Journal of the Chinese Institute of Environmental Engineering, Vol. 16, No. 1, pp. 47-55 (2006)

CONSENSUS ANALYSIS MODEL FOR ENVIRONMENTAL MANAGEMENT WITH FUZZY LINGUISTIC VARIABLES

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Key Words: Decision making, environmental problems, stakeholder, fuzzy theory, consensus analysis model

ABSTRACT

There are many criteria that must be considered in environmental decision making problems, such as the environmental, economical, social factors, among others. However, since these criteria are often conflicting, it is extremely difficult and complex to make decisions regarding environmental problems. This study proposes an approach for quantifying the degree of consensus of stakeholders and attempts to find a compromise solution between the stakeholders. This study integrates fuzzy theory and linguistic variables to develop a consensus analysis model. The opinions of each stakeholder are understood through the questionnaires and then the degree of consensus of the stakeholder is quantified for all alternatives. An example is presented to illustrate this consensus analysis model. This model can quantify the degree of consensus of the stakeholders for alternatives and attempts to seek a balance between the scientific decision making model and stakeholder value. The source of possible conflicts can also be determined in this model. The model presented here provides a useful tool for aiding decision making for real world environmental management problems.

INTRODUCTION

Environmental problems inevitably require simultaneously considering many criteria, such as the environmental, economical, social factors, among others. However, since these criteria are often conflicting, it is extremely difficult and complex to make decisions regarding environmental problems.

Many MCDM (multicriteria decision making) methods are available for solving the above environment problem, including the AHP (analytic hierarchy process) method [1-3], outranking methods [4-6], and the Technique for Order Preference by Similarity to Ideal Solution method [7]. However, for real world environmental management problems that involve many stakeholders and conflicting viewpoints, the traditional MCDM method is insufficient. Many researchers apply the Fuzzy theory to the MCDM method to avoid neglecting extreme values [8-10].

In recent years, the concept of the MCDM model lays stress on stakeholder participation in the decision making process [11-13]. Morrissey and Browne [14] proposed that the sustainable decision making model should not only be environmentally effective and economically affordable but also socially acceptable. Wilson et al. [15] evaluated 11 different leading-edge European municipal solid waste (MSW) programs in nine countries and proposed that "including the different stakeholder groups in the process from the very beginning can help to avoid the high levels of controversy and stakeholder opposition that have surrounded many MSW projects". Although there are many techniques to deal with environment problem involving many criteria and try to find a "balance point" between the stakeholders, these methods all have weaknesses: (1) differing results may occur among different approaches in the same decision making problems [16]; and (2) the concepts of all the methods are to seek a compromise solution between the criteria, not the stakeholders. However, the source of the conflict comes from the stakeholders' value.

Public participation can occur at one of three stages: scoping stage, a decision-making stage, and a policy active stage. Most researches have incorporated public participation into the scoping and policy active stages by utilizing policy education and public meetings. In previous MCDM methods that involve public participation in the decision-making stage, two proc-

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esses must be completed before obtaining a final solution: the consensus process and the selection process. The consensus process addresses how to obtain maximum consensus or agreement among experts or stakeholders for a set of alternatives; whereas the selection process determines how to acquire a solution set of alternatives from expert opinions regarding alternatives. The public's involvement in the consensus processes is typically in weight setting. The concept of all the methods is to seek a compromise solution between concerned criteria, not between the stakeholders. However, the source of the conflict comes from the stakeholders' complex web of value. The conflict would affect the feasibility of implementing the decision.

This study proposes an approach for quantifying the degree of consensus of stakeholders and attempts to find a compromise solution between the stakeholders. This study integrates fuzzy theory and linguistic variables to develop a consensus analysis model (CAM). The opinions of each stakeholder are sought through the questionnaires and then the degree of consensus of the stakeholder is quantified for all alternatives. Stakeholders in environmental problems generally can be divided into government section, experts, non-government structure and business. Each category of stakeholders also normally contains several members. For example, the government section consists of the Environmental Protection Administration of the national level and the environmental protection bureau of the local level; the non-government structure may have several environmental protection groups, related associations, etc. Figure 1 displays the situation of the stakeholders in real world.

