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Evaluating sustainable fishing development strategies using fuzzy MCDM approach

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Abstract

In actual environmental investment for industry, the stakeholders are often required to evaluate the investment strategies according to their own subjective preferences in terms of numerical values from various criteria, such as economic effectiveness, technique feasibility and environmental regulation. Thus, this situation can be regarded as a fuzzy multiple criteria decision-making (MCDM) problem, so the fuzziness and uncertainty of subjective perception should be considered. This paper proposes an alternative approach, the non-additive fuzzy integral, to cope with evaluation of fuzzy MCDM problems particularly while there is dependence among considered criteria. To illustrate the proposed procedure, the sustainable development strategy for aquatic product processors in Taiwan is investigated. In this paper we employ triangular fuzzy numbers to represent the decision makers' subjective preferences on the considered criteria, as well as for the criteria measurements to evaluate a sustainable development planning case for industry. Firstly, in this study we employ factor analysis to extract four independent common factors from those criteria. Secondly, we construct the evaluation frame using AHP composed of the above four common factors with twelve evaluated criteria, and then derive the relative weights with respect to considered criteria. Thirdly, the synthetic utility value corresponding to each sustainable development strategy is aggregated by the fuzzy weights with fuzzy performance values, and the best investment strategies can then be decided. Through this study, we successfully demonstrate that the non-additive fuzzy integral is an effective evaluation and appears to be more appropriate than the traditional simple additive weighted method, especially when the criteria are dependent.

Keywords: Fuzzy hierarchical analytic process; Sustainable development; Non-additive fuzzy integral; Multiple criteria decision-making; Factor analysis

1. Introduction

Over the past two decades environmental effects and ecological considerations are increasingly taken into account in making decision for technological and economic development. According to statistics from the US Environmental Protection Agency statistics of the United States in 2000, over 400 million tons of hazardous waste emissions and industrial waste is processed annually worldwide. In addition, over 480 million tons of municipal waste is produced from daily life. Protecting the earth on which we live is an urgent challenge for our time.

In sustainable development planning, reclaiming waste is an eco-effective technique that also provides the opportunity for sustainable business development. In 1992, the United

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Nations Environmental Planning Board (UNEP) presented *Agenda 21* of the Rio de Janeiro Declaration on Environment and Development as a guideline to improve sustainable development. Also in 1992, the United Kingdom declared 120 sustainable development indices, and then in 1996 integrated them into 13 major indices to evaluate the performance of economic development, social investment, climate change, environmental quality and ecological conservation. In addition, the UNEP proposed the structure and approaches for a sustainable development index in 1996. And the United States developed 10 goals and a related sustainable development index for their country in that year [1].

In real world systems, environmental planning and investment in sustainable development industries may essentially be conflict analyses characterized by sociopolitical, environmental, and economic value judgments. Several strategies should be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often inaccurate or uncertain. Due to lack of information, future states of the system might not be known completely. This type of uncertainty has been handled appropriately by probability theory and statistics. However, in many areas such as engineering, medicine, meteorology and manufacturing, human judgment, evaluation and decisions often employ natural language to express thinking and subjective preferences. In these natural languages, the meaning of a word might be well defined, but when using the word as a label for a set, the boundaries within which objects do or do not belong to the set become fuzzy or vague.

Furthermore, human judgment of events may be significantly different based on individuals' subjective perceptivity or personality, even when using the same words. Triangular fuzzy numbers have been developed to appropriately express linguistic variables. We will provide a more clear description of linguistic expression with fuzzy linguistic scale in Section 3.2.

Therefore, in this paper a fuzzy hierarchical analytic process was used to determine the weights of criteria from subjective judgment, and a non-additive integral technique was used to evaluate the performance of sustainable development strategies for aquatic products processors in Taiwan. Traditionally, researchers have used additive techniques to evaluate the synthetic utilities of each criterion meeting the assumption of independent relationship among criteria. In this study, we successfully demonstrate that the non-additive fuzzy integral is an effective method for evaluation and appears to be more appropriate, especially when the criteria are not independent situations.

In the next section, we will discuss the evolutionary review of sustainable development for industry. The fuzzy hierarchical analytic process for sustainable development planning is derived in Section 3. An empirical study of aquatic products processors in Taiwan is presented in Section 4. We also derive and discuss the value of the λ fuzzy measure, which is a parameter describing the substitutive or multiplicative effect among considered criteria when they are dependent. Finally, conclusions are presented in Section 5.

2. Evolutionary review of sustainable development for industry

According to Brundtland's *Our Common Future*, sustainable development is "development that meets the needs of the present without comprising the ability of future generations to meet their own needs." Consequently, depending on the declaration of the *World Commission on Environment and Development* in 1987, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made, consistent with future as well as present needs. Subsequently at the Earth Summit in 1992, nations extended the above definition and adopted a set of principles to guide future development. From then on, the international social system began to consider sustainable development and environmental issues as they continued to seek the economic progress [2].

In addition, there have been various national and international conferences, institutions, agreements, and government agencies dealing with environmental issues, all emphasizing socioeconomic development based on the principle of sustainability. Furthermore, environmental protection bodies in many countries have been established with legal power to approve or disapprove of development projects. The impact of regulation on the cost of production is expected to become an important determinant for the international competitiveness of industries. In response to cost pressures, industries have launched a number of initiatives aimed at improving efficiency and reducing environmental impact; as a result, effective reclaiming techniques are developed and economic approaches encouraging enterprises to achieve goals of sustainable development are implemented.

