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A Multi-Criteria Evaluation Incorporating Linguistic Computing for Service Innovation Performance

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***Abstract*—**The growing influence of service industries has prompted greater attention being paid to service operations management. However, service managers often have difficulty articulating the veritable effects of their service innovation. Especially, the performance evaluation process of service innovation problems generally involves uncertain and imprecise data. This paper presents a 2-tuple fuzzy linguistic computing approach to dealing with heterogeneous information and information loss problems while the processes of subjective evaluation integration. The proposed method based on group decision-making scenario to assist business managers in measuring performance of service innovation manipulates the heterogeneity integration processes and avoids the information loss effectively.

***Keywords*—**Group decision-making, Heterogeneity, Linguistic computing, Multi-criteria, Service innovation

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I. Introduction

SERVICE industries nowadays have developed into an important economic force and have become an integral part of modern society. Human needs are satisfied with not only physical goods but also services. Both of these two together raise and improve the quality of living. Provision of various quality service products to more demanding customers is the key for businesses to retain a competitive advantage. Consequently, the growing importance of the service industry has prompted greater attention being paid to service operations management [1]–[4]. It is indeed an important topic for firms, not only for entrepreneurs but also for policy makers.

However, service innovation is a complex, elusive, and uncertainty concept that is difficult to determine. To perceive and to measure the performance of service innovation effectively are real challenging tasks for company managers. It involves a search of the environment of opportunities, the generation of project options, and the evaluation by different experts of multiple attributes, both qualitative and quantitative. The decision-making domain of service innovation is therefore highly complex and uncertain due to a demanding environment characterized by increased globalization and segmentation of service markets, changing customer needs, and differentiating the recognition of the customers' perception of quality [5]–[7]. In order to evaluate the performance of service innovation more appropriately, it should consider not only quantitative index but also qualitative dimensions or factors which are evaluated by multiple experts or customers. Thus, the evaluation of service innovation performance should be regarded as a group multiple criteria decision-making problem as well.

Evaluators devote to judge by their experiential cognition and subjective perception in the decision-making process of measuring service innovation performance. However, there exist considerable extent of uncertainty, fuzziness and heterogeneity. This is not a seldom situation. In addition, it is prone to information loss happen during the integration processes, and gives rise to the evaluation result of performance level may not be consistent with the expectation of evaluators. Consequently, developing an easy way to calculate the performance ratings while the processes of evaluation integration and appropriately to manipulate the operation of qualitative factors and evaluator judgment in the evaluation process of service innovation could brook no delay. The purpose of this paper is to propose a suitable model based on 2-tuple fuzzy linguistic information to evaluate the service innovation performance. The proposed approach not only inherits the existing characters of fuzzy linguistic assessment but also overcomes the problems of information loss of other fuzzy linguistic approaches [8]–[9].

II. Literature Review

Customers, in a number of industries, are constantly bombarded with run-of-the-mill product and service offerings [10]. As a result, customers both desire and more often demand innovative alternatives. In response, many service-oriented firms are striving to integrate novel features into their product-service offerings [11]–[12]. Service is intangible. When the customer interacts with the service provider, the personnel, process, and physical features are the evidence of service. For decades, the importance of services to the global economy has grown steadily while the importance of goods has declined [13]. Companies are constantly seeking to provide better services, regardless of whether they are in a "pure" service business or in a manufacturing industry that must increasingly rely on its service operations for continued profitability. Most improvements to service activities are incremental, and are useful and indeed necessary. Nevertheless, they are limited in the kind of returns they can produce. Only rarely does a company develop a service that creates an entirely new market or so reshapes a market that the company enjoys unforeseen profits for a considerable length of time.

The diversity of service activities means that service innovations and innovation processes take various forms [11]. Berry et al. [13] stated that service innovations that create new markets differ from each other along two primary dimensions: the type of benefit offered and the degree of service "separability". On the first dimension, businesses can innovate

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by offering an important new core benefit or a new delivery benefit that revolutionizes customers' access to the core benefit. The second dimension concerns whether the service must be produced and consumed simultaneously. Health care has traditionally been an "inseparable" service. Executives who attempt to create a new market through service innovation must concentrate on the tasks that determine success or failure.

