MAUT Approach for Selecting a Proper Decommissioning Scenario

S.K. Kim, H.S. Park. K.W. Lee, C.H. Jung
Korea Atomic Energy Research Institute
150, Dukjin-Dong, Yuseong-Gu, Daejeon
Republic of Korea

ABSTRACT

When dismantling scenarios are selected, not only the quantitatively calculated results but also the qualitatively estimated results should be considered with a logical and systematic process. In this case, the MAUT (Multi-Attribute Utility Theory) is widely used for the quantification of subjective judgments in various fields of a decision making. This study focuses on the introduction and application of the MAUT method for the selection of decommissioning scenarios. To evaluate decommissioning scenarios, nine evaluation attributes are considered. These attributes are: the primary cost, the peripheral cost, the waste treatment cost, the worker's exposure, the worker's safety, the work difficulty, the originality of the dismantling technologies, their contributions to other industries, public relations for, and an understanding of the public. The weighting values of the attributes were determined by using the AHP (Analytic Hierarchy Process) method and their utility functions are produced from several questionnaires for the decision makers. As an implementation, this method was applied to evaluate two scenarios, the plasma arc cutting scenario and the nibbler cutting scenario for decommissioning the thermal column in KRR-1(Korea Research Reactor-1). As a result, this method has many merits even although it is difficult to produce the utility function of each attribute. However, once they are setup it is easy to measure the alternatives’ values and it can be applied regardless of the number of alternatives.

INTRODUCTION

As the number of obsolete research reactors and nuclear power plants increases, dismantling nuclear power facilities has become an influential issue [1, 2]. However, decommissioning a nuclear facility is still a costly and possibly hazardous task. So prior to an actual decommission, establishing proper procedures should be preceded before all other activities. Due to the fact that a significant difference in cost, exposure to a radiation, and safety might occur, a proper procedure is imperative for an entire engineering process. Traditionally a decision-maker has selected the dismantling procedures after an engineer set them up through his decommissioning experiences. But this might lead to an arbitrary decision because they did not consider a given decommissioning condition and other experienced engineers’ opinions. Therefore, we need to set up decommissioning scenarios with a more systematic and reasonable methodology in order to avoid a subjective decision.

A selection of a dismantling procedure is regarded as a decision making problem. In other words, this problem is to choose the best procedure among various dismantling procedures for dismantling an object by evaluating several evaluation criteria. In this case, the multi-attribute utility theory (MAUT) is an intuitively very useful method for formulizing and analyzing decision making problems. The multi-attribute utility model (named as a subjective evaluation model or a multi-criterion model) enables the consideration of factors that have different measures and vary in relative importance to a decision. The MAUT approach is resolutely founded in theory, specifically von Neumann and Morgenstern’s utility [3] theory, and the specific assessment techniques and elicitation procedures developed by Keeny and Raiffa in 1976 [4]. The validity of the MAUT has been proven by many researchers as given in the references [5-6]. MAUT has been applied to a wide range of decision-making problems, for example the selection of a construction location, alternative plans, a job, an R&D project, or an investment plan establishment. In particular, most recently its scope has been expanded to non-market fields, such as selecting a location for a thermal power plant that considers an environmental aspect [7, 8], selecting an optimal technology that considers the attributes of an enterprise’s situation and a technology-applied field [9], and deciding how to maximize the satisfaction of customers from a marketing aspect [10]. Recently a few researchers have tried to apply MAUT to a nuclear problem. Hwang [11] evaluated a decision-making problem by using the MAUT in order to obtain the best scenario to minimize a residents’ damage from the radioactive substances exposed to the environment at the initial stage of a nuclear power accident.

In this paper, a multi-attribute utility technique model is provided to quantitatively assess dismantling scenarios for decommissioning a research reactor; a unit utility function for respective attributes is drawn; and weighted values for each attribute are computed by exploiting the AHP method. Moreover, a diamond wire saw cut scenario and a core-boring cut scenario are compared and evaluated respectively for dismantling a thermal column of the KRR-1(Korea Research Reactor-1) as an example of the decommissioning scenario.

MAUT PROCEDURE

In this passage, the viewpoint of an evaluator on the attributes of the considered subjects is scrutinized through the developmental stages of a multi-attribute utility function by using the MAUT. In theory and practice, although a variety of application procedures of the MAUT exist, the application procedures are developed by the following five stages.