The CAM developed in this study is designed to: (1) assist in policy making; (2) understand the degree of consensus among stakeholders regarding particular alternatives; and (3) help decision makers to resolve possible conflicts during the decision making stage.

The rest of this paper is structured as follows. Section 2 describes methodology. Section 3 then presents an example illustration for waste management in Taiwan. Conclusions are finally drawn in Section 4, along with several advantages of the proposed model.

METHODOLOGY

1. Linguistic Variables

Owing to a high imprecision involved in real world situations, a precise description of numerous real life situations is virtually impossible. Zadeh [17] proposed fuzzy set theory for quantifying the inherent fuzziness present in ill-structure problems. Bellman and Zadeh [18] discussed the characteristics of fuzziness and randomness in decision making.

Linguistic variables are designed to represent

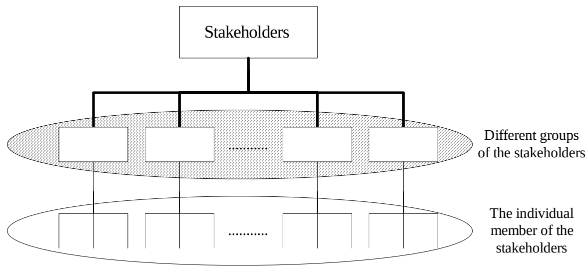


Fig. 1. The hierarchy of the stakeholders in real world.

words or sentences in a natural or artificial language. The linguistic variables comprise five variables (v, T, X, g, m), where v denotes the name of the variable, T represents the set of linguistic terms of v that refer to a base variable whose values range over universal set X, g is a syntactic rule for generating linguistic terms, and m denotes a semantic rule assigned to each linguistic term [19]. The linguistic variables are utilized to determine the performance of the qualitative criteria.

2. Consensus Analysis Model

The CAM analyses consensus among different stakeholders and possible coalition formation based on the proposed options. The "degree of consensus" denotes the degree of similarity of preference between stakeholders and the "consensus results" signifies the average preference of all stakeholders. Fuzzy set theory is introduced to deal with linguistic variables in the CAM. The opinions of each stakeholder are investigated using a questionnaire and stakeholders degree of consensus is then quantified for all alternatives. The CAM analyzes consensus among stakeholders and possible coalition formation based on proposed options. "Linguistic variables" are employed to identify stakeholder attitudes via a questionnaire and to establish a subjective decision matrix. Finally, stakeholder degree of consensus and consensus results are generated. The conflict analysis has three objectives: first, to support the MCDM methods; second, to understand the degree of consensus among stakeholders regarding alternatives; and, third, to allow decision makers to resolve the conflict among stakeholders during the decision making. The characteristics of this method comprise two parts: if all the stakeholders have the same choice, then the degree of consensus is equal to 1, and the greater the distance between the stakeholder choices the higher the possibility of conflict arising.

The procedures involved in the conflict analysis method are as follows:

1. Determining linguistic variables for alternative preferences. Five levels (including very good, good, moderate, bad, very bad) [20] are used to integrate the preferences by the experts, as shown in Fig. 2.
2. Building the fuzzy subjective decision matrix for each stakeholder. Since each stakeholder may comprise several individual members in real world

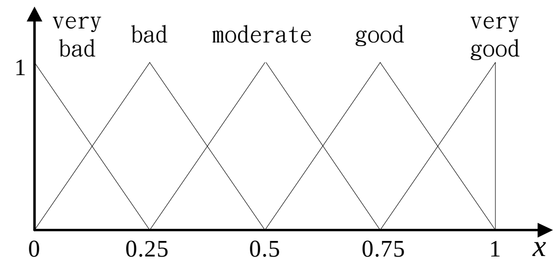


Fig. 2. The membership of five level linguistic variables.

