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Environmental Performance Evaluation Based on Fuzzy Logic

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Abstract— **The environmental Performance Evaluation (EPE) of organizations is becoming an independent and powerful management tool. In general, pros agree on the importance of measuring environmental performance related to their main missions and activities. The purpose of this paper is to describe the development of the fuzzy logic approach to decision making and its usefulness for managers by illustrating its application to environmental performance appraisals. The literature is reviewed to provide the framework for the model development in this research. Environmental performance evaluations represent a critically important decision that often involves subjective information. There are models and heuristic techniques that focus on the use of different types of information; however, with few exceptions, these models are not robust enough to be applied in a practical, managerially useful manner. Fuzzy logic models provide a reasonable solution to these common decision situations. Fuzzy logic can be a powerful tool for evaluating the environmental performance in comparison with traditional model. In this article a model for evaluating environmental performance was presented. Firstly through library research and interviews with experts the evaluation criteria are extracted and classified into 6 qualitative factors of evaluation criteria and then a fuzzy inference function will be utilized to rank environmental performances. The flexibility of the model allows the decision maker to introduce vagueness, uncertainty, and subjectivity in the evaluation system. Concerning the traditional quantitative methods, this research introduces an alternative method of the environmental performance evaluation system. Of course, further research in this area is needed to develop a method for relating membership values to linguistic variables in environmental performance evaluation, as well as testing the sensitivity of membership values and their impact on the outcome. This paper provides a simple-to-use fuzzy logic model for establishing a more meaningful environmental Performance evaluation system.**

Keywords- Environmental Performance Evaluation, Fuzzy Logic, Decision Making, Linguistics.

I. INTRODUCTION

The environmental performance evaluation (EPE) of organizations is turning into an independent management tool. Generally speaking, pros agree on the importance of measuring environmental performance related to their main missions and activities. Standard EPE is defined as a process to facilitate management decision making regarding an organization's environmental performance by selecting indicators, collecting and analyzing data, assessing information against environmental performance criteria, reporting and communicating, and periodically reviewing and improving this process [1]. In order to make decisions, environmental models should contain the best knowledge. Also, they should be supported by the necessary data to perform well against measuring issues. This has led to the development of more complex and fundamental models in recent years. Anyway, even the most advanced models are still associated with large uncertainties [2]. The alternative approach is to consider both the decision bringing about environmental improvements and the techniques which allow decisions to make models. These models may involve greater uncertainty than more complex models, but they facilitate more readily the treatment of uncertainty through sensitivity analysis. Moreover, the data requirements to run them are less stringent. In fact they may also allow broader factors to be included into the decision-making process, incorporating risk, and optimizing social and economic factors, etc. An environmental decision ought to depend on a criterion meeting a numerical objective with uncertainty treated explicitly. The way of including the uncertainty is to assume that the criterion involves the membership of a fuzzy set. This is an obvious application of fuzzy logic to environmental decision-making. In some cases, the environmental criterion is vague or imprecise, such as when dealing with the 'quality of life', the ranking of ecosystems in terms of environmental conditions, and impacts [3], or environmental impact assessment [4].

However, much of the information related to environmental performance appraisal is not quantifiable and precise with crisp boundaries. Rather, this information is presented in expressions or words in natural language and without precision. Fuzzy logic models provide a reasonable solution to these common situations, which may easily be converted into human linguistic forms and subjective constructs. Fuzzy logic is a problem solving methodology that provides a simple way of drawing definite conclusions from vague and imprecise information. Fuzzy set theory was first introduced by Zadeh[5]. He was motivated by observing that human reasoning can utilize concepts and knowledge that don't have well-defined boundaries [6]. Fuzzy set theory is a generalization of the ordinary set theory. A useful approach for examining many real-world problems is fuzzy approximate reasoning or fuzzy logic. Fuzzy set theory [5] was developed to address contexts in which decision makers need to accurately analyze and process information that is imprecise in nature. Fuzzy sets provide a conceptual framework, as well as an analytical tool to solve real world problems where there is a lack of specific facts and precision ([7] and [8]). However, the application of fuzzy set theory and logic to management decisions has been generally lacking despite its potential value in many common situations [9]. On the other hand, the usage of multi-granularity linguistic information can eliminate the difference from evaluators [10]. In this paper the environmental performance evaluation criteria, are defined through expert's ideas and the weight of each one. First, through library research the available articles related to the subject were identified and analyzed. Then the interviews with managers and experts were conducted and 6 qualitative criteria was identified as shown in table 1. The purpose of this paper is to develop a framework for the application of fuzzy logic to environmental performance appraisal. This study attempts to develop an assessment approach to environment performance to improve the previous techniques. In this paper, we describe a detailed qualitative procedure for evaluating environmental performance.