Setting the objective and establishing the attributes for the goal

Creating quantitative figures of attributes

Deriving the utility functions of individual attribute

Calculating the weighting factors of individual attribute

Deriving the multi attribute utility function

1) Setting the Objective and Establishing the Attributes for the Goal

A concrete target establishment and attribute identification are crucial stages for an evaluating process by using the MAUT. To begin with, a goal of the evaluation is explicitly defined, and directly related attributes are determined. A common method is to interview experts who are familiar with the components associated with the goal or to determine key attributes by founding scientific bases through extensive researches on pertinent references and excluding unnecessary attributes. In adopting the attributes, the most significant matter is whether the selected attributes are included in the required scope. In other words, it is critical to aptly define the scope of an analysis, and desirable to establish a limit through direct discussions with decision makers.

2) Creating Quantitative Figures of the Attributes

In measuring the level of the attributes, setting a potential scope for the selected attributes from the best level to the worst level for a decommissioning scenario evaluation is instrumental [12]. An upper limit and a lower limit of the attribute scope are determined by using the existing research results and through a scientific analysis on the basis of an engineering model [13].

3) Deriving the Utility Functions of Each Attribute

This stage is where a function form of a single-attribute utility function, which is an element of the multi-attribute utility function, is determined. At first, to determine whether to increase or decrease the utility function, the direction of increase or decrease is determined according to a social desirability of the applicable attributes. For instance, the increase function is for the decommissioning cost and the decrease function is for an exposed worker. Subsequently, a complete form of the utility function is sought in accordance with risk-averse, risk-neutral, and risk-prone, all of which constitute a risk attitude. By and large, given that the following index and linear utility function are assumed, they are sufficient for most cases, and their form is solid.

$$u(x) = a - b\exp(-cx) \qquad \text{(Eq. 1)}$$

$$u(x) = a + b(cx) \qquad \text{(Eq. 2)}$$

$$u(x) = a + b\exp(cx) \qquad \text{(Eq. 3)}$$

In this case, a and b are a constant bigger than 0, which ensures $u(x) \in [0,1]$, and c is (+) in an increase function, and (-) in a decrease function. In addition, c indicates a risk averse level in equation (1), and if c is the increase function, it is +1 and if the decrease function, it is -1. Equation (1) is a risk-averse type, equation (2) is a risk-neutral type, and equation (3) is a risk-prone type respectively.

4) Calculating the Weighting Factors of Each Attribute

This stage is where the decision makers determine the relative importance of various attributes. The general method is a swing technique where the decision makers label a weighted value after setting the rank of the attributes in the order of their importance. The methods for determining the weighted values are the AHP method and the DVM technique (Difference Value Measurement). In this research, the importance of each attribute is computed by means of the AHP method [14-17]. The preference of each attribute is formed by a matrix through a survey obtained from the experts, and the weighted values of each attribute are computed by employing an eigenvector method. As the AHP is based on the experience and intuition of the decision makers for an evaluation, the quantitative evaluation standard expressed in numbers and qualitative evaluation standards, which must be considered even though they are intractable to handle when making decisions, are readily processed. Also the process of an analysis is intuitive and relatively plain.

5) Deriving the Multi-Attribute Utility Function

With the previously-calculated utility function of each attribute and the weighted values, an evaluation index is developed for the general goal. In brief, to select an optimal decommissioning scenario, it can be expressed by the multi-attribute utility function, which is a single mathematical equation that shows how much these attributes contribute to the goal. Equation (4) shows the multi-attribute utility function equation.

$$U(x_1, \cdots, x_m) = k_1 u_1(x_1) + \cdots + k_m u_m(x_m) \qquad \text{(Eq. 4)}$$

where $k_1, \cdots, k_m$ are the weighting factors of the utility functions and $\sum_{i=1}^{m} k_i$ equals 1. In equation (4), u_m represents a utility function.