situations, the model developed in this investigation first expresses their opinions of particular alternatives using a mathematical formula. Assume m stakeholders and n alternatives are considered, and each stakeholder comprises p individual members. The fuzzy subjective decision matrix for each stakeholder can be established as follows: fuzzy subjective decision matrix for each stakeholder

$$\tilde{x}_{ik} = [x^l_{ik}, x^m_{ik}, x^r_{ik}] \quad (1)$$

$$x^l_{ik} = \min\left\{ x^l_{ijk} \right\}$$

$$x^m_{ik} = geomean\left\{ x^m_{ijk} \right\}$$

$$x^r_{ik} = \max\left\{ x^r_{ijk} \right\}$$

where x^l_{ik} denotes the left value of the fuzzy number of preference for the alternative k judged by the stakeholder i, x^m_{ik} represents the medium value of the fuzzy number of preference for the alternative k judged by the stakeholder i, x^r_{ik} is the right value of the fuzzy number of preference for the alternative k judged by the stakeholder i, x^l_{ijk} denotes the left value of the fuzzy number of preference for the alternative k judged by the member j of the stakeholder i, x^m_{ijk} represents the medium value of the fuzzy number of preference for the alternative k judged by the member j of the stakeholder i, and x^r_{ijk} denotes the right value of the fuzzy number of preference for the alternative k judged by the member j of the stakeholder i.

3. Determining stakeholder preferences regarding alternatives. The fuzzy subjective decision matrix can be established by defuzzying the data using the centric method [21].

   fuzzy subjective decision matrix

$$F = \begin{pmatrix} f_{ll} & \cdots & \cdots & \cdots & f_{ln} \\ \vdots & \ddots & & & \vdots \\ \vdots & & f_{ik} & & \vdots \\ \vdots & & & \ddots & \vdots \\ f_{ml} & \cdots & \cdots & \cdots & f_{mn} \end{pmatrix} \quad (2)$$

$$f_{ik} = \frac{2}{3}[(x^m_{ik} + x^r_{ik})/2 - x^l_{ik}] + x^l_{ik} \quad (3)$$

   where f_{ik} is the defuzzied value of the stakeholders i for alternative k.

4. Calculating the consensus results for the alternatives (CR). The consensus results of each alternative can be expressed as the mean value of the defuzzied value of the triangle fuzzy numbers for the stakeholders, as follows:

$$CR = \left[\bar{f}_1, \bar{f}_2, ..., \bar{f}_k, ..., \bar{f}_n\right] \quad (4)$$

$$\bar{f}_k = \frac{\sum_{i=1}^{m} f_{ik}}{m} \quad (5)$$

   where $\overline{f}_k$ is the average of the defuzzied value of all the stakeholders for alternative k.

5. Obtaining the consensus degree for the alternatives. After determining the consensus results for the alternatives, the consensus degree for the alternatives can also be defined in this model. The degree of consensus is determined based on the concept of semantic distance. If the consensus results of the stakeholders for particular alternatives are similar, then the opinions of the stakeholders are compromised. The calculation is as follows:

   (1) Calculation of the semantic standard deviation distance for each alternative (sd_k)
   The semantic standard deviation distance sd_k can be determined as the standard deviation of defuzzication of the linguistic variables of all the stakeholders for each alternative, and can be expressed as follows:

$$sd_k = \sqrt{\frac{\sum_{i=1}^{m}(f_{ik} - \overline{f}_k)^2}{m}} \quad (6)$$

   (2) Normalization of the semantic distance (d^{norm}_k)
   The normal semantic distance can be normalized by the following equation:

$$d^{norm}_k = \frac{sd_k}{sd^*} \quad (7)$$

   where sd^* is the maximum of all the possible sd_k. When considering m kinds of stakeholders, the number of the possible sd_k is $H^5_m = C^{(5+m)-1}_m$. Table 1 lists the results of m = 3 to 7.

   (3) Building the consensus degree for each alternatives (CD_k).
   The consensus degree for each alternative can be calculated using the following equation:

$$CD_k = 1 - d^{norm}_k \quad (8)$$

6. Plotting the consensus diagram and interpretation. A consensus diagram can be plotted based on the degree of consensus, as illustrated in the example provided in the next section.