Typical service firms incur a 25-35% penalty cost as a result of poor quality [12]. One important lesson learned from the quality movement is that the prevention of service failure, resulting in large part from design excellence, is the most effective and efficient route to achieving higher levels of quality and customer satisfaction. Poor planning or performance evaluation not only impacts initial service quality but also contributes to cycle of service failure. Accordingly, performance measurement plays an important role in ensuring the success of any project, and a reliable performance measurement system is essential for sound management decisions and company growth [14]–[16].

It is however difficult and laborious to measure service innovation performance using traditional crisp value directly as the process of service innovation performance measurement is possessed of many intangible or qualitative factors and items. Linguistic variable representation is therefore favorable for evaluators to express and evaluate the ratings of service innovation project under such situation [6]. The fundamentals of 2-tuple fuzzy linguistic approach are to apply linguistic variables to stand for the difference of degree and to carry out processes of computing with words easier and without information loss during the integration procedure [8]–[9]. That is to say, decision participators or experts can use linguistic variables to estimate measure items and obtain the final evaluation result with proper linguistic variable. It is an operative method to reduce the decision time and mistakes of information translation and avoid information loss through computing with words.

III. Fuzzy Linguistic Computing Approach

Increasingly uncertain world nowadays yields a highly competitive environment for every business. The imprecise and vague terms will exist around. Zadeh (1975) first introduced fuzzy set theory, which was oriented on the rationality of uncertainty due to imprecision or vagueness to deal with vagueness of human thought. It not only represents vague knowledge but also allows mathematical operators and programming to apply to the fuzzy domain.

A. 2-Tuple fuzzy linguistic term

For easing the computation and identifying the diversity of each evaluation item, linguistic terms are often possessed of some characteristics like finite set, odd cardinality, semantic symmetric, ordinal level and compensative operation. The linguistic information with a pair of values is called 2-tuple that composed by a linguistic term and a number [8]–[9]. This representation benefits to be continuous in its domain. It can express any counting of information in the universe of the discourse, and can be denoted by a symbol $L=(s_i, \alpha_i)$ where s_i denotes the central value of the i^{th} linguistic term, and α_i indicates the distance to the central value of the i^{th} linguistic term. For example, a set of five terms S could be given as follows:

$$S=\{s_0:VL, s_1:L, s_2:A, s_3:H, s_4:VH\}$$

It means that a linguistic term set S contains five linguistic terms, ″Very Low″, ″Low″, ″Average″, ″High″, and ″Very High″, which are denotes s_0, s_1, s_2, s_3, and s_4, respectively. (See Fig. 1)

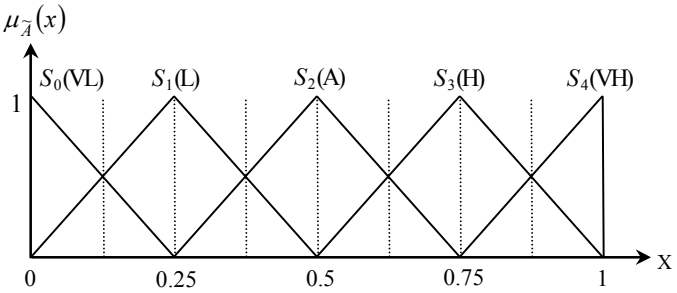


Fig. 1 Linguistic term set of five labels with its semantics.

B. Conversion between 2-Tuples and numeric values

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$$\Delta : [0, 1] \to S \times [-\frac{1}{2g}, \frac{1}{2g})$$

$$\Delta(\beta) = (s_i, \alpha) \text{ with } \begin{cases} s_i, & i = round(\beta \bullet g) \\ \alpha = \beta - \dfrac{i}{g}, & \alpha \in [-\dfrac{1}{2g}, \dfrac{1}{2g}) \end{cases} \quad (1)$$

where $\beta \in [0, 1]$. A value β is translated into the closest linguistic term s_i in S with a value α through the symbolic translation. The 2-tuple fuzzy linguistic approach applies the concept of symbolic translation to represent the linguistic variable using 2-tuples (s_i, α), $s_i \in S$. The interval of value α is derived from the number of linguistic terms. On the contrary, the 2-tuple can be converted into an equivalent numeric value β ($\beta \in [0, 1]$) by the following formula.

$$\Delta^{-1}(s_i, \alpha) = \frac{i}{g} + \alpha = \beta \quad (2)$$

Δ and Δ^{-1} transform numerical values into a 2-tuples and vice versa without loss of information. According to an ordinary lexicographic order we may complete the comparison of linguistic information represented by 2-tuples. Let (s_i, α_i) and (s_j, α_j) be two 2-tuples, with each one representing a counting of information as follows:

