which of the five proposed Utah transportation routes would be the best for delivering nuclear wastes if Paradox Valley, Utah, was chosen as a repository site.

Before the cost-effectiveness model is applied to these issues, background information is given on them. Model applications will then be illustrated for both issues in a step-by-step manner.

#### Issue 1

At the present time, there are five proposed sites under consideration for a nuclear repository site in the United States:

- Paradox Valley, Utah,
- Hanford, Washington,
- Yucca Mountain, Nevada,
- Permian, Texas, and
- the Gulf Interior region in Mississippi (GIR).

The five sites are being considered along with two major nuclear waste producers, the West Valley Plant and the Savannah River Plant (11). The question to be addressed is which of the sites would be the best choice as far as transportation is concerned.

#### Issue 2

Early in 1980, it was announced that southeastern Utah was one of five potential sites for a nuclear waste repository. Since that time, the possibility of a nuclear repository in Utah has been a topic of great popular interest. There were, initially, as many as four different proposed sites in the Paradox Valley area of southeastern Utah. The four sites have presently been narrowed down to one site, the Gibson Dome area. Many citizens, especially those in southeastern Utah, support the possibility of the site because they believe that it would help their economic situation. On the other hand, there are citizens, especially environmentalists, who believe that the Utah site is too dangerous and that placement in Utah would be extremely detrimental to the natural beauty of the area. On May 4, 1984, the former governor of Utah, Scott Matheson, announced that he was strongly opposed to selection of the Utah site. Governor Matheson stated several reasons for his opposition, including the site's proximity to the Colorado River and other environmental factors. However, the major reason was that the U.S. Department of Energy had not provided enough information on the effects that a depository would have on the area (S.M. Matheson--unpublished data).

There are many unknown factors with respect to the Gibson Dome site. One that remains unanswered is the method of transporting nuclear wastes within the state. There are two options under consideration: (a) transporting nuclear wastes over existing transportation systems, or (b) building new transportation systems to be used especially for delivering nuclear wastes to the proposed repository site. According to officials of the Utah Department of Transportation, it is most likely that the nuclear wastes will arrive in Utah by rail. Possible locations for building a transfer station along the route have been considered carefully; it was found that the only feasible location would be Potash, Utah. With this in mind, the answer that is still unknown is to the question of what route would be best for the transfer of nuclear material from Potash to the proposed site.

#### MODEL APPLICATION

##### Identification of Transportation Strategies

The first step is to identify what transportation strategies are available for the evaluation of relative impacts as the result of transporting nuclear wastes.

#### Issue 1

There are 10 possible alternative routes (11):

1. Gulf Interior Region by truck,
2. Permian Basin by truck,
3. Paradox Valley by truck,
4. Yucca Mountain by truck,
5. Hanford by truck,
6. Gulf Interior Region by rail,
7. Permian Basin by rail,
8. Paradox Valley by rail,
9. Yucca Mountain by rail,
10. Hanford by rail.

#### Issue 2

Five different alignments are compared as to which is the best route for nuclear waste transportation through southeastern Utah:

1. Spanish Valley route via the low bridge,
2. Spanish Valley route via the high bridge,
3. Kane Springs route,
4. Colorado Canyon route,
5. Spanish Valley route via LaSal Junction.

The first four routes were suggested in a study performed by the Bechtel Group, Inc. (12), whereas the last route was advocated through a study by Stearns-Roger Services Inc. (13).

##### Determination of Objective Impact Measures

It is now necessary to determine all objective impacts that are relevant to the issues in question. As mentioned earlier, the direct costs involved in implementing individual transportation strategies are considered as objective impacts. After all of the strategy costs are determined, it then becomes necessary to determine the corresponding cost ratios for available strategies. Cost ratios may be obtained by dividing the lowest strategy's total cost into each of the resulting values. The cost ratio is then normalized to a value between 0 and 1 as the objective impact measure (OIM) for each transportation strategy.

#### Issue 1

The objective impact used in this issue was total cost, which consists of shipping, maintenance, and capital costs. Capital costs are specifically defined by a reference source (11) as the cost of transportation packaging and its trailer or railcar. They do not include fixed facility requirements such as highway or rail-line construction to the repository site or facility-handling equipment requirements. Maintenance costs include the money needed for system upkeep (e.g., containers and trailers or railcars). Shipping costs are expenses charged by the carrier. As would be expected, the shipping costs are closely related to the distance traveled.