The question arises: what does “degree of consensus” actually mean, and what degree of agreement is required before we can claim that consensus exists regarding a particular decision? The above question

Table1. The number of the possible sd_k when different numbers of stakeholders is considered

Number of stakeholders, m	3	4	5	6	7
possible sd_k	35	70	126	210	330
sd^*	0.393	0.417	0.409	0.417	0.413

Table 2. The "compromise" degree of consensus when different numbers of stakeholders is considered

Numbers of stakeholders	3	4	5	6	7
The "compromise" degree of consensus	0.500	0.426	0.401	0.400	0.381

may be answered after this model has been applied to numerous case studies in the real world. However, this investigation tries to propose another viewpoint to answer this question. Because the number of possible situations is known, if the degree of consensus exceeds a certain probability, then we can say that the results reach a compromise (or are acceptable), and the median is a not-bad choice. Table 2 lists the "compromise" degree of consensus when different numbers of the stakeholders are considered. The "compromise" degree of consensus decreases with larger numbers stakeholders, and this is rational in real world situation. Figure 3 shows those stakeholder opinions in real situations for which the consensus degree is greater than or equal to the compromise degree of consensus under the situation of 3, 4, 5, 6, and 7 stakeholders, respectively. For example, when there are three stakeholders, and one stakeholder chooses "very bad" and two stakeholders choose "moderate", then the degree of consensus is 0.50, which is equal to the compromise degree of consensus, and hence a compromise could be deemed reached.

The CAM model is developed to assess the consensus degree between the stakeholders for specific alternatives. An illustrative example will be provided to demonstrate the practicality of this approach.

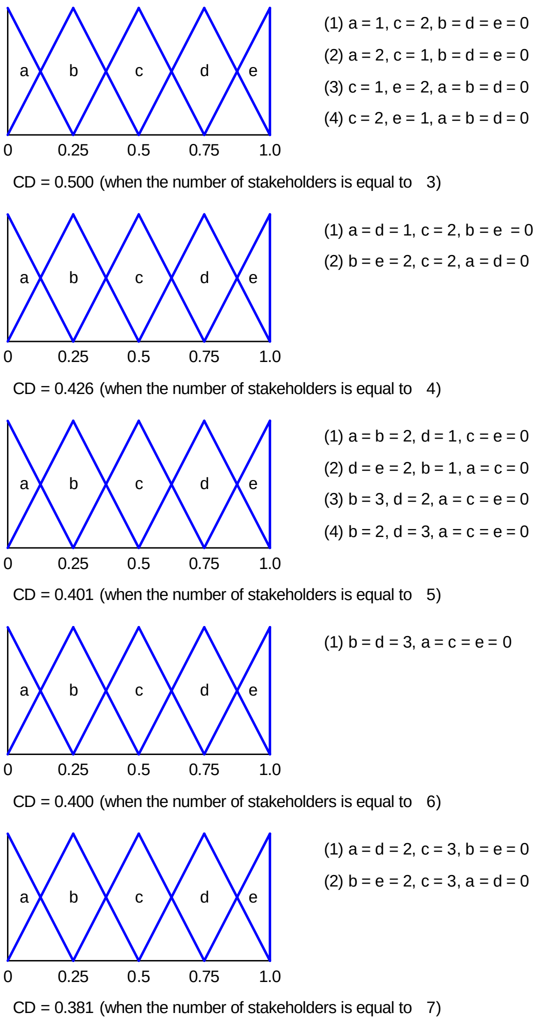


Fig. 3. The opinion of the stakeholders in real situation when the compromise degree of consensus is achievable. Where a is the number of the stakeholder whose opinion is "very bad", b is the number of the stakeholder which his or her opinion is "bad", c is the number of the stakeholder opinion is "moderate", d is the number of the stakeholder opinion is "good", e is the number of the stakeholder opinion is "very good".

EXAMPLE ILLUSTRATION

The CAM proposed is used to aid decision making for food waste management problem in Taipei, Taiwan. The density of the population of Taipei is the highest in Taiwan. Food waste as defined here includes household kitchen waste, and residual food from restaurants, markets and schools. The quantity of food waste is about 40% of the MSW in Taipei. If the food waste is recycled, then the amount of MSW will decrease significantly.