Furthermore, economic development, social progress and environmental protection are interdependent and naturally intensifying components of sustainable development. This is because the enterprises must take the responsibility to value natural resources by complying with regulations, while they also pursue their own maximum profit in this context. As a result, reclaiming techniques may be an eco-efficient strategy for sustainable development issue. Typically, because sustainable development planning has multiple and mutually conflicting objectives, it is important to evaluate all available alternatives and to determine preferable strategies which conform to sustainable development. There are many multicriteria analysis methods which have been used to deal with environmental issues, and the main approaches can be classified based on the type of decision model used:

(1) Value or utility function based methods, such as multiple attribute utility theory [3–6], AHP [7,8], DEA

[9], and stochastic multiobjective acceptability analysis methods (SMAA) [10–12], SMAA-DEA [13].

(2) Outranking methods such as ELECTRE methods [14–21], PROMETHEE method [22–24].

3. Fuzzy hierarchical analytic process for sustainable development planning

Traditional evaluation methods usually take the minimum cost or the maximum benefit as their single index of measurement criteria [25], although these approaches may not be sufficient for the increasingly complex and diversified decision-making environment. Thus, we utilize a fuzzy hierarchical analytic process to assess the sustainable development strategies for industry.

In this study, we divide the evaluation process into four stages. First, the various stakeholders will be defined after identifying the problem. These stakeholders typically include the decision-makers, various interest groups affected by the decision, experts in the appropriate fields, as well as planners and analysts responsible for the preparations and managing the process. We consider critical criteria from various points of view based on responsibility and effect for sustainable development planning. We also consider available strategies from the life cycles of products to validate the meaning of sustainable development. The hierarchical system for our problem is then set up in this stage.

Secondly, fuzzy set theory is introduced to determine the fuzzy weights of criteria as well as performance values of strategies. Thirdly, because in real world problems independent relationships are not necessary among criteria, we employ factor analysis to extract some independent common factors from criteria that are simultaneously considered, and use the non-additive fuzzy integral to compute the synthetic utility value within each common factor. Because of the independence among common factors, we then aggregate the final utility value of each strategy by additive weighting sum method. Fourth and finally, decision makers decide on the best strategy based on the final utility value.

3.1. Building a hierarchical system for multiple criteria decision making

The evaluators must establish a hierarchical system for analysis and evaluation in the multiple criteria decision-making problem. Keeney and Raiffa [3] suggest that five principles must be followed when criteria are being formulated: (1) Completeness, (2) Operationality, (3) Decomposability, (4) Nonredundancy and (5) Minimum size.

Following the assumption of Chiou and Tzeng [26], we establish the hierarchical frame of a sustainable development map using a literature survey and group conferencing for scenario writing and brainstorming, as shown in Fig. 1. Phase 1 includes developing our goal for sustainable development planning. We consider three aspects for achieving goals in Phase 2, including business activities, government policy and socio-economic effects. Furthermore, we consider four criteria in business activities, five criteria in government policy, and three criteria in socio-economic effects with respect to the aspects we consider, as evaluated and listed in Phase 3. All criteria are measured by evaluators using their individual subjective judgment. Finally, eight feasible sustainable development strategies selected using the life cycle of products from participating enterprises are listed in Phase 4.

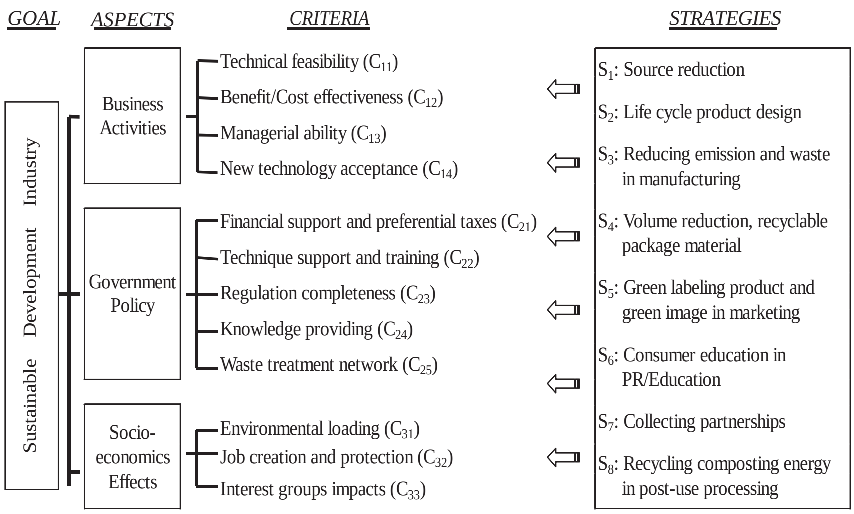

Fig. 1. Hierarchy frame for sustainable development planning.

Table 1
Definitions of criteria and strategies for sustainable development industry