1. If $i>j$ then (s_i, α_i) is better than (s_j, α_j);
2. If $i=j$ and $\alpha_i>\alpha_j$ then (s_i, α_i) is better than (s_j, α_j);
3. If $i=j$ and $\alpha_i<\alpha_j$ then (s_i, α_i) is worse than (s_j, α_j);
4. If $i=j$ and $\alpha_i=\alpha_j$ then (s_i, α_i) is equal to (s_j, α_j), i.e. the same information.

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C. Operation of 2-tuples

Suppose $L_1=(s_1, \alpha_1)$ and $L_2=(s_2, \alpha_2)$ are two 2-tuples. The main algebraic operations are shown as follows:

$$L_1 \oplus L_2=(s_1, \alpha_1) \oplus (s_2, \alpha_2)=(s_1+s_2, \alpha_1+\alpha_2) \quad (3)$$

$$L_1 \otimes L_2=(s_1, \alpha_1) \otimes (s_2, \alpha_2)=(s_1 s_2, \alpha_1 \alpha_2) \quad (4)$$

where $\oplus$ and $\otimes$ stand for the addition and multiplication operations of parameters, respectively. Symbolic translation functions, Δ and Δ^{-1}, are applied in the process of information aggregation to guarantee the aggregation of 2-tuple linguistic variables can be a 2-tuple and without any information loss. Let $S=\{(s_1, \alpha_1),\ldots,(s_n, \alpha_n)\}$ be a 2-tuple linguistic variable set and $W=\{w_1, \ldots, w_n\}$ be the weight set of linguistic terms, their arithmetic mean $\bar{S}$ can be calculated as

$$\bar{S}=\Delta[\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i,\alpha_i)]=\Delta(\frac{1}{n}\sum_{i=1}^{n}\beta_i)=(s_m,\alpha_m) \quad (5)$$

The 2-tuple linguistic weighted average $\bar{S}^w$ can be computed as

$$\bar{S}^w=\Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}(s_i,\alpha_i)\cdot w_i}{\sum_{i=1}^{n}w_i}\right)=\Delta\left(\frac{\sum_{i=1}^{n}\beta_i\cdot w_i}{\sum_{i=1}^{n}w_i}\right)=(s^w,\alpha^w) \quad (6)$$

Furthermore, let $W=\{(w_1, \alpha_{w1}), \ldots, (w_n, \alpha_{wn})\}$ be the linguistic weight set of linguistic terms. Such linguistic weighted average operator is extended from weighted average operator and can be computed as

$$\bar{S}^w=\Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}\beta_i\cdot\beta_{wi}}{\sum_{i=1}^{n}\beta_{wi}}\right)=(s^w,\alpha^w) \quad \text{with } \beta_i$$
$$=\Delta^{-1}(s_i, \alpha_i) \quad \text{and } \beta_i^w=\Delta^{-1}(s_i, \alpha_i) \quad (7)$$

IV. Multi-criteria Linguistic Computing Evaluation Model

A 2-tuple-based evaluation model in accordance with concepts of fuzzy linguistic computing approach is proposed in this paper to measure the performance level of the service innovation project. The algorithm procedure for the proposed evaluation approach is organized sequentially into following six steps.

Step 1: Form an experts committee who are concerned and familiar with customer features and needs, market, characteristics competitive environment and potential impact of technical services. Assume that there are n criteria $C_i(i=1, 2, \ldots, n)$ and each criterion contains several sub-criteria in an evaluation framework of the service innovation project performance. Identify and divide the evaluation criteria into positive criteria (the higher the rating, the greater the preference) and negative criteria (the lower the rating, the greater the preference).

TABLE I
Selectable Category of Linguistic Terms for Each Evaluator

Type	# of linguistic	Linguistic variable
A	3	Poor (s_0^3), Average (s_1^3), Good (s_2^3)
B	5	Very poor (s_0^5), Very Poor (s_1^5), Poor (s_2^5), Average (s_3^5), Good (s_4^5)
C	7	Very poor (s_0^7), Poor (s_1^7), Fair (s_2^7), Average (s_3^7), Good(s_4^7), Very Good (s_5^7), Extremely Good (s_6^7)

Step 2: Selectable categories of linguistic terms in Table 1 are prepared for evaluators when they apply the linguistic importance variables to represent the weight of each criterion and employ the linguistic rating variables to evaluate the performance of sub-criteria with respect to each criterion.