Hung et al. [22] apply Fuzzy AHP method to determine the feasible alternative for food waste management. Five alternatives related to food waste treatment, including incineration (INC), landfill (LAN), composting (COM), hog feeding (HOG), and anaerobic digestion (ANA), are considered. Figure 4 shows the Fuzzy AHP hierarchy of food waste management problems. Applying the fuzzy AHP method involves five steps: (1) construction the hierarchical structure of the waste management problems; (2) calculation the criteria weights; (3) determination the fuzzy performance of the alternatives for each criteria; (4) aggregation the fuzzy weights and fuzzy perform

Table 3. Fuzzy subjective matrix showing the alternatives vs. the stakeholders for food waste management problem in Taipei

Stakeholders	INC	LAN	COM	HOG	ANA
Government					
member 1	moderate	good	good	good	bad
member 2	bad	bad	good	good	good
member 3	very bad	moderate	good	very good	bad
Experts					
member 1	bad	moderate	moderate	very good	bad
member 2	bad	bad	good	moderate	good
member 3	moderate	very bad	good	good	good
member 4	very good	moderate	bad	very bad	good
member 5	bad	moderate	good	good	good
NGOs					
member 1	bad	bad	good	bad	moderate
member 2	very bad	bad	good	good	good
Business					
member 1	bad	bad	very good	very good	moderate
member 2	bad	bad	moderate	good	very good

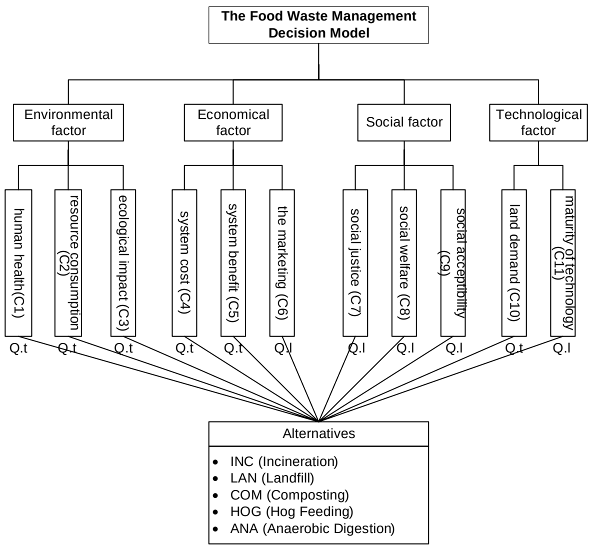


Fig. 4. Fuzzy AHP hierarchy of food waste management problems. Q.t: quantitative; Q.l: qualitative.

ance; and (5) rank the final score of the alternatives.

This study considers four objectives, namely environmental, economic, social, and technological factors. Environmental factors involve human health, resource consumption and ecological impacts. Economic factors include the cost and benefit of the waste management process and the marketing potential of the byproducts. The social factors comprise social justice, social welfare and social acceptability, and technological factors include land demand and technology maturity. The criteria weights are determined by the questionnaires to reflect the opinion of the stakeholders (including: government, experts, non-governmental organizations (NGOs) and business). The priorities assigned to each criterion by these stakeholders are integrated to develop the fuzzy criteria weights. The performance on environmental objective was determined by life cycle assessment with the eco-indicator 99 calculated using SimaPro 5.1. The performance on economic and technological objectives was calculated using the data from the Bureau of Environmental Protection of Taipei. The system cost contains the construction and operating cost, and the system benefit is defined as the profit from the treatment units. The linguistic variables are used to calculate the performance of the qualitative criteria. The fuzzy weighting and fuzzy performance can be aggregated to obtain the final score and the food waste management alternatives are ranked as:

