APPLICATION OF DECISION-AIDING TECHNIQUES TO TRANSPORTATION ROUTES

Ruth F. Weiner

ABSTRACT

This paper discusses the application of the techniques of multi-attribute decision analysis to the problem of selection of routes for the transportation of spent nuclear fuel. In particular, the paper develops a non-quantitative, semi-intuitive application of the quantitative method of Keeney and Raiffa. The need for a non-quantitative application became evident in work with state agencies, citizens' groups, and other non-Federal stakeholders. These groups wanted to help select transportation routes for spent nuclear fuel through their communities and states, had no particularly organized method for selecting criteria on which to base such selections, and tended to mistrust and dismiss quantitative decision aiding methods. The criteria being considered included minimizing trip length, minimizing the likelihood of accidents, minimizing large cities transited by the shipments, avoiding tribal lands, and generally avoiding certain locations.

The paper presents a simplified quantitative decision-aiding method using examples from the TRAGIS routing code, with transportation risk assessed using the program and code RADTRAN. A non-quantitative, but not particularly intuitive result is developed from the quantitative method.

INTRODUCTION

Multi-attribute decision analysis (MUA: Keeney and Raiffa, 1986, 1993) was developed to help formulate decisions whose objectives might be inconsistent or contradictory. For example, in selecting occupational safety measures and techniques to ensure ALARA , minimizing both cost and worker dose might not be possible. Examples where the technique has been used are: siting electric generating plants (Keeney, 1980), the selection of Yucca Mountain for characterization (Keeney, 1987; Keeney and Merkhofer, 1987; Weiner and Quiggle, 1987), and the selection of experiments to complete the certification application for the Waste Isolation Pilot Plant (Prindle, et al, 1996a and b). The method is unique among decision-aiding methods in that it incorporates and quantifies the wishes and biases of the decision-maker (or decision-making group). Moreover, the resulting decision depends on the decision-maker; different persons or groups will make different decisions.

The selection of acceptable routes for transporting spent nuclear fuel from reactors to a repository is the sort of decision problem for which MUA is eminently suited. The "not-in-my-backyard" reaction of many stakeholders to this transportation can be one criterion for choosing a route but cannot be the only criterion, because the route is going to go through someone's "backyard." MUA requires the decision maker to examine the criteria for route selection closely, to ensure that they are independent and to examine his or her predilections toward one or another criterion. In this illustrative example, the author played the role of decision-maker.

The overall goals of this surrogate decision-maker are (1) to minimize risk and (2) to identify acceptable routes. These goals may be subdivided as:

- Avoid certain states
- Minimize transit through urban areas
- Minimize transit across tribal lands
- Minimize route length
- Minimize likelihood of accidents

Other subdivisions are possible, but these capture the criteria that form the bases for the decision and illustrate how all goals may not be equally achievable.

SELECTION OF ROUTES AND CRITERIA

Route Selection

Four alternate routes from Fernald, OH to Caliente, NV were chosen to illustrate the method; these are shown on the map in Figure 1.