TABLE 2 Costs, Cost Ratios, and OIMs for Issue 1 Transportation Alternatives (11)

	Transportation Alternative <sup>a</sup>									
	1	2	3	4	5	6	7	8	9	10
Costs (\$x10 <sup>6</sup> )										
Capital	173	199	220	247	258	206	233	252	272	274
Maintenance	111	129	142	160	167	124	140	151	163	165
Shipping	492	662	812	984	1,040	484	595	680	779	805
Total	776	990	1,170	1,390	1,460	814	968	1,080	1,210	1,240
Cost ratio (percent)	1.00	.78	.66	.56	.53	.95	.80	.72	.64	.62
OIM	.137	.108	.091	.077	.073	.132	.110	.099	.088	.086

<sup>a</sup>Refer to the route numbers in the text for the 10 possible transportation alternatives.

TABLE 3 Costs, Cost Ratios, and OIMs for Issue 2 Alternative Routes (14).

	Alternative Route <sup>a</sup>				
	1	2	3	4	5
Capital costs (\$x10 <sup>6</sup> )	364	384	669	327	288
Cost ratio (percent)	.79	.75	.43	.88	1.00
OIM	.205	.194	.112	.228	.259

<sup>a</sup>Refer to the route numbers in the text for the 5 possible transportation routes.

Table 2 shows the total costs, the cost ratios, and the OIMs for Issue 1. The costs for each alternative were estimated by Sandia National Laboratories (11).

#### Issue 2

The only data available for the Utah issue was capital costs. Because the lengths of all five routes are approximately the same, it is reasonable to assume that the maintenance costs and shipping costs will be fairly equal for the five alternatives. [The data used in this study were gathered by Stearns-Roger Services Inc. (13).] The capital costs, cost ratios, and objective impact measures for Issue 2 are given in Table 3.

#### Determination of Subjective Weight Matrix

It is now necessary to determine the subjective impacts for each issue. After all subjective impacts

are determined, ratings are assigned to each alternative for every subjective impact. For simplicity, a linear utility function is assumed, and these ratings run from -3 to 3. For positive impacts, a positive number is used with a higher positive number being a more positive impact. Conversely, a negative number means a negative effect, ranging from 0 to -3. The ratings are then normalized (NR values) and developed into strategy weights by dividing each NR value by its respective total number.

#### Issue 1

For Issue 1, four subjective impacts were considered:

1. Projected fatalities,
2. Environmental impacts,
3. Economic impacts, and
4. Traffic impacts.

Projected fatality weights were obtained through a study by Sandia National Laboratories (11). Environmental impact weights were determined by comparing railway versus highway environmental effects. Economic impacts are defined as the changes in economic base as a result of nuclear waste repository activities that take place in the area. Traffic impacts are caused by construction activities and increased traffic volumes in the area. Table 4 lists the ratings, the normalized ratings, and the strategy weights (SW<sub>k</sub>) for the Issue 1 subjective impacts.

#### Issue 2

Subjective impacts for the proposed Utah routes were selected on the basis of the general transportation

TABLE 4 Ratings, Normalized Ratings, and Strategy Weights of Subjective Impacts for Issue 1 Transportation Alternatives

	Transportation Alternative <sup>a</sup>									
	1	2	3	4	5	6	7	8	9	10
Rating										
SI 1	-2	-2	-2	-2	-2	0	0	0	0	0
SI 2	-2	-2	-3	-3	-3	0	0	-1	-1	-1
SI 3	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1
SI 4	2	2	2	2	2	1	1	1	1	1
Normalized rating										
SI 1	.16	.16	.16	.16	.16	.50	.50	.50	.50	.50
SI 2	.16	.16	0	0	0	.50	.50	.33	.33	.33
SI 3	.16	.16	.16	.16	.16	.33	.33	.33	.33	.33
SI 4	.83	.83	.83	.83	.83	.66	.66	.66	.66	.66
Strategy weight (SW <sub>k</sub> )										
SI 1	.05	.05	.05	.05	.05	.15	.15	.15	.15	.15
SI 2	.06	.06	0	0	0	.19	.19	.12	.12	.12
SI 3	.07	.07	.07	.07	.07	.13	.13	.13	.13	.13
SI 4	.11	.11	.11	.11	.11	.09	.09	.09	.09	.09

Note: SI = subjective impact.