IMPLEMENTATION OF MAUT

Finding the Attributes for the Decommissioning Scenario Evaluation

To obtain the required attributes for the decommissioning scenario evaluation, various evaluation elements affecting the decommissioning scenario evaluation are examined through domestic and foreign references. This information is re-organized to fit the domestic situation, and then, the attributes are primarily selected. Furthermore, the attributes are finally established by a group of 10 experts who were serving in a decommissioning department as shown in Table I. The goal is to select the optimal decommissioning scenario, which takes various evaluation elements into account. This goal is categorized into four sub-goals, covering the decommissioning cost, work safety, technical characteristics, and a social acceptance.

Table I. The attributes for the selection of a decommissioning scenario

Goal	Selecting the best decommissioning scenario for the thermal column
Criteria	Sub-criteria
1. Decommissioning cost	1.1 Peripheral cost 1.2 Primary cost 1.3 Waste treatment cost
2. Work safety	2.1 Worker’s exposure 2.2 Difficulty degree
3. Technical characteristics	3.1 Originalities 3.2 Contributions
4. Social acceptance	4.1 Public relations 4.2 Public understandings

Creating Quantitative Figures of the Attributes

In this paper, the quantitative figures of a part of the attributes (decommissioning cost) were calculated by using the decommissioning digital mock-up system in order to quantify the attributes [18]. However, the rest of the attributes were all qualitative ones so a considerable amount of time was spent to quantify them. First of all, for setting up the range of the evaluation, a thorough grasp of the information about a decommissioning of domestic research reactors was obtained and also a foreign countries’ decommissioning information was gathered. The quantitative ranges for the attributes were setup through the information collected. Table II shows the units and the ranges for the determined attributes.

Table II. The units and the ranges for the attributes

Attributes and units		Unit	Worst	Best
1.1	Minimization of the peripheral cost (The cost used for the preparation of decommissioning work)	million won	500	5
1.2	Minimization of the primary cost (The cost used for doing decommissioning works)	million won	400	50
1.3	Minimization of the waste treatment cost (The cost used for the waste treatment)	million won	200	10
2.1	Minimization of the worker’s exposure (The degree of worker’s exposure during work)	%	60	0
2.2	Minimization of work difficulty degree (Work difficulty degree)	%	100	0
3.1	Maximization of technology originalities (Technology originalities)	%	0	100
3.2	Maximization of technology contributions (Contributions of the technology to other industries)	%	0	100
4.1	Maximization of public relations (Public relations about decommissioning technology)	%	0	100
4.2	Maximization of public understandings (Public understandings about decommissioning technology)	%	0	100

Deriving the Utility Functions

The next step in the MAUT process involves an aggregation of the component scores. The additive and multiplicative forms are commonly used for the MAUT models. The general form of the additive model is:

$$u_i(x_i) = \sum_{j=1}^{n} k_{ij} u_{ij}(x_{ij}) \qquad \text{(Eq. 5)}$$

where j is the attribute of interest; x_{ij} is the evaluation unit for the j attribute in the i criterion ; u_{ij} is the decision-maker’s preference or single attribute utility function for x_{ij} ; and k_{ij} is the relative importance of the j attribute in the i criterion, for the n attributes such that $\sum_{j=1}^{n} k_{ij} = 1$.

In order to derive the single utility function $u_{ij}(x_{ij})$, questionnaire surveys were conducted by the certainty equivalence judgment method and the personal results synthesized by using a geometric mean. The analysis results showed that the peripheral cost, primary cost, waste treatment cost, worker’s exposure, and work difficulty showed a risk aversion trend and the technical originalities, public relations, and public understandings showed a risk prone trend. Table III shows the single attribute utility equations that were obtained from the results of the decision makers’ questionnaires.

Table III. Single attribute utility equations and risk trends of the individual attributes

Attributes	Equations $u_{ij}(x_{ij})$	Parameter descriptions	Units	Risk trends	Rise or fall
Peripheral cost	$y=1.02686-0.03313e^{0.00684x}$	x= the costs obtained from the DMU	million won	Risk aversion	Fall
Primary cost	$y=1.01501-0.01108e^{0.01128x}$		million won	Risk aversion	Fall
Waste treatment cost	$y=1.09799-0.09569e^{0.01217x}$		million won	Risk aversion	Fall
Worker's exposure	$y=1.00228-0.01241e^{0.08814x}$	x= evaluation scores of experts	%	Risk aversion	Fall
Difficulty degree	$y=1.13865-0.13884e^{0.02052x}$		%	Risk aversion	Fall
Originalities	$y=-0.12258+0.15418e^{0.01955x}$		%	Risk prone	Rise
Contributions	$y=0.02727+0.01009x$		%	Risk neutral	Rise
Public relations	$y=-0.55621+0.5876e^{0.00931x}$		%	Risk prone	Rise
Public understandings	$y=-0.3128+0.35083e^{0.01238x}$		%	Risk prone	Rise