Step 3: Aggregate the fuzzy linguistic assessments of the N evaluators for each criterion.

$$\bar{S}_{ij}=\Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}(s_{ijn},\alpha_{ijn})\right)=\Delta(\frac{1}{N}\sum_{N=1}^{N}\beta_{ijn})=(s_{ij},\alpha_{ij}) \quad (8)$$

$$\overline{W}_{ij}=\Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}(s_{ijn}^w,\alpha_{ijn}^w)\right)=\Delta(\frac{1}{N}\sum_{n=1}^{N}\beta_{ijn}^w)=(s_{ij}^w,\alpha_{ij}^w) \quad (9)$$

$$\overline{W}_{i}=\Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}(s_{in}^w,\alpha_{in}^w)\right)=\Delta(\frac{1}{N}\sum_{n=1}^{N}\beta_{in}^w)=(s_{i}^w,\alpha_{i}^w) \quad (10)$$

where, s_{ijn} is the fuzzy rating of sub-criteria j with respect to C_i of the n^{th} evaluator, s_{ijn}^w is the fuzzy importance of sub-criteria j with respect to C_i of the n^{th} evaluator;

Step 4: Apply Eq. (7) to obtain the fuzzy aggregated rating of $C_i(\bar{S}_i)$;

$$\bar{S}_i^w=\Delta\left(\frac{\sum_{j=1}^{l_i}\Delta^{-1}\beta_{ij}\cdot\beta_{ij}^w}{\sum_{j=1}^{l_i}\beta_{ij}^w}\right)=(s_i^w,\alpha_i^w) \quad \text{with } \beta_{ij}$$
$$=\Delta^{-1}(r_{ij}, \alpha_{ij}) \quad \text{and } \beta_{ij}^w=\Delta^{-1}(w_{ij}, \alpha_{ij}^w) \quad (11)$$

Step 5: Compute the overall performance level (OPL) of the service innovation project, the linguistic term s_T, can be applied to represent the control and management performance level of service innovation projects as well as being the improvement index directly.

$$OPL=\Delta\left(\frac{\sum_{i=1}^{n}\beta_i\cdot\beta_{w_i}}{\sum_{i=1}^{n}\beta_{w_i}}\right)=(s_T,\alpha_T) \quad \text{with } \beta_i$$
$$=\Delta^{-1}(r_i, \alpha_i) \quad \text{and } \beta_{w_i}=\Delta^{-1}(w_i, \alpha_{w_i}) \quad (12)$$

Step 6: Conclude from the results to develop and manage the strategic partnership through service innovation development programs,

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V. Application of Proposed Method

Suppose after preliminary sifting the related information that a marketing committee of three experts, E_1, E_2 and E_3, has been formed to evaluate the service innovation performance of three service projects, P_1, P_2 and P_3. Five thoughtful criteria are considered: reliability (C_1), responsiveness (C_2), attitude (C_3), support (C_4) and speed (C_5). At the outset, they make their individual opinion in accordance with own knowledge, expertise, as well as experience to infer the overall performance level of service innovation projects. The proposed method is applied to solve this problem, the computational procedure of which is summarized as follows:

Step 1: The experts refer to the linguistic labels (shown in Table 1) to assess the importance of the criteria and the linguistic rating of the projects with respect to each criterion. Afterward the rating outcome is shown in Tables II and III.

TABLE II
LINGUISTIC EVALUATIONS OF EACH EXPERT FOR EACH PROJECT WITH RESPECT TO EACH CRITERION

Criteria	*Project*	*Expert*		
		E_1	E_2	E_3
Reliability (C_1)	P_1,	VG	A	P
	P_2	VG	A	VG
	P_3	A	A	VG
Responsiveness (C_2)	P_1,	G	VG	A
	P_2	VG	G	A
	P_3	G	VG	P
Attitude (C_3)	P_1,	A	VG	A
	P_2	VG	G	A
	P_3	G	A	VG
Support (C_4)	P_1,	VG	A	VG
	P_2	P	VG	VG
	P_3	A	VG	VG
Speed (C_5)	P_1,	G	A	VG
	P_2	VG	G	A
	P_3	A	VG	A