II. BACKGROUND

Literature review has exposed that the perspectives promoted in the various conceptual frameworks and methods for implementation of environmental performance evaluation, that appear to be dependent on the specialized foundation and field of interest of the researchers. The expression environmental performance is often used in different contexts with distinct objectives, meanings, and broad domains. Some of environmental management and policy tools use these expressions for environmental performance: environmental auditing, environmental impact assessment, environmental risk assessment and environmental management systems (EMS), among others [11]. EPE helps the management of an organization to assess the status of its environmental performance and to identify areas for improvement as needed.

Qualitative factors, involving expert judgment of the pedigree of a model, should be part of an assessment of model performance, going beyond traditional scientific approaches, such as sensitivity analysis and model validation. Fuzzy decision-making is closely related to other environmental decision-making frameworks, such as multi-criteria decision analysis [12], or the weighted utility approach [13]. In this paper different criteria are classified in six categories as shown in table 1 and are used in the presented model. It is not proposed that fuzzy decision-making is superior to these other methods, but it provides a structured framework within which other methods may be incorporated.

A. Fuzzy sets structure and analysis

The most fundamental form of a fuzzy set A in a universe X is:

$$A = \{x, \mu_A(x) \mid x \in X\}$$

Where $\mu_A(x)$ represents the grade of membership or compatibility function of element x of X in fuzzy set A. Element x may show a full membership in A (i.e. $\mu_A(x)$ = 1), as well as partial membership (0< $\mu_A(x)$ <1) or non-membership ($\mu_A(x)$ = 0). For example, the fuzzy linguistic variable performance can be characterized by terms: very strong, strong, average, weak, poor, and very poor. Each term is called a linguistic modifier. Therefore, a fuzzy set is formed when a linguistic variable is combined with a linguistic modifier (i.e. strong performance). In our example, each linguistic modifier is linked to a numerical value on a scale of 1 to 7 that represents the level of performance. Thus, the performance set A and its modifiers can be represented by a fuzzy set as:

$$A = \{1.0 \mid 0, 2.0 \mid 0.10, 3.0 \mid 0.30, 4.0 \mid 0.40, 5.0 \mid 0.60, 6.0 \mid 0.80, 7.0 \mid 1.0\}$$

In this fuzzy set, each element represents a corresponding value in the universe of discourse and a degree of membership. That is, 7 has a full membership grade of 1 corresponding to very strong performance, and 1 with a non-membership grade of 0 indicating no performance as well as 5 with a partial membership grade of 0.60 representing average performance.

Another example of constructing fuzzy sets for linguistic variables is presented in Fig. 1, where three fuzzy sets are used to characterize an environment's performance.

The Fuzzy linguistic variable performance can be defined by terms or linguistic modifiers as poor, average, outstanding, with the membership value from 0 to 1, describing the level of performance on a scale from 0 to 5. In Fig. 1, if the norm for performance is average, number 3 represents the highest level of the term average with a membership grade of 1 and number 4 defines average with a grade of 0.10 or outstanding with a grade of 0.60. Therefore, number 4 describes the performance of an environment that is 60 per cent outstanding and 10 percent average. Fig. 1 represents three fuzzy sets:

$$Poorperformance = \{0 \mid 1.0, 0.50 \mid 0.80, 1.0 \mid 0.50, 1.50 \mid 0.40, 2.0 \mid 0.30, 2.5 \mid 0.1, 3.0 \mid 0.0, 3.50 \mid 0.0, 4.0 \mid 0.0, 4.50 \mid 0.0, 5.0 \mid 0.0\}$$

$$Averageperformance = \{0 \mid 0.0, 0.50 \mid 0.0, 1.0 \mid 0.0, 1.50 \mid 0.0, 2.0 \mid 0.10, 2.50 \mid 0.40, 3.0 \mid 1.0, 3.50 \mid 0.50, 4.0 \mid 0.10, 4.50 \mid 0.0, 5.0 \mid 0.0\}$$

$$Outs\tan dingperformance = \{0 \mid 0.0, 1.0 \mid 0.0, 1.50 \mid 0.0, 2.0 \mid 0.0, 2.50 \mid 0.0, 3.0 \mid 0.0, 3.50 \mid 0.20 \mid 4.0 \mid 0.60, 4.50 \mid 0.80, 5.0 \mid 1.0\}$$

These sets represent the decision maker's intuitive understanding of the linguistic variable performance and its modifiers: poor, average, and outstanding.