Criteria	Description
C_{11}. Technical feasibility	To measure the degree of reclaiming technique
C_{12}. Benefit/cost effectiveness	To measure the benefit/cost effectiveness from leading reclaiming technique, including the value-increasing of new products and reduction of power expenditure and waste treatment costs, etc
C_{13}. Managerial ability	To measure who has the managerial ability in technique of waste treatment and reclaiming from product processing
C_{14}. New technology acceptance	To measure the degree of acceptance of all inner members about reclaiming technique in waste treatment and recovery
C_{21}. Financial support and preferential taxes	This criterion will encourage a business to engage in reclaiming the waste from process or material
C_{22}. Technique support and training	To measure the degree of government intervention needed to provide the reclaiming technique and knowledge in waste that will enhance business competence
C_{23}. Regulation completeness	This criterion will indirectly encourage business to develop and lead in the reclaiming techniques, it also gives protection to the legitimate companies
C_{24}. Knowledge providing	To have periodical or non-periodical technical seminars and publications by government or particular organizations to provide the knowledge of waste reclaiming techniques
C_{25}. Waste treatment network	It will provide the channel of waste treatment that will prevent and reduce environmental damage to ensure sustainable development
C_{31}. Environmental loading	To measure the degree of loading from enterprise or municipal waste, including water waste, waste liquid, viscera, mud, fishbone, shell, in addition to the offensive smell of fish in aquatic products processing
C_{32}. Job creation and protection	To measure one of the contributions to the community from the enterprise
C_{33}. Interest groups impacts	Including the protest by civil organizations, or residents of the impact area for pollution accident
Strategies	
S_1. Source reduction	Material and source reduction in fore part of product manufacturing
S_2. Life cycle product design	Expanded product lifecycles in design stage
S_3. Reducing emission and waste in manufacturing	Emission and waste reduction in manufacturing process
S_4. Volume reduction, recyclable package material	Volume reduction, using recyclable package material
S_5. Green labeling product and green image in marketing	Produce green labeling products and establish green image in marketing will encourage consumers to buy and use it
S_6. Consumer education in PR/Education	Green label products will lead consumers to value whole resources of our mother earth
S_7. Collecting partnerships	Establish good collecting partnerships and complete recycling networks
S_8. Recycling composting energy in post-use processing	Develop new reclaiming technology transfer the waste that from produce and post-used process to new products, it will create new value to original products and also may bring new niches to industry

Furthermore, each enterprise will choose strategies based on technical feasibility, finance status, managerial ability, and relevant business situation, etc. The definitions of relevant criteria and strategies in sustainable development industry are listed in Table 1.

3.2. Determining the fuzzy criteria weights

Because the effects on evaluation from criteria are instinct with variance, we cannot assume that each considered criterion is of equal importance. There are many methods that can be employed to determine weights [27], such as the eigenvector method, weighted least square method, entropy method, AHP, as well as linear programming techniques for multidimensions of analysis preference. The selection of method depends on the nature of the problems. Here, we utilize the fuzzy AHP approach to determine the criteria weights used in this paper.

AHP was originally proposed by Saaty in 1971, and this approach is now widely used in many fields, such as economic planning, portfolio selection, and benefit/cost analysis by government agencies for resource allocation, etc. Subsequently, Saaty [7,8] used the principal eigenvector of the pairwise comparison matrix contrived by scaling ratio to find the comparative weight among the criteria of hierarchy systems.

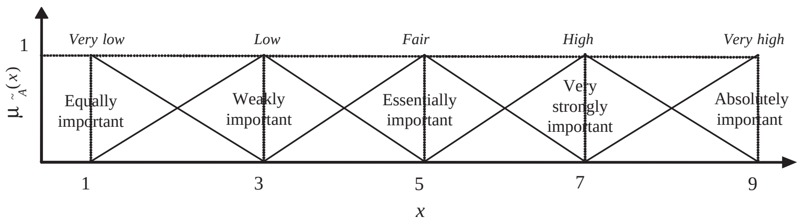

Fig. 2. Membership functions for the five levels scale of linguistics variables.

On the other hand, Buckley [28] investigated fuzzy weights and fuzzy utility for AHP technique, extending AHP by the geometric mean method to derive the fuzzy weights. He considered a fuzzy positive reciprocal matrix, $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]$, where $\tilde{a}_{ij}$ represents the value of subjective judgment by the jth evaluator corresponding to the ith criterion. Extending the geometric mean technique, Buckley defined the fuzzy geometric mean $\tilde{r}_i$ and fuzzy weights $\tilde{w}_i$ of the ith criterion from m evaluators as follows:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{im})^{1/m};$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1}; \ \forall i, \tag{1}$$

where $\oplus$ and $\otimes$ represent the addition and multiplication operations of fuzzy numbers, respectively. According to the characteristics of triangular fuzzy numbers and the extension principle which was put forward by Zadeh [29], the operational laws of two triangular fuzzy numbers $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ are as follows:

(1) Addition of two fuzzy numbers $\oplus$

$$(a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3), \tag{2}$$

(2) Subtraction of two fuzzy numbers Θ

$$(a_1, a_2, a_3)\Theta(b_1, b_2, b_3) = (a_1 - b_3, a_2 - b_2, a_3 - b_1), \tag{3}$$

(3) Multiplication of two fuzzy numbers $\otimes$

$$(a_1, a_2, a_3) \otimes (b_1, b_2, b_3) \cong (a_1b_1, a_2b_2, a_3b_3), \tag{4}$$

(4) Multiplication of any real number k and a fuzzy number $\odot$

$$k \odot (a_1, a_2, a_3) = (ka_1, ka_2, ka_3), \tag{5}$$

(5) Division of two fuzzy numbers Δ

$$(a_1, a_2, a_3)\Delta(b_1, b_2, b_3) \cong (a_1/b_3, a_2/b_2, a_3/b_1). \tag{6}$$

After Bellman and Zadeh [30] described the decision-making method under fuzzy environments, an increasing number of studies have dealt with uncertain problems by applying fuzzy set theory. In addition, it is very difficult for conventional quantification to express reasonably those situations that are overly complex or hard to define [31]. Thus, using a linguistic variable is a variable whose values are words or sentences in natural language that is necessary in such situations. We use this kind of expression to compare two considered criteria in a fuzzy environment as "absolutely important", "very strongly important", "essentially important", "weakly important" and "equally important" on a five level scale. The use of linguistic variables is currently widespread and the linguistic effect values of strategies found in this paper are primarily used to assess the linguistic ratings given by evaluators. Furthermore, linguistic variables are used as a way to measure the performance value of sustainable development strategies for each criterion as "very low", "low", "fair", "high", and "very high". This paper employs a triangular fuzzy number to express the membership functions of above expression values on a five level scale (Fig. 2 and Table 2).