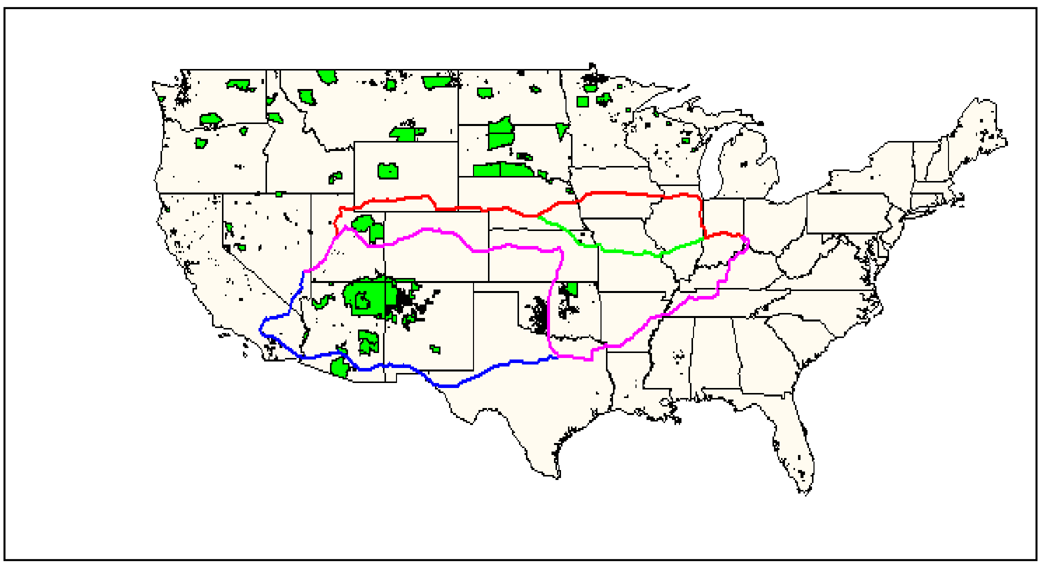

Figure 1. Four alternate routes from Fernald, OH to Caliente, NV. Shaded areas indicate tribal lands.

The routes were selected using the routing code WebTRAGIS (Johnson and Michelhugh, 2003). The most direct route, through Indiana, Illinois, Missouri, Kansas, Colorado, and Utah was the base case. Alternatives to the base case each avoided going through a particular state(s), since this criterion distinguished clearly among alternatives *ab initio*, before any other analysis was done. The northernmost route avoided Missouri and the southernmost route avoided Illinois, Missouri and Kansas. The route north of the latter avoided Illinois.

Criteria Selection

Table 1 presents potential criteria for route selection. These criteria are almost but not entirely independent (e.g., radiological risk is not entirely independent of distance). MUA requires that each criterion have an associated metric that uses either a natural scale, like kilometers for route length, or a constructed scale where no natural scale exists. The metrics are listed in Table 1, as are any constraints. An axiom of decision analysis is that the more criteria there are, the less clear the decision will be.

Table 1. Potential Criteria for Route Selection.

POTENTIAL CRITERION	METRIC	CONSTRAINTS
distance	kilometers; miles	none
radiological risk	rem; person-rem	regulation maxima for cask external dose rate, occupational dose
non-radiological risk	accidents per km or per mile; total accidents on route	none
transportation cost	dollars	none
exposed population	population; population density	none
urban areas transited	number of urban areas	some specific to mode and urban area, e.g. rush-hour limits
tribal lands transited	kilometers; miles	may be some prohibitions
rail interchanges	number	
number of shipments (on a given route or route segment)	number	none
track quality	track class	some constraints
emergency preparedness	number of responders; distance to responders	none
“avoid my state” (acceptability)	constructed scale	none
farmland transited	kilometers; miles	none

Table 2 shows the criteria that are used in the present analysis. The values of the criteria presented in Table 2 are clearly different for the different routes and have distinct metrics and natural scales. A scale was constructed for “acceptability” which is not shown in Table 2.

Table 2 . Values of Decision Criteria for Each Route

ROUTE	TOTAL KM	RURAL KM	SUBURBAN KM	URBAN KM	ACCIDENTS	CITIES
Baseline (Route 1)	3341.5	2823.9	428.2	89.5	1.20E-03	3
MO Blocked (Route2)	3450.8	2831.1	495.1	124.5	1.40E-03	4
CA, MO, IL, IA Blocked (Route 3)	4638.5	3753.7	742.1	142.9	1.70E-03	5
MO, IL, IA Blocked (Route 4)	4653.8	3613.8	853.5	186.6	2.77E-03	6

ANALYSIS

The decision analysis requires that the values of the criteria be “desirable” or “undesirable” depending on the extent to which they further the goals of the decision, and that “desirability” be quantitated in some way. Numerical values for desirability allow criteria to be ranked and compared and allow this comparison on a normalized basis, so that, for example, kilometers can be compared to radiation dose. Numerical values are applied by identifying the “most desirable” and “least desirable” values for each criterion and making a graph of the values for each alternative. Two examples are:

Total distance traveled

Decreasing the total distance traveled would be most desirable. In this case, 2500 km was chosen somewhat arbitrarily as the most desirable total distance and given a rank of one. 5000 km was chosen as the least desirable distance and given a rank of zero. Table 3 shows the ranking, by desirability, of the total length of the four routes, in km. Route 1 could have been used as the best case, and Route 4 as the worst case, but these selections could prove disadvantageous later in the analysis.