Constructing the Multi-Attribute Function

The multi-attribute function consists of four sub-attribute elements such as a decommissioning cost, work safety, technology characteristics, and social acceptance. From the results of equation 4 the multi-attribute function can be expressed as equation 6.

$$U(x_1, x_2, x_3, x_4) = k_1u_1(x_1) + k_2u_2(x_2) + k_3u_3(x_3) + k_4u_4(x_4) \qquad \text{(Eq. 6)}$$

where $\sum_{i=1}^{4} k_i$ equals 1 and k_i is a weighting factor for the criterion. Generally the swing weighting method is used to calculate weighting factors but in this paper, the AHP (analytic hierarchy process) method was used instead because it is more reasonable and more systematic than the others. The process of the AHP is as follows.

In order to obtain a prioritization of each criteria and sub-criteria like Table I by using the AHP method, questionnaires were mailed to an expert group and the results collected were analyzed. To compare the relative preference with respect to the main criteria and the sub-criteria, the questions were assigned the highest rank of 9 and the lowest rank of 1. The prioritizations were calculated by using the geometric mean method to minimize a weakness in that the evaluation was controlled by a few lowest values and/or highest values.

Table IV. Weighting factors of criteria and sub-criteria using AHP

Criteria	Weighting factors	Sub-criteria	Weighting factors
Decommissioning cost	0.2410	Peripheral cost	0.199
		Primary cost	0.336
		Waste treatment cost	0.465
		Sub-total	1.000
Work safety	0.4162	Worker's exposure	0.642
		Difficulty degree	0.358
		Sub-total	1.000
Technical characteristics	0.1599	Originalities	0.326
		Contributions	0.674
		Sub-total	1.000
Social acceptance	0.1829	Public relations	0.414
		Public understandings	0.586
		Sub-total	1.000
Total	1.0000		

Table IV shows the weighting factors of the criteria and sub-criteria for the evaluation of the decommissioning scenarios by using the AHP. In order to verify the weighting of the criteria, the C.R. (consistency ratio) of all the main criteria was calculated. They were all bounded by the limit (C.R.<0.2) The experts valued work safety as the highest weighting factor among the criteria and thus it accounts for 41.6% of the total. The second highest weighting factor of the criterion was the decommissioning cost and the technical characteristics and the social acceptance had almost the same weighting factor. The result shows that the experts consider the safety of workers as the top priority. Therefore k_i in equation (6) can be expressed as follows.

k_1 =0.2410, k_2 =0.4162, k_3 =0.5990, k_4 =0.1899

And also according to equation 5, the utility function regarding the decommissioning cost can be expressed with a summation of the peripheral cost, the primary cost, and the waste treatment cost's utility functions along with their weighting factors. Equation 7 shows the mathematical form.

$$u_1(x_1) = u_1(x_{11}, x_{12}, x_{13}) = k_{11}u_{11}(x_{11}) + k_{12}u_{12}(x_{12}) + k_{13}u_{13}(x_{13}) \quad \text{(Eq. 7)}$$

where $\sum_{j=1}^{3} k_{1i}$ equals 1 and the values of u_{ij} can be calculated by using the utility functions in Table III. The weighing factors k_{ij} of the sub-criteria were calculated by the same procedure and they are summarized in Table IV. In the decommissioning cost part, the weighting of the waste treatment cost is the highest and it accounts for 46.5% and then the primary cost is 33.6% and the peripheral cost is 19.9% respectively. In the work safety part, the worker's exposure is 64.2%, the difficulty degree is 35.8%. In the technical characteristics part, the technological contributions is 67.4% and the originalities is 32.6%. In the social acceptance part, public understanding is 58.6% and public relations is 41.4%. k_{ij} are summarized as follows

k_{11} =0.199, k_{12} =0.336, k_{13} =0.465

k_{21} =0.642, k_{22} =0.358

k_{31} =0.326, k_{32} =0.674

k_{41} =0.414, k_{42} =0.586

The final values of the multi-attribute utility (Table V) can be obtained by using the weighing factors k_{ij} and the utility functions in Table III.