TABLE III
LINGUISTIC EVALUATIONS OF EACH EXPERT FOR THE IMPORTANCE OF EACH CRITERION

Criteria	*Expert*		
	E_1	E_2	E_3
Reliability (C_1)	VI	A	I
Responsiveness(C_2)	I	VI	A
Attitude (C_3)	I	VI	VI
Support (C_4)	VI	A	VI
Speed (C_5)	A	VI	VI

Step 2: The 2-tuple fuzzy linguistic aggregation method is used to compute fuzzy evaluation weighting and rating values of each criterion for projects. For example, fuzzy rating and weighting value of expert 1 for criterion "Speed" with respect to project 2 are computed as

$$\overline{S}_{15} = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_3,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_2,0)+\Delta^{-1}(s_4,0)\right)\right]$$
$$= \Delta\left[\frac{1}{4}\left(0.75+1+0.5+1\right)\right] = \Delta(0.8125) = (s_3, 0.0625)$$

$$\overline{W}_{15} = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_2,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_2,0)+\Delta^{-1}(s_2,0)\right)\right]$$
$$= \Delta\left[\frac{1}{4}\left(0.5+1+0.5+0.5\right)\right] = \Delta(0.625) = (s_2, 0.125)$$

Step 3: The aggregated weighting value of each criterion can be calculated as follows, "Reliability" for example.

$$\overline{W}_1 = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_3,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_4,0)\right)\right]$$
$$= \Delta\left[\frac{1}{4}\left(0.75+1+1+1\right)\right] = \Delta(0.9375) = (s_4, -0.0625)$$

Step 4: The weighted rating can be calculated as, "Support" for example.

$$\overline{S}_4^w = \Delta\left[\frac{\begin{array}{l}\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,0)\cdot\Delta^{-1}(s_3,-0.0625)\\ +\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,-0.0625)\end{array}}{\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,-0.0625)+\Delta^{-1}(s_3,-0.0625)}\right]$$
$$= \Delta\left[\frac{0.875\cdot0.75+0.75\cdot0.6875+0.875\cdot0.6875}{0.75+0.6875+0.6875}\right]$$
$$= \Delta(0.83456) = (s_3, 0.08456)$$

Step 5: According to values of the weighted rating and aggregated weighting of each criterion to compute the overall performance level (*OPL*) of service innovation project 1 as

$$OPL = \Delta\frac{\left(\begin{array}{l}\Delta^{-1}(s_4,-0.0625)\times\Delta^{-1}(s_3,0.0625)+\\ \Delta^{-1}(s_4,-0.0625)\times\Delta^{-1}(s_3,0.0221)+\\ \Delta^{-1}(s_4,-0.125)\times\Delta^{-1}(s_3,0.079)+\\ \Delta^{-1}(s_3,0.125)\times\Delta^{-1}(s_3,0.0846)\end{array}\right)}{\begin{array}{l}[\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_4,-0.0625)+\\ \Delta^{-1}(s_4,-0.125)+\Delta^{-1}(s_3,0.125)]\end{array}}$$
$$= \Delta\left(\frac{\begin{array}{l}0.8125\times0.9375+0.7722\times0.9375+\\ 0.829\times0.875+0.8346\times0.875\end{array}}{0.9375+0.9375+0.875+0.875}\right)$$
$$= \Delta(0.8114) = (s_3, 0.0614)$$

Step 6: Comprehend and rank the performance of each project. i.e. P_1 is the most preferable service innovation project, P_2 is the worst one, and P_3 is moderate, respectively. Afterward managers are capable of concluding from the results to develop and manage the strategic partnership through service innovation development programs,

VI. Conclusion

The benefits of service innovation are apparent. What is not as clear is how managers should decide on which innovations to implement. Innovative service offerings are not only necessary just to maintain a firm's current market share but also may enhance service differentiation and induce financial gains. The performance evaluation process of service innovation problems generally involves uncertain and imprecise data. This paper proposes a novel group multi-criteria decision-making model,

based on linguistic computing, which is capable of dealing with the evaluation of service innovation performance effectively. According to the OPL, decision makers can determine not only the level of service innovation but also the ranking order of all feasible service innovation projects. Obviously the evaluation criteria and the membership functions of linguistic labels should be determined by considering the factual requirements of the practical scenario.

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