Table 2
Fuzzy scale and linguistic expression of relative importance between two criteria and *performance values* of strategies

Intensity of fuzzy scale	Definition of linguistic variables
$\tilde{1} = (1, 1, 3)$	Equally important; *Very low*
$\tilde{3} = (1, 3, 5)$	Weakly important; *Low*
$\tilde{5} = (3, 5, 7)$	Essentially important; *Fair*
$\tilde{7} = (5, 7, 9)$	Very strongly important; *High*
$\tilde{9} = (7, 9, 9)$	Absolutely important; *Very high*
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate values between two adjacent judgments

3.3. Obtaining the synthetic utility value

Considering the assessment attributes among criteria that are not quite independent, factor analysis can be introduced to extract common factors such that the factors are mutually independent. Fuzzy integral technique can then be used to calculate the synthetic performance of each factor for which criteria are dependent. Finally a simple additive weighted method is used to aggregate the final synthetic utility value corresponding to each strategy. The process of assessing the final synthetic utility values is shown in Fig. 3.

Factor analysis is a dimension reduction method of multivariate statistics, which explores the latent variables from manifest variables. Two methods for factor analysis are generally in use, principal component analysis and the maximum likelihood method. The main procedure of principal

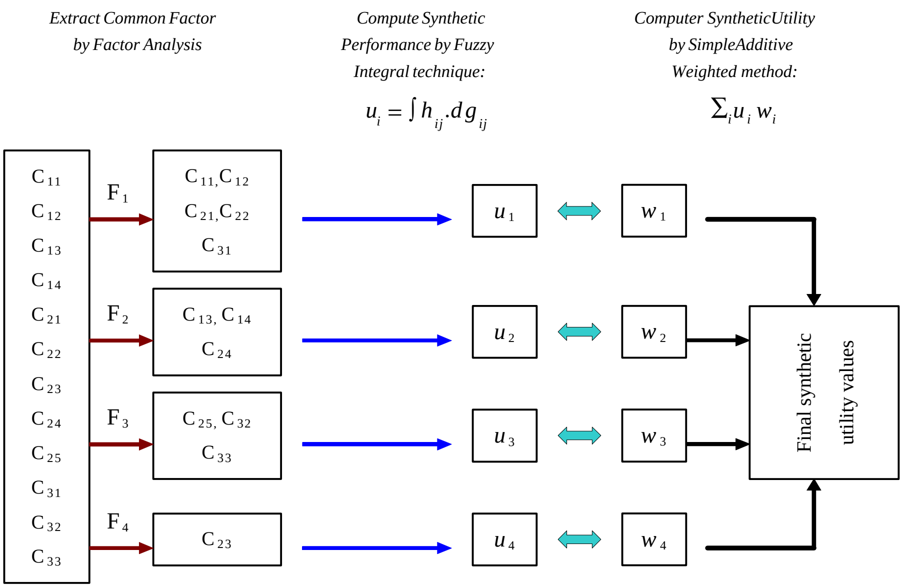

Fig. 3. The process of assessing final synthetic utility values.

component analysis can be described in the following steps when applying factor analysis:

Step 1: Find the correlation matrix or variance–covariance matrix for the objects to be assessed;

Step 2: Find the eigenvalues and eigenvectors for assessing the factor loading and the number of factors;

Step 3: Consider the eigenvalue ordering to decide the number of common factors, and pick the number of common factors to be extracted by a predetermined criterion.

Step 4: According to Kaiser [32], use varimax criteria to find the rotated factor loading matrix, which provides additional insights for the rotation of factor-axis;

Step 5: Name the factor referring to the combination of manifest variables.

In Step 3 above, how to decide on the number of factors to extract is a crucial topic. When a large set of variables is factored, the method first extracts the combinations of variables, explaining the greatest amount of variance, and then proceeds to combinations that account for progressively smaller amounts of variance. Two kinds of criteria are generally used for selecting the number of factors: latent root criterion and percentage of variance criterion. The former criterion is that any individual factor should account for the variance of at least a single variable if it is to be retained for interpretation. In this criterion only the factors having eigenvalues greater than 1 are considered significant. The latter criterion is based on achieving a specified cumulative percentage of total variance extracted by successive factors. Its purpose is to ensure that the extracted factors can explain at least a specified amount of variance. Practically, to be satisfactory the total amount of variance explained by factors should be at least 95 percent in the natural sciences, and 60 percent in the social sciences. However, no absolute threshold has been adopted for all applications [33].

Secondly, we are concerned with aggregating the synthetic utility value within a common factor. For this, Sugeno [34] first introduced the concept of fuzzy measure and fuzzy integral, generalizing the usual definition of a measure by replacing the usual additive property with a weak monotonicity. This is useful with respect to fuzzy decision theory, especially for problems with non-additive situations. Subsequently, more detailed accounts of the theory of fuzzy measure and fuzzy integrals were proposed, such as Dubois and Prade [35], Grabisch [36], Hougaard and Keiding [37], etc.