Table V. Input values of each scenario

Criteria	Sub-criteria	Input values	
		Scenario 1 (Plasma)	Scenario 2 (Nibbler)
Decommissioning cost	Peripheral cost	10.9	13.8
	Primary cost	161.7	127.9
	Waste treatment cost	33.0	39.0
Work safety	Worker's exposure	1.21	0.56
	Difficulty degree	49.7	40.3
Technical characteristics	Originalities	50.3	42.7
	Contributions	52.3	40.8
Social acceptance	Public relations	50.3	45.6
	Public understandings	43.2	51.8

Dismantling Scenarios for the Thermal Column

To apply the MAUT model to a real dismantling item we selected the thermal column in KRR-1 and setup the plasma arc cutting scenario and the nibbler cutting scenario. The details of both scenarios are as follows.

- Plasma arc cutting scenario

Firstly, the worker surveys the entire thermal column by using a detector. According to the real detecting results, the radioactivity level of the inside of the thermal column is quite low so the graphite blocks staked in the thermal column can be removed manually. In order to remove the thermal column, lead shield plates and plasma arc cutting equipment are installed in the opposite side of the thermal column. The thermal column and the thermalizing column are both removed by the installed equipment and the pieces of waste are collected into a waste container and then the container is moved out of the reactor pool and the waste is managed by a waste treatment process.

- Nibbler cutting scenario

Firstly the procedures of a survey and removing the graphite blocks for the nibbler cutting method are the same procedures for the plasma arc cutting scenario. Then in order to make sure that there is enough space for the nibbler equipment to be inserted into the thermal column, the top of the thermal column and the thermalizing column are cut by plasma arc cutting equipment. Then the nibbler equipment and a cradle for the worker are installed on the top of the reactor pool and then the thermal column and the thermalizing column are dismantled by the nibbler equipment. Then the cutting waste is moved out of the reactor pool and sealed in a waste container.

Table VI. Synthesized priorities and ranks for the goal

Criteria	Sub-criteria	Weighting factor	utility function		Multi-utility function	
			Scenario 1 (Plasma)	Scenario 2 (Nibbler)	Scenario 1 (Plasma)	Scenario 2 (Nibbler)
Decommissioning cost (0.2410)	Peripheral cost	0.199	0.9912	0.9905	0.2312	0.2317
	Primary cost	0.336	0.9464	0.9681		
	Waste treatment cost	0.465	0.9550	0.9442		
	Combined utility		0.9593	0.9614		
Work safety (0.4162)	Worker’s exposure	0.642	0.8546	0.9897	0.3407	0.3868
	Difficulty degree	0.358	0.7537	0.8212		
	Combined utility		0.8185	0.9294		
Technical characteristics (0.1599)	Originalities	0.326	0.2896	0.2327	0.0749	0.0594
	Contributions	0.674	0.5550	0.4389		
	Combined utility		0.4685	0.3717		
Social acceptance (0.1829)	Public relations	0.414	0.3823	0.3422	0.0596	0.0638
	Public understandings	0.586	0.2861	0.3534		
	Combined utility		0.3260	0.3487		
Total					0.7064	0.7417
Rank					2	1

6) EVALUATION RESULTS

The input values for evaluating the dismantling scenarios of the thermal column by the MAUT are shown in Table V. The values of the utility of each attribute can be obtained by substituting this input data into the single attribute utility equations in Table III and when the values we obtained are substituted into Equation 4 we can obtain the final multi-attribute utility values that are bounded by a limit from 0 to 1 regarding each dismantling scenario. Table VI shows the results of the combined utility values with respect to each attribute and the total multi-utility values regarding each scenario. According to the results we drew conclusions about the two scenarios. When we review the multi-attribute utility values for each criterion in Table VI, the two scenarios have a similar tendency but in the work safety part the nibbler scenario is much higher than the plasma scenario moreover the impact factor of a work safety is the highest among the criteria so it has a big influence on the total score. Consequently, the value of the plasma cutting scenario is 0.7064 and the nibbler cutting scenario is 0.7417 so we can conclude that the plasma cutting scenario is better in both scenarios.