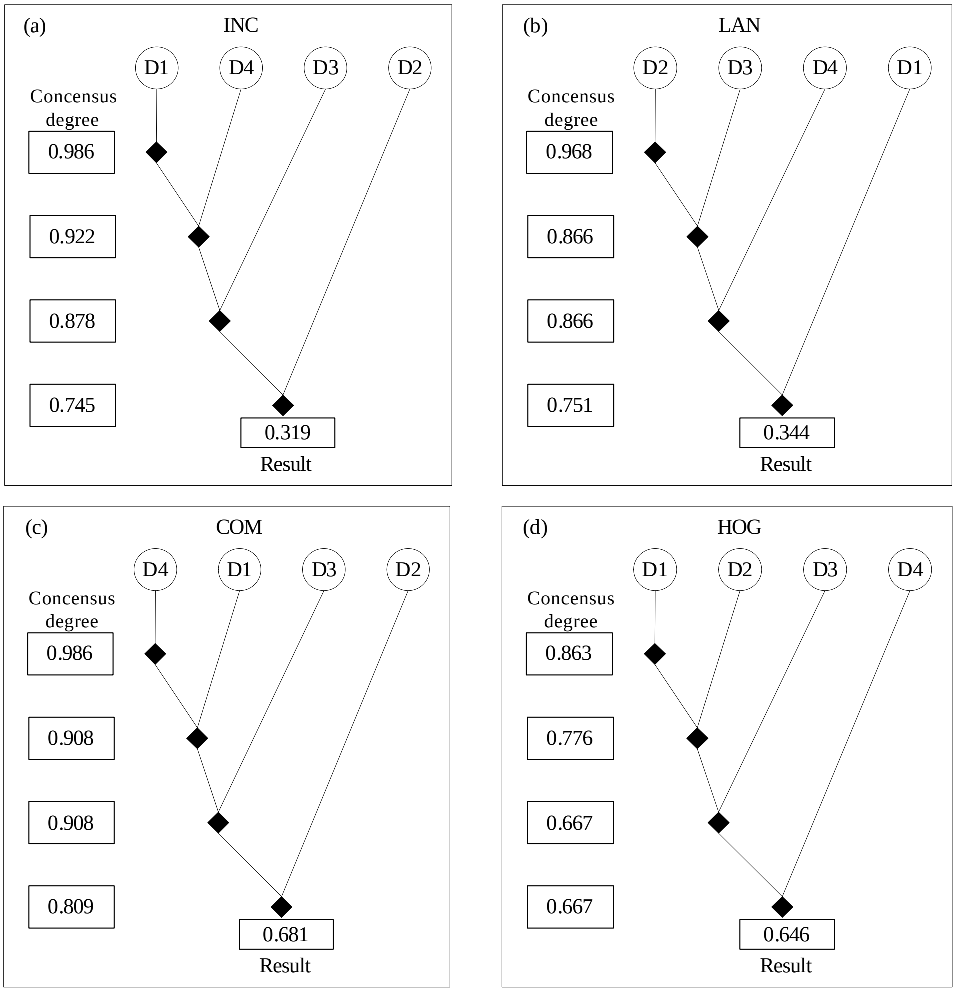
ANA > INC > HOG > COM > LAN

Four groups of stakeholders (government, experts, NGOs, and business, denoted D1, D2, D3, D4, respectively), where each stakeholder group has individual members, were asked by questionnaire. Table 3 lists the preferences of the alternatives for each stakeholder.

1. Determining the Preferences of Each Stakeholder Regarding Alternatives

The preference of each stakeholder regarding the alternatives can be determined using Eq. 2 as follows:

$$F = \begin{bmatrix} 0.333 & 0.500 & 0.750 & 0.778 & 0.472 \\ 0.486 & 0.375 & 0.556 & 0.514 & 0.556 \\ 0.208 & 0.250 & 0.750 & 0.500 & 0.625 \\ 0.250 & 0.250 & 0.667 & 0.792 & 0.667 \end{bmatrix}$$



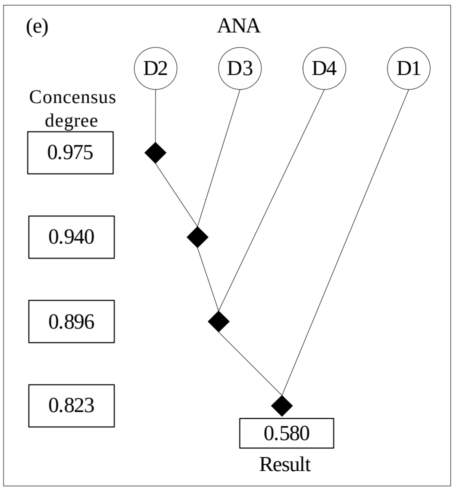


Fig. 5. Consensus diagram. (a) INC, (b) LAN, (c)COM, (d) HOG, (e) ANA. D1: government, D2: experts, D3: NGOs, D4: business.