Based on Keeney and Raiffa's [3] decomposition theory, let g_λ be a λ fuzzy measure, which is defined on a power set $P(x)$, for the finite set $X = \{x_1, x_2, \ldots, x_n\}$, the density of fuzzy measure $g_i = g_\lambda(\{x_i\})$ can be formulated as follows:

$$\begin{aligned} g_\lambda(\{x_1, x_2, \ldots, x_n\}) &= \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} g_{i_2} + \cdots \\ &\quad + \lambda^{n-1} g_1 \cdot g_2 \cdots g_n \\ &= \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda g_i) - 1 \right| \\ &\quad \text{for} -1 \leqslant \lambda < \infty. \end{aligned} \tag{7}$$

In a specific case with two criteria, x_1 and x_2, one of the following three cases will be sustained, based on the above properties:

(1) If $\lambda > 0$, i.e. $g_\lambda(\{x_1, x_2\}) > g_\lambda(\{x_1\}) + g_\lambda(\{x_2\})$ this implies that x_1 and x_2 have multiplicative effect;

(2) If $\lambda = 0$, i.e. $g_\lambda(\{x_1,x_2\}) = g_\lambda(\{x_1\}) + g_\lambda(\{x_2\})$ this implies that x_1 and x_2 have additive effect;
(3) If $\lambda < 0$, i.e. $g_\lambda(\{x_1,x_2\}) < g_\lambda(\{x_1\}) + g_\lambda(\{x_2\})$ this implies that x_1 and x_2 have substitutive effect.

Letting h be a measurable set function defined on the fuzzy measurable space, and supposing that $h(x_1) \geqslant h(x_2) \geqslant \cdots \geqslant h(x_n)$, then the fuzzy integral of fuzzy measure $g(\cdot)$ with respect to $h(\cdot)$ can be defined as follows [38]. In this paper we employ the value of fuzzy integral to express the aggregated fuzzy synthetic performance by fuzzy weights measure $g(\cdot)$ of each criterion with fuzzy evaluated score $h(\cdot)$ corresponds to each strategy.

$$\begin{aligned}\int h\,\mathrm{d}g &= h(x_n)g(H_n) + [h(x_{n-1}) - h(x_n)]g(H_{n-1}) + \cdots \\ &\quad + [h(x_1) - h(x_2)]g(H_1) \\ &= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) \\ &\quad - g(H_{n-2})] + \cdots + h(x_1)g(H_1), \end{aligned} \tag{8}$$

where $H_1=\{x_1\}$, $H_2=\{x_1,x_2\},\ldots,H_n=\{x_1,x_2,\ldots,x_n\}=X$. Furthermore, in order to clarify the operation of the fuzzy integral technique, we also give a numerical example in Appendix.

On the other hand, the result of fuzzy synthetic decisions reached by each strategy is a fuzzy number derived from overall fuzzy judgment. However, the fuzzy value is not a clear definite value, so it cannot be used for comparison. In the next step, defuzzification is made in order to decide the priority of the proposed strategies [39]. Generally, there are three kinds of defuzzification methods, including mean of maximal, Centroid method (*center-of-gravity*), and α-cut method [40–43]. Utilizing the Centroid method to determine the BNP is a simple and practical method, and there is no need to introduce the preferences of any evaluators.

The BNP (crisp) value, R^{Cent}, of the triangular fuzzy number $\tilde{R} = (L, M, U)$ can be found by the following equation:

$$R^{\text{Cent}} = [(M - L) + (U - L)]/3 + L; \qquad \text{or}$$

$$R^{\text{Cent}} = (L + M + U)/3. \tag{9}$$

For the reasons discussed above, the Centroid method is employed in this study to conduct the BNP value of considered criteria for the purpose of comparing the importance of criteria. According to the value of the derived BNP, the evaluation of each sustainable development strategy can then proceed.

4. An illustrative example

In this section we take an illustrative example for evaluating sustainable development industries to demonstrate that these methods of fuzzy measure and non-additive fuzzy integral appear to be more appropriate, especially when the criteria are not independent situations in a fuzzy environment. This section is divided into five subsections: (1) problem description, (2) determining the evaluation criteria weights, (3) determining the performance matrix, (4) calculating the non-additive fuzzy synthetic utilities and (5) discussion.

4.1. Problem description

The aquatic products industry is a branch of the foodstuff products industry. There are abundant fishery resources in Taiwan because of its geographical features, and aquatic products are an important dietary resource in daily life. However, about 50 percent of the harvested fish material is not edible, and how to recover this waste is an important challenge.

In Japan, special techniques are used to process the waste from aquatic products for extracts such as fish oil, fish meal and fish solution, which are used to make health foods, cosmetics, forage additives and so on, in addition to uses in agriculture and medical science.

Based on the Fisheries Annual Report in 2000, there are about 600 aquatic products processors in Taiwan, the majority of which are small-sized enterprises. Only some of them have engaged in recovery of the waste from processing of aquatic products as fish, shrimp and shells fish. In this study, we apply the fuzzy hierarchical analytic approach and the non-additive fuzzy integral technique to calculate the performance of sustainable development strategies, reviewing ten companies as samples of aquatic products processors in Taiwan.

4.2. Determining the evaluated criteria weights

Firstly, we establish the hierarchy frame for sustainable development planning, as shown in Fig. 1, where the preliminary classification consists of three aspects involving business activities, government policy and socioeconomic effect, with twelve criteria selected. We also take eight feasible strategies from the product life cycle to confirm the meaning of sustainable development. Secondly, we have fifteen evaluators including staff from the government sector who are in charge of sustainable development, academic experts, executives of aquatic products processors, members of environmental interest groups and residents. We integrate their subjective judgments to develop the fuzzy criteria weights with respect to aspects by the fuzzy geometric mean method as Eq. (1). We further derive the final fuzzy weights and nonfuzzy BNP values corresponding to each criterion, as shown in Table 3.