B. Fuzzy set operations

Fuzzy sets can be manipulated by one of the four standard fuzzy set operations: union, Intersection, complementation, and implication operations [14]. For more details, assume A and B are fuzzy sets with membership functions $\mu_A(x) = \{1, 3, 5, 7, 8\}$ and $\mu_B(y) = \{1, 2, 4, 6, 9\}$, respectively. The union of A and B is a fuzzy set $C = A \cup B$, where $\mu_C(z) = \mu_{A \vee B}(z) = \mu_A(x) \vee \mu_B(y)$. A union operation is identical to a logical OR operation and a fuzzy set union is performed by applying the Max function to the elements of two sets, thus:

$$\mu_{A \vee B}(z) = \{1, 3, 5, 7, 9\}$$

A logical AND can be used to determine a fuzzy set $D = A \cap B$ with $\mu_D(\omega) = \mu_{A \wedge B}(\omega) = \mu_A(x) \wedge \mu_B(y)$.

Fuzzy set intersections are done by applying the min function; therefore:

$$\mu_{A \wedge B}(\omega) = \{0, 2, 4, 6, 8\}.$$

The complement of a set is computed by subtracting each element of the set from its Maximum possible value, in our example 10. So:

$$\mu_{\bar{A}}(x) = 10 - \mu_A(x) = \{10, 7, 5, 3, 2\}$$

$$\mu_{\bar{B}}(y) = 10 - \mu_B(y) = \{9, 8, 6, 4, 1\}.$$

The implication function is employed to decide if A is true, to what extent that implies that B is true? The implication operation is done by computing $\mu_{\bar{A} \cup B}(u)$, known as Kleene-Dienes implication, where:

$$\mu_{\bar{A} \vee B}(u) = \mu_{\bar{A}}(x) \vee \mu_B(y)$$

$$\mu_{\bar{A} \vee B}(u) = \{10, 7, 5, 6, 9\}.$$

It should be noted that fuzzy set operations are not limited to those used here; for other fuzzy operations see [14].

III. Environmental Performance Appraisal with Fuzzy Logic: A Numerical Example

Performance evaluations of environment are not easy. Many criteria and standards that are involved should be considered. However, for illustration purposes and to keep matters relatively simple to follow, the example used in this paper includes seven Environments ($E_1, E_2, ..., E_7$) and six categories of performance evaluations for each Environment. These categories are shown in Table 1.

We form a fuzzy set C in a universe U with the unit interval [0, 1], where:

$$C = \{u \mid \mu_C(u), u \in U\}$$

$$\mu_C(u) = \{1.0, 0.60, 0.40, 0.80, 0.90, 0.70\}.$$

Each element of the set is given a score between 0 and 1; the score signifies the relative importance of that category (fuzzy element) to the decision maker. Equal membership means equal importance. For each of the six categories, a qualitative judgment is employed to determine the degree of environment performance for that category. These qualitative judgments could be: "not acceptable", "poor", "below average", "slightly below average", "average", "slightly above average", "above average", and "outstanding", thus forming a fuzzy set P in universe V with unit interval [0, 1] and a fuzzy membership function:

$$P = \{v \mid \mu_P(v), v \in V\}$$

$$\mu_P(v) = \{0.10, 0.20, 0.30, 0.40, 0.60, 0.70, 0.80, 1.0\}$$

As shown in Table 2.

To illustrate how the manipulation of fuzzy sets can result in a decision making system for environment performance evaluation, several steps must be taken. The first step is to assess the performance of each environment by each category that is based on the fuzzy opinion of the decision maker, as depicted in Table 3.

Table 4 contains seven fuzzy sets $P_1, P_2, ..., P_7$ with membership functions $\mu_{P_1}(v), \mu_{P_2}(v), ..., \mu_{P_7}(v)$. For example, the fuzzy set and membership function for Environment 1 is:

$$P_1 = \{1.0 \mid 0.30, 2.0 \mid 0.10, 3.0 \mid 0.70, 4.0 \mid 0.80, 5.0 \mid 0.60, 6.0 \mid 0.60\}$$

$$\mu_{P_1}(v) = \{0.30, 0.10, 0.70, 0.80, 0.60, 0.60\}.$$

The principal step in the decision making process is to establish a fuzzy implication relation between a specific category and each Environment's performance for that category. That is to say, given the relative importance of a category, does that imply a good performance by the environment for that category? Assuming that the importance assigned to each category is the maximum value for that category, the implication relationship is established by taking the complement of the category importance. This complementation creates a minimum performance value assigned to all environments given the category. The Max function is applied to each environment's performance set, i.e. $\mu_{P_1(v)}, \mu_{P_2(v)}, \ldots, \mu_{P_7(v)}$ and the complement of set $\mu_C(u)$. So:

$$\mu_{\overline{C} \vee P_1}(r) = \mu_{\overline{C}}(u) \vee \mu_{P_1}(v)$$

$$\mu_{\overline{C} \vee P_1}(r) = \{0, 0.40, 0.60, 0.20, 0.10, 0.30\} \vee$$

$$\{0.30, 0.10, 0.70, 0.80, 0.60, 0.60\} =$$

$$\{0.30, 0.40, 0.70, 0.80, 0.60, 0.60\}.$$

The final step is to combine various performances of the environment across all categories in order to obtain an overall evaluation. This is done by applying the min function to the set derived from the previous step. Table 5 shows the overall rating of the environments once the process is completed.