<sup>a</sup>Refer to the route numbers in the text for the 10 possible transportation alternatives.

**TABLE 5 Ratings, Normalized Ratings, and Strategy Weights of Subjective Impacts for Issue 2 Alternative Routes**

	Alternative Route <sup>a</sup>				
	1	2	3	4	5
Rating					
SI 1	0	0	-2	2	0
SI 2	-2	-3	-1	2	-2
SI 3	-1	-1	-2	0	1
SI 4	-1	-1	0	-2	-2
SI 5	0	0	1	2	0
SI 6	-	-1	2	1	-3
Normalized rating					
SI 1	.50	.50	.16	.33	.50
SI 2	.16	0	.33	.83	.16
SI 3	.33	.33	.16	.5	.33
SI 4	.33	.33	.5	.16	.16
SI 5	.5	.5	.66	.83	.5
SI 6	.33	.33	.83	.66	0
Strategy weight (SW <sub>k</sub> )					
SI 1	.2	.2	.06	.33	.2
SI 2	.11	0	.22	.56	.11
SI 3	.17	.17	.08	.25	.33
SI 4	.22	.22	.34	.11	.11
SI 5	.17	.17	.22	.28	.17
SI 6	.15	.15	.39	.30	0

Note: SI = subjective impact.

<sup>a</sup> Refer to the text for the 5 possible transportation routes.

guidelines provided by the Department of Energy (14). Many subjective factors would tend to make one route more favorable than another. The subjective impacts of five routes that were used in this study included

1. Cuts and fills,
2. Tunnels and bridges,
3. Curves and bridges,
4. Length of route,
5. Environmental effects, and
6. Archaeological effects.

Although the first four are tangible factors that indicate the level of effort required for route implementation, they influence the route safety in terms of accident potentials, and thus would subjectively affect the relative desirability of alternative routes. To obtain the subjective strategy weights, information was taken from quadrangle maps of the area prepared by Bechtel Group, Inc. (12). For example, a route that required extreme curves and steep grades would get a strategy weight of -3 and a route that was straight and flat would receive a strategy weight of +3. Table 5 lists the ratings, normalized ratings, and strategy weights (SW<sub>k</sub>) for the Issue 2 subjective impacts.

#### Determination of Decision Weights

After all of the alternatives have been compared by using different subjective impacts, the relative weights of objective versus subjective impacts as well as among the subjective impacts (W<sub>o</sub> versus W<sub>s</sub> and SIW<sub>k</sub>) are then determined. These weights are usually determined by using the views of various interest groups.

To determine the weight values of these impacts, questionnaires were distributed to six members of the technical staff of the Utah Department of Transportation, three concerned citizens, and one city leader (an elected official). These questionnaires included information so that those questioned could respond to Issues 1 and 2. Ten respondents may be considered a small sample of opinion, but they were carefully selected to represent a balanced make-up of interested sectors. The results of the questionnaire with regard to decision weights are shown in Tables 6-9. For more statistically meaningful results, it would be desirable to enlarge the sample size so that the contracting views of all parties involved could be realistically and accurately reflected. The establishment of relative subjective weights for the various considerations is a social and political issue. A strong point of the proposed model is that it leaves these political decisions to the political arena, and that it can be used to implement whatever values are decided on.

#### Determination of Subjective Impact Measures

Subjective impact measures (SIMs) of each strategy are defined as the product of the strategy weight and the subjective impact weight as given by Equation 3. The results of SIM values of all alternatives considered for Issues 1 and 2 are given in Tables 10 and 11.

#### Prioritization of Alternatives

The alternative strategies are ranked by using the values of the composite measure of effectiveness (CMOE) that is computed by Equation 1. The resulting CMOE value of alternatives in Issue 1 and Issue 2 are given in Tables 12 and 13.