From Table 3, the three most important criteria in sustainable development planning are environmental loading (C_{31}), technical feasibility (C_{11}), and benefit/cost effectiveness (C_{12}); whereas the three least unimportant criteria are financial support and preferential taxes (C_{21}), technique support and training (C_{22}), and new technology acceptance (C_{14}). If persons want to engage in this field, they must initially pay much attention to the environmental loading

Table 3
Criteria weights for evaluating sustainable development strategy

Aspects and criteria	Local weights	Overall weights	BNP values	
Business activities	(*0.103,0.311,0.917*)			
Technical feasibility	(0.102,0.337,1.178)	(0.011,0.105,1.080)	0.398	(2)
Benefit/Cost effectiveness	(0.086,0.307,1.032)	(0.009,0.096,0.946)	0.350	(3)
Managerial ability	(0.050,0.185,0.731)	(0.005,0.058,0.670)	0.244	(8)
New technology acceptance	(0.040,0.171,0.653)	(0.004,0.053,0.598)	0.219	(*10*)
Government roles	(*0.128,0.373,1.080*)			
Financial support and preferential taxes	(0.036,0.133,0.444)	(0.005,0.049,0.480)	0.178	(12)
Technique support and training	(0.049,0.169,0.537)	(0.006,0.063,0.580)	0.216	(11)
Regulation completeness	(0.087,0.251,0.738)	(0.011,0.094,0.797)	0.301	(5)
Knowledge providing	(0.066,0.201,0.639)	(0.008,0.075,0.690)	0.258	(7)
Waste treatment network	(0.085,0.246,0.735)	(0.011,0.092,0.793)	0.299	(6)
Socioeconomics effects	(*0.109,0.316,0.945*)			
Environmental loading	(0.162,0.454,1.288)	(0.018,0.143,1.218)	0.460	(1)
Job creation and protection	(0.072,0.206,0.687)	(0.008,0.065,0.649)	0.241	(9)
Interest groups impacts	(0.108,0.340,0.954)	(0.012,0.107,0.902)	0.340	(4)

Parentheses () denote the order of importance (BNP weights) of each criterion.

factor, and then evaluate their own technical ability to treating waste, and the degree of benefit/cost effectiveness.

4.3. Determining the performance matrix

To determine the performance value of each strategy, the evaluators can define their own individual range for the linguistic variables based on their subjective judgments within a fuzzy scale. Under future uncertainties, the anticipated performance values of unquantifiable criteria cannot be specified with qualitative numerical data in qualitative evaluation pertaining to the possible achievement value of each strategy.

Let $\tilde{h}_{ij}^k$ represent the fuzzy evaluated score of the ith strategy under the jth criterion by the kth evaluator. Since the perception of each evaluator varies according to individual experience and knowledge, we select the fuzzy geometric mean method to integrate the fuzzy evaluated score $\tilde{h}_{ij}$ from m evaluators, as shown in Table 4. That is,

$$\tilde{h}_{ij} = (\tilde{h}_{ij}^1 \otimes \tilde{h}_{ij}^2 \otimes \cdots \otimes \tilde{h}_{ij}^m)^{1/m}. \tag{10}$$

Furthermore, we use the centroid method to compute the BNP values of fuzzy evaluated score $\tilde{h}_{ij}$, as shown in Table 5.

4.4. Calculating the final synthetic utilities for sustainable development strategies

First of all, considering the evaluated criteria are not quite mutually independent in real fuzzy MCDM problems, we utilize factor analysis to extract the criteria in four mutually unrelated common factors. The first factor, with 47.98% variance explanation, includes five criteria: technical feasibility (C_{11}), benefit/cost effectiveness (C_{12}), financial support and preferential taxes (C_{21}), technique support and training (C_{22}), and environmental loading (C_{31}). The second factor, with 17.14% variance explanation, includes three criteria: managerial ability (C_{13}), new technology acceptance (C_{14}) and knowledge providing (C_{24}). The third factor, with 14.51% variance explanation, includes three criteria: waste treatment network (C_{25}), job creation and protection (C_{32}) and interest groups impacts (C_{33}). The final factor, with 10.82% variance explanation, includes only one criterion, regulation completeness (C_{23}). The total proportion of variance explanation is 90.34%.

Secondly, employing the fuzzy integral technique to compute the synthetic performance of each common factor, and then the simple additive weighted method is to aggregate the final synthetic utility value with respect to each sustainable development strategy.

4.5. Discussion

In Section 3.3, we introduced the λ value representing the properties of substitutive or multiplicative between two criteria, where λ values range from -1 to positive infinite value (∞). Observing the relative weights of criteria and results from factor analysis, we utilize Eq. (7) to obtain the λ values corresponding to common factors. There is a substitutive effect among criteria of factor 1 ($\lambda_1 = -0.759$), whereas there are multiplicative effects among criteria of factor 2 ($\lambda_2 = 1.447$) and there are also multiplicative effects among criteria of factor 3 ($\lambda_3 = 0.45$).

Furthermore, we rank the synthetic utility values of sustainable development strategies as follows: $S_8 \succ S_7 \succ S_3 \succ S_5 \succ S_6 \succ S_4 \succ S_1 \succ S_2$, where $A \succ B$ means that A is preferred to B. Moreover, compared to results by traditional