Table 3. Ranking of Total Length of Each Route.

ROUTE	TOTAL KM	RANK
Best Case	2500	1.0
Route 1	3341.5	(5000-3341.5)/2500 = 0.67
Route 2	3450.8	(5000-3450.8)/2500 = 0.62
Route 3	4638.5	(5000-4638.5)/2500 = 0.14
Route 4	4653.8	(5000-4653.8)/2500 = 0.14
Worst Case	5000	0

Figure 2 is a graphical representation of Table 3, and shows a straight line approximation to the data.

Native American Lands Traversed

The decision-maker has ascertained that a number of Native American tribes object to these shipments crossing tribal lands, so crossing no tribal land is clearly the best case. The worst case was selected to cross about 15% more than the route that crosses the most tribal land. Values and ranks for the four routes are shown in Table 4 and Figure 3.

Table 4. Ranking of Total Kilometers of Native American Lands Along Each Route.

ROUTE	KM INDIAN LAND	RANK
Best case	0	1.00
Route 1	0	1.00
Route 2	4.2	0.65
Route 3	51.3	0.41
Route 4	264.0	0.12
Worst case	300	0.00

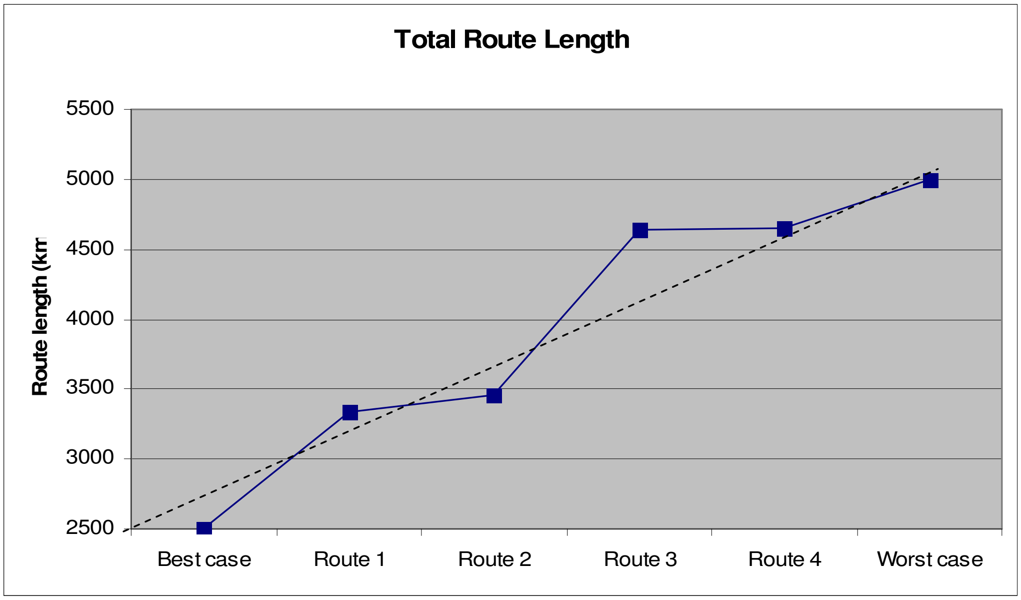

Figure 2. Total Route Lengths

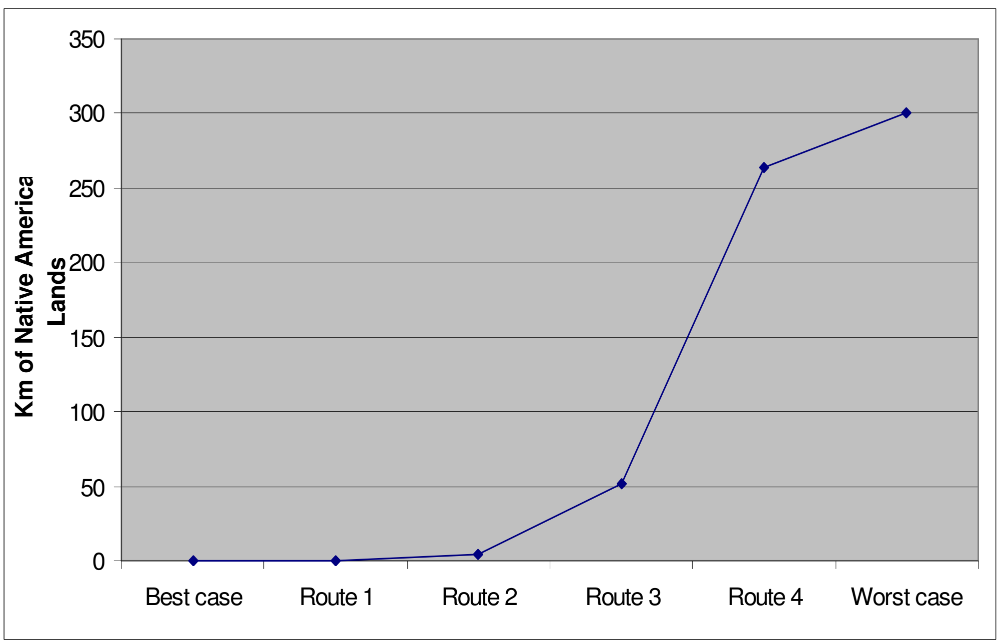

Figure 3. Native American Land Traversed

Table 5 shows the ranking for all the criteria used. The criterion "avoid Illinois" is used as a surrogate for "acceptance", and the ranking was binary: avoiding Illinois was the best case (rank = 1); traversing that state was the worst case (rank = 0). The other criteria had natural scales.

The decision-maker's preferences can also be quantified. The most easily intuited scale for these preferences is to give the decision-maker 100 points to divide among the criteria. Preferences are thus not entirely independent of each other. The most mathematically sound method is to have the decision-maker perform a two-by-two tradeoff analysis of the criteria (e.g., how many more km of tribal land would the decision-maker accept in order to shorten the total route by 500 km?). However, for a preliminary or non-binding decision, the 100-point method is adequate.