CONCLUSION

In this study, we established the attributes for evaluating dismantling scenarios through a decommissioning expert group and derived their utility functions to allow us to quantify them. Also we developed a multi-attribute utility model that can quantitatively evaluate dismantling scenarios by combining the weighting factors with the utility functions.

This MAUT model was implemented to choose the best scenario regarding the thermal column in KRR-1 and these scenarios were evaluated quantitatively through the MAUT method. As a result, both scenarios had almost the same scores, but the nibbler scenario had a high score in the work safety part where it has the highest priority. Finally we decided that the nibbler scenario is better than the plasma scenario for dismantling the thermal column of KRR-1.

This study has a great meaning in that it can present a reliable scenario through a reasonable decision making method and this method is very helpful for decision makers to evaluate scenarios easily with a quantified score of the quantitative items while this work had only been done through a subjective evaluation in the past. This study will be applied to the KRR-1 decommissioning project to obtain the best scenarios. We believe it will be a useful engineering tool for other nuclear facility decommissionings.

REFERENCES

1. Jung, K. J. (1997). Decommissioning of TRIGA Mark 1&2. *KAERI/RR-1798/97*.
2. Park, J. H. (2003). Decontamination and Decommissioning Project for the Nuclear Facilities, *KAERI/RR-2304/2002*.
3. von Neumann, J., Morgenstern, O. (1947). Theory of Games and Economic Behavior, *Princeton University Press*, Princeton, NJ.
4. Keeney, R. L. and Raiffa, H. (1976). Decisions with Multiple Objectives. *Wiley*, New York.
5. Fishburn, P. (1967). Methods of Estimating Additive Utilities. *Management Science*, Vol. 13, No. 7.
6. Winterfeldt, D. V. and Ward, E. (1986). Decision Analysis and Behavioral Research. *Cambridge University Press*.
7. McDaniels, T. L. (1996). A Multiattribute Index for Evaluating Environmental Impacts of Electric Utilities. *Journal of Environmental Management*. Vol. 46, pp. 57-66.
8. Hobbs and Benjamin, F. (1980). A Comparison of Weighting Methods in Power Plant Siting. *Decision Science*, Vol. 11, No. 4, pp. 725-723.
9. Keeney, R. L., Lathrop, J. F. and Sicherman, A. (1986). An Analysis of Baltimore Gas and Electric Company's Technology Choice. *Operation Research*, Vol. 34, No. 1, pp. 18-39.
10. Parker, B. R. and Srinivasan, V. (1976). A Customer Preference Approach to the Planning of Rural Primary Health-Care Facilities. *Operations Research*, Vol. 24, No. 5, pp. 992-1025.
11. Hwang. W. T. (2004). Application of Multi-Attribute Utility Analysis for the Decision Support of Countermeasures in Early Phase of a Nuclear Emergency. *Journal of Korean Association Radiation Protection*, Vol. 29, No. 1, pp. 65-71.
12. Johnson, F. R. and Desvousges, W. H. (1997). Estimating Stated Preferences with Rated-Pair Data : Environmental, Health, and Employment Effects of Energy Programs", *Journal of Environmental Economics and Management*. Vol. 34, pp. 79-99.
13. Goicoechea, A., Hansen, D. R. and Duckstein, L. (1982). Multiobjective Decision Analysis with Engineering and Business Applications, *John Wiley & Sons*, New York.
14. Saaty, T. L. (1980). The Analytic Hierarchy Process", *McGraw-Hill*, New York.

15. Wind, Yoram and Saaty, T. L. (1980). Marketing Applications of the AHP. *Management Science*, Vol. 26, No. 7.
16. Saaty, T. L. (1978). Modelling Unstructured Decision Problems : The Theory of Analytical Hierarchies. *Mathematics and Computers in Simulation*, Vol. 20, No. 30.
17. Saaty, T. L. (1977). A Scaling Method for Priority in Hierarchical Structures, *Journal of Mathematical Psychology*, Vol. 15, No. 3.
18. Kim. S. K. (2006). Development of a Digital Mock-Up System for Selecting a Decommissioning Scenario. *Annals of Nuclear Energy*. Vol. 33, pp. 1227-1235.