#### Issue 1

After having examined the CMOE values, it is clear that the best transportation alternative for Issue 1 is strategy 6. This corresponds to locating the nuclear waste repository at the Gulf Interior region in Mississippi, with rail as the mode of transportation. (It is interesting to note that rail was pre-

**TABLE 6 Results of Questionnaire With Regard to Relative Weights of Issue 1 Subjective Impacts**

Subjective Impact	Transportation Alternative <sup>a</sup>										SIW <sub>k</sub>
	1	2	3	4	5	6	7	8	9	10	
Fatalities	40	60	50	20	96	50	30	10	30	60	.446
Environment	25	18	20	35	2	15	60	25	45	20	.260
Economic	25	20	20	35	0	15	5	60	20	20	.220
Congestion	10	2	10	10	2	20	5	5	5	5	.074
Total	100	100	100	100	100	100	100	100	100	100	1.000

<sup>a</sup> Refer to the text for the 10 possible transportation alternatives.

**TABLE 7 Results of Questionnaire With Regard to Relative Weights of Issue 2 Subjective Impacts**

Subjective Impact	Transportation Alternative <sup>a</sup>										SIW <sub>k</sub>
	1	2	3	4	5	6	7	8	9	10	
Cuts and fills	20	10	4	15	10	10	20	10	15	5	.119
Tunnels and bridges	20	20	2	15	10	10	20	15	15	5	.132
Curves and grade	20	30	85	15	10	20	25	20	15	35	.275
Length	25	20	3	5	10	10	0	10	15	5	.103
Environmental	10	10	3	30	30	20	25	25	25	25	.203
Archaeological	5	10	3	20	30	30	10	20	15	25	.168
Total	100	100	100	100	100	100	100	100	100	100	1.000

<sup>a</sup>Refer to the text for the 10 possible transportation alternatives.**TABLE 8 Results of Questionnaire With Regard to Relative Weights of Objective Versus Subjective Issue/Impacts**

Decision Weight	Transportation Alternative <sup>a</sup>										Avg
	1	2	3	4	5	6	7	8	9	10	
Objective	60	50	80	50	75	60	70	20	60	35	56
Subjective	40	50	20	50	25	40	30	80	40	65	44
Total	100	100	100	100	100	100	100	100	100	100	100

<sup>a</sup>Refer to the text for the 10 possible transportation alternatives.**TABLE 9 Relative Weights of Objective Versus Subjective Issue 2 Impacts**

Decision Weight	Transportation Alternative <sup>a</sup>										Avg
	1	2	3	4	5	6	7	8	9	10	
Objective	50	50	20	10	50	20	25	20	50	5	30
Subjective	50	50	80	90	50	80	75	80	50	95	70
Total	100	100	100	100	100	100	100	100	100	100	100

<sup>a</sup>Refer to the text for the 10 possible transportation alternatives.**TABLE 10 Subjective Impact Measures for Issue 1**

Subjective Impact	Weight	Transportation Alternative <sup>a</sup>									
		1	2	3	4	5	6	7	8	9	10
1	.074	.004	.004	.004	.004	.012	.012	.012	.012	.012	.012
2	.446	.016	.016	0	0	0	.084	.084	.053	.053	.053
3	.260	.018	.018	.018	.018	.018	.034	.034	.034	.034	.034
4	.220	.024	.024	.024	.024	.024	.020	.020	.020	.020	.020
Total		.062	.062	.046	.046	.054	.150	.150	.119	.119	.119

<sup>a</sup>Refer to the text for the 10 possible transportation alternatives.**TABLE 11 Subjective Impact Measures for Issue 2**

Subject Impact	Weight	Alternative Route <sup>a</sup>				
		1	2	3	4	5
1	.119	.024	.024	.007	.004	.024
2	.132	.015	0	.029	.074	.015
3	.275	.047	.047	.022	.068	.091
4	.203	.044	.044	.067	.022	.022
5	.168	.029	.029	.037	.047	.029
6	.103	.016	.016	.040	.031	0
Total		.175	.160	.202	.246	.181

<sup>a</sup>Refer to the text for the 5 possible alternative routes.**TABLE 12 Composite Measure of Effectiveness and Ranking in Issue 1**

Transportation Alternative <sup>a</sup>	Objective Impact Measure	Subjective Impact Measure	Composite Measure of Effectiveness	Rank
1	.137	.062	.1033	6
2	.108	.062	.0878	7
3	.091	.046	.0712	8
4	.077	.046	.0633	10
5	.073	.054	.0647	9
6	.132	.150	.1399	1
7	.110	.150	.1276	2
8	.099	.119	.1078	3
9	.088	.119	.1017	4
10	.086	.119	.1106	5

<sup>a</sup>Refer to the text for the 10 possible transportation alternatives.