Table 5. Ranking the Criteria

	Route 1	Route 2	Route 3	Route 4
route length	0.67	0.62	0.14	0.14
accident likelihood	0.64	0.58	0.48	0.15
routine dose	0.65	0.7	0.44	0.35
urban centers	0.625	0.5	0.25	0
Native American lands	1	0.65	0.41	0.12
avoid IL	0	0	1	1

Table 6 presents the decision-maker's preferences: minimizing route length, minimizing accident probability, and avoiding urban centers are about equally important to the decision-maker and are somewhat more important than the other three criteria. The decision-maker can also gain insight into the decision by varying the preferences. In Table 6 this is done by changing which criterion is considered least important, giving that criterion a score of zero, and dividing those points among the other criteria.

Table 6. Decision-maker's Preference Scores

		Least Important Criteria			
Criteria	**Initial preferences**	**Tribal lands**	**State acceptance**	**Route length**	**State acceptance, routine radiation dose**
route length	22	25	24.6	0	27.75
accident likelihood	20	23	22.6	24.4	25.75
routine dose	10	13	12.6	14.4	0
urban centers	20	23	22.6	24.4	25.75
indian lands	15	0	17.6	19.4	20.75
avoid IL	13	16	0	17.4	0

RESULTS AND CONCLUSIONS

The decision analysis is completed by multiplying the rank of each criterion by the decision-maker's preference score for that criterion, as shown in Table 7. The numbers in these tables have no absolute significance.

When the products of ranking and importance are added for each route, the comparative results indicate to the decision-maker which routes are more acceptable, considering the decision-maker's preferences. In this instance Route 1 is clearly preferred and Route 4 is unacceptable by comparison. The decision-maker can then estimate the sensitivity of this result to his or her preferences by changing the preference scores, as was shown in Table 6.