Table 4
Fuzzy performance score of sustainable development strategies

Strategies	Criteria			
	C_{11}	C_{12}	C_{13}	C_{14}
S_1. Source reduction	(1.55,2.65,4.91)	(1.63,3.06,5.30)	(2.83,4.91,6.94)	(2.27,4.44,6.49)
S_2. Life cycle product design	(2.81,4.99,7.06)	(3.71,5.91,7.67)	(2.03,4.22,6.27)	(2.95,5.16,7.24)
S_3. Reducing emission and waste in manufacturing	(2.39,4.59,6.65)	(1.25,2.39,4.59)	(1.25,2.67,4.83)	(1.25,2.67,4.83)
S_4. Volume reduction, recyclable package material	(2.95,5.16,7.24)	(2.27,4.44,6.49)	(2.79,5.08,7.18)	(4.44,6.49,8.35)
S_5. Green labeling product and green image in marketing	(3.11,5.34,7.42)	(3.78,5.96,7.87)	(2.14,4.36,6.43)	(1.73,3.47,5.62)
S_6. Consumer education in PR/education	(2.67,4.83,6.88)	(3.30,5.44,7.48)	(3.41,5.57,7.48)	(2.98,5.08,7.12)
S_7. Collecting partnerships	(2.67,4.83,6.88)	(1.82,4.01,6.07)	(2.25,4.51,6.60)	(1.93,4.08,6.12)
S_8. Recycling composting energy in post-use processing	(3.78,5.96,7.87)	(3.13,5.26,7.30)	(3.30,5.44,7.48)	(3.68,5.72,7.74)
	C_{21}	C_{22}	C_{23}	C_{24}
S_1. Source reduction	(1.12,3.16,5.17)	(3.30,5.44,7.48)	(1.25,2.67,4.83)	(3.24,5.39,7.30)
S_2. Life cycle product design	(1.12,2.03,4.22)	(1.39,3.50,5.53)	(1.92,3.33,5.62)	(2.03,4.22,6.27)
S_3. Reducing emission and waste in manufacturing	(1.00,1.93,4.08)	(2.39,4.59,6.65)	(3.47,5.62,7.67)	(2.14,4.36,6.43)
S_4. Volume reduction, recyclable package material	(1.31,2.21,4.47)	(1.25,2.39,4.59)	(1.12,2.27,4.44)	(3.68,5.72,7.74)
S_5. Green labeling product and green image in marketing	(1.00,1.25,3.32)	(2.81,4.99,7.06)	(3.30,5.44,7.48)	(3.59,5.76,7.67)
S_6. Consumer education in PR/Education	(1.46,2.90,5.12)	(2.33,4.14,6.27)	(3.78,5.96,7.87)	(3.65,5.81,7.87)
S_7. Collecting partnerships	(1.25,2.39,4.59)	(3.11,5.34,7.42)	(4.08,6.12,8.14)	(3.87,5.92,7.94)
S_8. Recycling composting energy in post-use processing	(1.82,4.01,6.07)	(4.44,6.49,8.35)	(5.08,7.12,8.78)	(4.44,6.49,8.35)
	C_{25}	C_{31}	C_{32}	C_{33}
S_1. Source reduction	(3.30,5.44,7.48)	(4.29,6.33,8.35)	(1.00,1.12,3.16)	(1.00,1.55,3.68)
S_2. Life cycle product design	(1.39,2.52,4.75)	(2.95,5.16,7.24)	(1.00,1.55,3.68)	(1.12,2.27,4.44)
S_3. Reducing emission and waste in manufacturing	(4.22,6.27,8.14)	(4.36,6.43,8.14)	(2.53,4.67,6.71)	(2.14,4.36,6.43)
S_4. Volume reduction, recyclable package material	(5.16,7.24,8.56)	(1.39,2.52,4.75)	(1.82,3.22,5.48)	(1.39,3.13,5.26)
S_5. Green labeling product and green image in marketing	(3.91,6.11,7.87)	(1.54,3.00,5.25)	(1.00,1.55,3.68)	(2.14,3.91,6.11)
S_6. Consumer education in PR/education	(3.65,5.81,7.87)	(1.25,1.92,4.14)	(1.00,1.39,3.50)	(1.12,1.46,3.62)
S_7. Collecting partnerships	(5.44,7.48,8.78)	(4.08,6.12,8.14)	(1.46,2.90,5.12)	(2.95,5.16,7.24)
S_8. Recycling composting energy in post-use processing	(3.11,5.34,7.42)	(2.81,4.99,7.06)	(1.92,3.33,5.62)	(1.72,3.53,5.72)

Table 5
BNP values of fuzzy performance score with respect to criteria

Strategies	BNP values of criteria											
	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
S_1. Source reduction	3.035	3.328	4.894	4.399	3.148	5.406	2.914	5.309	5.406	6.321	1.758	2.077
S_2. Life cycle product design	4.953	5.766	4.175	5.118	2.455	3.473	3.620	4.175	2.884	5.118	2.077	2.608
S_3. Reducing emission and waste in manufacturing	4.544	2.741	2.914	2.914	2.336	4.544	5.589	4.312	6.210	6.311	4.638	4.312
S_4. Volume reduction, recyclable package material	5.118	4.399	5.012	6.424	2.665	2.741	2.608	5.714	6.987	2.884	3.505	3.260
S_5. Green labeling product and green image in marketing	5.290	5.870	4.312	3.608	1.856	4.953	5.406	5.676	5.963	3.265	2.077	4.054
S_6. Consumer education in PR/education	4.793	5.406	5.489	5.059	3.162	4.247	5.870	5.779	5.779	2.436	1.962	2.065
S_7. Collecting partnerships	4.793	3.965	4.453	4.043	2.741	5.290	6.111	5.909	7.232	6.111	3.162	5.118
S_8. Recycling composting energy in post-use processing	5.870	5.229	5.406	5.714	3.965	6.424	6.992	6.424	5.290	4.953	3.620	3.654

AHP method, it assumed that the criteria are mutually independent, then derive the synthetic utilities and yields a different outranking as follows: $S_8 \succ S_7 \succ S_5 \succ S_3 \succ S_6 \succ S_4 \succ S_1 \succ S_2$ (see Table 6 and Fig. 4). Actually this result is the same as while $\lambda = 0$ situation in fuzzy integral procedure, however it ignores the substitutive or multiplicative

Table 6
Synthetic utility values in different scenarios

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Fuzzy integral method	4.245	4.161	4.691	4.368	4.604	4.423	5.177	5.377
Order of outranking[a]	7	8	3	6	4	5	2	1
Traditional AHP method	4.041	4.020	4.467	4.252	4.469	4.283	5.062	5.299
Order of outranking[a]	7	8	4	6	3	5	2	1

[a]The greater the number, the lower the order of outranking.