It is not surprising that Environment 7 has been ranked top performer in this example since the proposed system favors the environment with a high rating in the most important category. So, the higher the relative importance of the category is, the more influence that category has in the final output.

IV. Discussion and Conclusions

This study develops an evaluation approach to measure environment performance. Many factors are subjective and difficult to quantify in the environment evaluation process. Fuzzy logic enables the evaluator or the decision maker to incorporate information in the environment evaluation system which is vague and subjective. There are several advantages in using the model presented in this paper as opposed to a previous technique. The mathematics is extremely simple and can be easily computerized by such software as MATLAB. It is also extremely flexible, allowing the decision maker to use a broad range of linguistic variables and modifiers for finer discrimination or to make changes to membership values and/or environment performance categories. Finally, it is an ideal system when the decision maker is faced with a series of sub-decisions where available data is based on vagueness, uncertainty, and opinion. These sub-decisions are then combined into an overall system for environment performance evaluation.

Fuzzy logic can be a powerful tool for managers to evaluate the environments' performance. The flexibility of the model allows the decision maker to introduce vagueness, uncertainty, and subjectivity into the environment performance evaluation system. This research calls attention to an alternative method of the environment performance evaluation system.

Applying principles of qualitative environmental performance measurement opens up many promising areas of research. First, one needs to continue to analyze and compare various types of methods, to determine which design is appropriate for environmental performance evaluation. Second, we believe that emissions environmental performance evaluation is a natural application of economic control, for which extensive theory exists but relatively little practical implementation. Third, better understanding of the precise form of regulatory measurements is needed. Future research in this area is needed to develop a method for relating environment performance values to linguistic variables in environment performance evaluation, as well as testing the sensitivity of environment performance values and their impact on the outcome. This paper provides a simple-to-use fuzzy logic model for establishing a more meaningful environment performance evaluation system.

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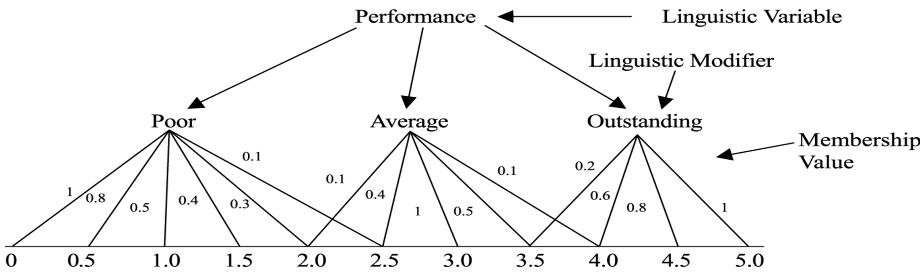

Figure 1. **Fuzzy set structure of performance**

Table 1: Importance of criteria in the numerical example

Criteria	**Symbol**	**Relative Importance**
Government relations	C1	1
Valuation of environmental issues	C2	0.6
Planning horizon	C3	0.4
Effects on resources	C4	0.8
Ecological end effects	C5	0.9
Effects on human health	C6	0.7

Table 2: Importance of linguistics variables in the numerical example

Relative Importance	**Symbol**	**linguistics variables**
0.1	Na	not acceptable
0.2	P	poor
0.3	ba	below average
0.4	Sba	slightly below average
0.6	Ave	average
0.7	Saa	slightly above average
0.8	Aa	above average
1	O	outstanding

Table 3: Environment performance by category (environment performance rating)

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
C1	Ba	ave	Aa	saa	ave	saa	aa
C2	P	ave	Saa	ave	ba	ave	aa
C3	Saa	Aa	Saa	aa	sba	sba	aa
C4	Aa	ave	Aa	sba	aa	ave	o
C5	Ave	Saa	Saa	ave	sba	aa	aa
C6	Ave	Aa	Aa	p	saa	o	o

Table 4: Membership grades of Environment performance by category

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
C1	0.3	0.4	0.8	0.7	0.6	0.7	0.8
C2	0.1	0.6	0.7	0.6	0.8	0.6	0.8
C3	0.7	0.8	0.4	0.8	0.4	0.4	0.8
C4	0.8	0.6	0.8	0.4	0.8	0.6	1
C5	0.6	0.7	0.7	0.6	0.4	0.8	0.8
C6	0.6	0.8	0.8	0.2	0.7	1	1

Reference: Tables 1, 2, 3.

Table 5: Environments overall rating in the numerical example

Environment	**Score**
E1	0.3
E2	0.6
E3	0.7
E4	0.3
E5	0.4
E6	0.6
E7	0.8

Reference: Calculations of present paper