Table 7. Combining Decision-maker's Scores and Criterion Ranking

Criterion	Score	Ranking Route 1	Ranking Route 2	Ranking Route 3	Ranking Route 4	Importance x Ranking Route 1	Importance x Ranking Route 2	Importance x Ranking Route 3	Importance x Ranking Route 4
route length	22	0.67	0.62	0.14	0.14	14.7	13.6	3.1	3.1
accident likelihood	20	0.64	0.58	0.48	0.15	12.8	11.6	9.6	3.0
routine dose	10	0.65	0.7	0.44	0.35	6.5	7.0	4.4	3.5
urban centers	20	0.625	0.5	0.375	0.25	12.5	10.0	7.5	5.0
indian lands	15	1	0.65	0.41	0.12	15.0	9.8	6.2	1.8
avoid IL	13	0	0	1	1	0.0	0.0	13.0	13.0
TOTALS						**62**	**52**	**44**	**29**

Table 8 shows the results of applying the different scores in Table 6 to the ranking of the criteria. The relative desirability of Route 1 and the relative undesirability of Route 4 appear insensitive to changes in the preference score. When tribal lands are least important, the route that traverses the most tribal land, Route 4, becomes somewhat more desirable, but still remains the worst of the alternative routes. Routes 2 and 3 never exceed Route 1 in desirability, but their desirability relative to each other is sensitive to score changes.

Table 8. Sensitivity of Acceptability to Preference Scores

	original importance weights	Tribal lands least important	state acceptance least important	route length least important	state acceptance, routine dose least important
Route 1	**62**	**54**	**71**	**60**	**72**
Route 2	52	49	60	49	59
Route 3	44	45	36	53	34
Route 4	*29*	*33*	*19*	*35*	*17*

Table 8 demonstrates that the relative acceptability of these routes does not change significantly with large changes in decision-maker preferences. That is, the order of acceptability remains Route 1, then Route 2, then Route 3, then Route 4, although the range of acceptability changes. One explanation is the (albeit weak) interdependence of some of the criteria. Accident likelihood, routine radiation dose, and avoiding one state all depend to a greater or lesser extent on route length; only "tribal lands transited" and "urban centers transited" are independent. Selection of the best and worst cases also influences the relative acceptability by strongly influencing the rank.

This application of MUA is predicated on transporting spent nuclear fuel on a cross-country route. Choosing not to transport, which might have led to different relative acceptability, is not an option for the decision-maker in this exercise. The exercise does not "make" a decision. Its purpose is to provide the decision-maker with insight into his or her decisions and with some insight into what other decision-makers might find acceptable or unacceptable.

References

Johnson, P. E. and Michelhaugh, R.D. *Transportation Routing Analysis Geographic Information System User's Manual*, https://tragis.ornl.gov , ORNL/NTRC-006, Oak Ridge National Laboratory, TN, 2003.

Keeney, Ralph: *Siting Energy Facilities*, Academic Press, New York, 1980

Keeney, Ralph and Raiffa, Howard: *Decisions With Multiple Objectives,* Wiley, New York, 1986.

Keeney, Ralph and Raiffa, Howard: *Decisions With Multiple Objectives,* Wiley, New York, 1993

Keeney, Ralph "An Analysis of the Portfolio of Sites to Characterize for Selecting a Nuclear Repository," *Risk Analysis,* 7, 195-218, 1987
.
Keeney, Ralph and Merkhofer, M. W. "A Multiattribute Utility Analysis of Alternative Sites for the Disposal of Nuclear Waste," *Risk Analysis*, 7, 173-194, 1987.

.Prindle, M. H., Tierney, M., Weiner, R. F., Boak, D. M., Hora, S. "Decision-Making for Geological Repositories" International Conference on Geologic Disposal of Radioactive Waste, Winnipeg, Canada, September, 1996a.

Prindle, M. H., et al. *Second Iteration of the System Prioritization Method v. III: Analysis for Final Programmatic Recommendations*, Sandia National Laboratories, Albuquerque, NM, 1996b

Weiner, R. F. and Quiggle, R. " Multiattribute Decision Analysis for the HLW Repository Sites Selected for Characterization" _*Research Notes; Northwest Environmental Journal*, 1987, pp. 165-166

Weiner, R.F., Osborn, D.M, Hinojosa, D. Orcutt, D.J., Heames, T. J. *RADCAT2.3 User Guide* SAND2005-1963 , Sandia National Laboratories, 2006