**TABLE 13 Composite Measure of Effectiveness and Ranking in Issue 2**

Alternative Route <sup>a</sup>	Objective Impact Measure	Subjective Impact Measure	Composite Measure of Effectiveness	Rank
1	.205	.175	.1840	3
2	.194	.160	.1702	5
3	.112	.202	.1750	4
4	.228	.247	.2406	1
5	.259	.181	.2044	2

<sup>a</sup> Refer to the text for the 5 possible alternative routes.

ferable to highway transport, regardless of which site is selected.) The other sites are ranked according to their CMOE's in Table 12.

#### Issue 2

The CMOE ranking for Issue 2 reveals that strategy 4 would be the optimal local-transport route. This corresponds to the Colorado River corridor. The ranking of the other alternatives are also shown in Table 13.

#### CONCLUSIONS

Little attention has been given to the manner in which transportation requirements might dictate the choice of a nuclear repository site. Because there are no known comprehensive methodologies that specifically address this issue, an effective and comprehensive procedure is needed to aid the concerned agency, and public alike, in prioritizing alternative transportation strategies under given situations.

In addition to discussions of the risk actually involved in transportation of nuclear waste as indicated by historical record, the paper presents a cost-effectiveness model for ranking possible transportation alternatives for nuclear waste disposal. The model has been applied to two current transportation issues; one that involves potential repository sites in the United States and the other that involves possible routes for a given Utah site. Based on the available data, the results show that the best repository location is the Gulf Interior site in Mississippi, with a railroad connection to and from the points of waste production. It was also determined that the best railroad route to the Gibson Dome site in Utah is the Colorado Canyon route. It should be noted that these results are based on the standpoint of transportation only. To facilitate actual applications, the model has been implemented on a microcomputer. The approach presented is expected to provide a major contribution in the area of selecting nuclear waste repository sites from a transportation perspective.

#### REFERENCES

1. Transportation of Hazardous Materials: Toward a National Strategy, Vol. 1. Special Report 197. TRB, National Research Council, Washington, D.C., 1983, 38 pp.
2. Safety Enforcement Efforts in Hazardous Materials Transportation by Truck. Report NTSB-SEE-81-2. National Transportation Safety Board, U.S. Department of Transportation, Feb. 1981.
3. Transportation of Hazardous Materials. Urban Consortium for Technology Initiatives, Public Technology, Inc., Washington, D.C., Sept. 1980.
4. G. Swindell. Obtaining Safety Assurance Through International Agreements. Nuclear Engineering International, Dec. 1980.
5. E. Wilnot. Transportation Accident Scenarios for Commercial Spent Fuel. Report SAND 80-2124. Sandia National Laboratories, Albuquerque, N. Mex., Feb. 1981.
6. W. Andrews, R. Rhoads, and A. Franklin. Transportation Risks: Moving Waste Products From a Nuclear Power Generation Site. Professional Safety, Nov. 1981.
7. M.P. Mills. Radioactive Shipments--Questions and Answers. Science Concepts, Vienna, Va., Oct. 1982.
8. Can Nuclear Wastes be Transported Safely? Office of Nuclear Waste Isolation, U.S. Department of Energy, Columbus, Ohio, 1983.
9. Natural Background Radiation in the United States. Proc., National Conference on Radiation Protection and Measurements, Vol. 17, No. 4, July 1976, p. 471.
10. J.C. Yu and L.M.G. Pang. Cost-Effectiveness Model for Prioritizing Transportation Energy Conservation Strategies. In Transportation Research Record 988, TRB, National Research Council, Washington, D.C., 1984, pp. 1-11.
11. E.L. Wilnot et al. A Preliminary Analysis of the Cost and Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites. Sandia National Laboratories, Albuquerque, N.Mex., June 1983.
12. Southeastern Utah Nuclear Waste Transportation Study. Bechtel Group, Inc., San Francisco, Calif., Oct. 1982.
13. Engineering Factors and Costs for National Waste Terminal Storage Repository Site Selection. Stearns-Roger Services, Inc., Denver, Colo., May 1983.
14. General Guidelines for Recommendation of Sites for Nuclear Waste Repositories. Report DOE/NE-44301-T1. U.S. Department of Energy, Nov. 1983, 40 pp.

Publication of this paper sponsored by Committee on Intermodal Freight Terminal Design.