2. Calculating the Consensus Results for the Alternatives

The consensus results for the alternatives can be determined using Eq. 4 as:

$$CR = [0.319,\ 0.344,\ 0.681,\ 0.646,\ 0.580]$$

3. Obtaining the Degree of Consensus for the Alternatives

The degree of consensus for the alternatives can be determined using Eqs. 6-8, and are presented below:

$$CD = \begin{bmatrix} 0.986 & 0.968 & 0.986 & 0.863 & 0.975 \\ 0.922 & 0.866 & 0.908 & 0.776 & 0.940 \\ 0.878 & 0.866 & 0.908 & 0.667 & 0.898 \\ 0.745 & 0.751 & 0.809 & 0.667 & 0.823 \end{bmatrix}$$

The above results can be integrated and listed in Table 4.

Table 4. The results of conflict analysis

Stakeholders vs. Alternatives	INC	LAN	COM	HOG	ANA
Government	0.333	0.500	0.750	0.778	0.472
Experts	0.486	0.375	0.556	0.514	0.556
NGOs	0.208	0.250	0.750	0.500	0.625
Business	0.250	0.250	0.667	0.792	0.667
Consensus results	0.319	0.344	0.681	0.646	0.580

4. Plotting the Consensus Diagram and Interpretation

Table 4 shows the results of conflict analysis, and Figs. 5a to 5e illustrate the consensus diagram. The left number indicates the degree of consensus. Take alternative INC for example, experts has the furthest semantic distance, indicating the lowest degree of consensus, and thus experts can be expected to have the highest possibility of causing conflict. The final consensus result and the degree of consensus of the four stakeholders for alternative INC are 0.319 and 0.745, respectively. Restated, the stakeholder tends not to accept alternative INC. The degrees of consensus of these five alternatives all are larger than 0.43. The degree of consensus for alternative COM is higher than that of other alternatives, and hence the result of COM is acceptable. In other words, alternative COM is better than alternative INC from the perspective of consensus analysis.

The score of the alternatives (excluding LAN) calculated by fuzzy AHP method is nearly the same, but INC is better than HOG, COM and LAN in the traditional thinking. According to the CAM developed in this study, the stakeholder tends not to accept INC and LAN. After the communication between the stakeholders, ANA, HOG and COM are preferred in the food waste management.

CONCLUSIONS

The CAM presented here provides a useful tool for aiding decision making for real world environmental management problems. This model can quantify the degree of consensus and consensus results of the stakeholders for different alternatives. The source of possible conflicts can also be determined in this model. The MCDM methods are usually used to find the best alternative regarding the “criteria”. This model can seek the compromised alternative regarding the “stakeholders” and attempt to look for a balance between the scientific decision making model and stakeholder value. The decision maker can use this model and MCDM methods to resolve conflict between the stakeholders in decision making process.

ACKNOWLEDGMENTS

The authors would like to thank the Bureau of Environmental Protection of Taipei, Taiwan for financially supporting this research.

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Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-Chief within six months of publishcation.

Manuscript Received: Febuary 24, 2005
Revision Received: June 21, 2005
and Accepted: July 15, 2005

共識分析模式於環境管理決策上之應用

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摘　要

在環境管理問題上，一直具有衝突特性，如場址居民抗爭、處理方案間之互斥衝突等，而以往環境管理政策之制訂上大都由決策者（政府）及專家學者所共同制訂，忽略了相關利害關係人之態度及政策執行後對其造成之影響，因此本研究將發展出一衝突分析方法以整合決策者、利害關係人及專家學者之觀點，尋找各相關團體之環境管理妥協可行方案，本研究主要以語意變數爲基礎建立各方案之「共識指標」，以量化各相關團體對各可行方案之共識程度，瞭解方案執行後之可能衝突來源，以作爲政府政策執行時參考。共識分析模式之進行可先由問卷調查得知各決策者對可行方案之語意評量結果，建立決策者直覺評量可行方案(5 種語意變數)之模糊決策矩陣（直覺決策矩陣），計算各方案間之語意距離，建立各方案之共識程度指標，最後以共識圖表現結果。