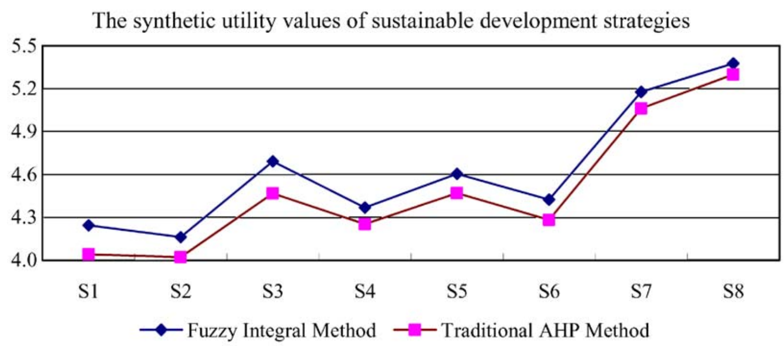

Fig. 4. Diagram of synthetic utility values in different scenarios.

effect between considered criteria and may not conform the nature in real problems.

Evaluating and planning the strategies and criteria in sustainable development industry or in other real fuzzy MCDM problems, can result in a vast body of data that are often inaccurate or uncertain, coming from the subjective judgments by the various stakeholders who are the evaluators. Moreover, the conventional AHP method is based on the assumption of independence among criteria within the evaluating system, with the subsequent decision-making activities being performed in an additive type. However, in such complex fuzzy MCDM problems, using factor analysis can verify that there are independent situations between two common factors. Therefore, we demonstrate that the fuzzy integral technique is more appropriate for coping with such fuzzy MCDM problems.

5. Conclusions

Generally, sustainable development planning and fuzzy MCDM problems that are essentially conflict analyses are characterized by sociopolitical, environmental, and economic value judgments. Several alternatives/strategies must be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often inaccurate or uncertain. In this study, we use the triangular fuzzy numbers to express linguistic variables that consider the possible fuzzy subjective judgment of the evaluators. Furthermore, the fuzzy geometric mean technique is an effective method to conduct the final fuzzy weights of each criterion.

Using this method, we demonstrate that the non-additive fuzzy integral technique can overcome the criteria non-independent case. Actually, with real fuzzy MCDM problems, where the criteria are not necessarily mutually independent, if we employ an additive aggregating method to derive the synthetic utility, which is the same as the traditional assumption for independent relationship among criteria, it will overestimate when the criteria have substitutive property, or underestimate when the criteria have multiplicative property.

In this paper, we propose a fuzzy hierarchical analytic process, which is an effective fuzzy method to derive the weight of considered criteria and the final synthetic utility values, and then rank the importance of the criteria as well as the sustainable development strategies. The results are useful for new businesses in this industry. Furthermore, this method will yield a different preference order if there are different λ values for the properties of criteria, and this will provide useful information regarding the property of substitutive or multiplicative effects among the considered criteria. In addition, the non-additive fuzzy integral technique is an effective method to evaluate the individual synthetic utility of participating companies.

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Appendix

In this article we utilize non-additive fuzzy integrals to aggregate fuzzy performance scores with weights. Here we give an example to compare the results with traditional independent assumption among considered criteria.

Considering the case of an employer who would like to recruit new staff for the company, the recruiting committee set three criteria, skill (C_1), professional knowledge (C_2) and experience (C_3). Three persons, A, B and C, are interviewed, and the scores from interviewers are summed up as shown in the following table:

Recruiter	Skill (C_1)	Knowledge (C_2)	Experience (C_3)
A	90	80	50
B	50	60	90
C	70	75	70

In addition, the committee sets the weights as follows:

$\mu(\{C_1\}) = \mu(\{C_2\}) = 0.45; \quad \mu(\{C_3\}) = 0.3;$

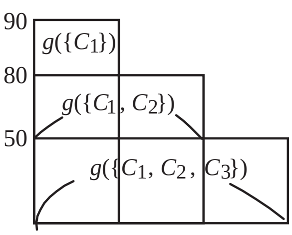
$\mu(\{C_1, C_2\}) = 0.5;$

$\mu(\{C_2, C_3\}) = \mu(\{C_1, C_3\}) = 0.9.$

Applying the fuzzy integral with above fuzzy measure and traditional simple additive weighted (SAW) method leads to following evaluation:

Recruiter	Global evaluation (fuzzy integral)	Global evaluation (SAW method)
A	69.50[a]	76.25[b]
B	68.00	63.75
C	72.25	71.875

[a] Non-independent case among criteria:



$g(\{C_1\})$=0.45; $g(\{C_1, C_2\})$=0.50$g(\{C_1, C_2, C_3\})$=1.0

Global evaluation

= (90-80)*0.45+(80-50)*0.5+50*1.0 = 69.50

where $g(\cdot)$ presents fuzzy measure of criteria, and C_1, C_2, and C_3 are defined as above.

[b] Independent case among criteria:

1. Find the criteria weights through normalization:
   $g(\{C_1\}) = g(\{C_2\}) = 0.375; g(\{C_3\}) = 0.25$
2. Global evaluation $= 90^*0.375 + 80^*0.375 + 50^*0.25 =$ 76.25.

Through the above results, we can see the difference between independent and non-independent cases based on ranking by global evaluation. If the considered criteria have non-independent relationships (either substitutive or multiplicative), fuzzy integrals might be an appropriate method for evaluation.

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