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SELECTION OF AN IMPROVEMENT STRATEGY IN INTERNAL SERVICE OPERATIONS: THE MCDM APPROACH WITH FUZZY AHP AND NONADDITIVE FUZZY INTEGRAL

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Abstract. *Service operation strategy has been widely adopted by firms who wish to enhance their competitive advantage to be better prepared to face external challenges. Previous studies have shown that internal service quality (ISQ) ultimately drives the profit of enterprises. This research has thus chosen ISQ as the focus for the development of an assessment model to reform organizations that undertake ISQ to enhance their core competencies. This paper describes a fuzzy hierarchical analytic approach to determine the weighting of subjective judgments and presents a nonadditive fuzzy integral technique to evaluate an ISQ case as a fuzzy multiple criteria decision-making (MCDM) problem. Through literature reviews and experts interviews, 26 criteria are generated along with nine dimensions and five strategy alternatives. By ranking fuzzy weights and fuzzy synthetic utility values, the relative importance of criteria and the best strategies can be determined. An empirical case of ISQ improvement strategy for a Taiwanese semiconductor manufacturer is demonstrated to show the effectiveness of the proposed methods when dealing with criteria that are not independent. The empirical results show that employee rewards and recognition outrank other strategies with regard to improving the ISQ. These results will not only help organizations that aim to improve their internal service operations, but can also assist human resource professionals in more effectively monitoring and improving the performance of employees.*
Keywords: Analytic hierarchy process (AHP), Fuzzy integral, Internal service quality, Multiple criteria decision-making (MCDM), Strategic service operation

1. **Introduction.** Service quality significantly affects customer satisfaction, and customer satisfaction in turn impacts profitability [24]. Researchers and managers have focused their attention on improving the quality of services and products, and over the last decade or so an increasing emphasis has been placed on the idea of internal customer service as a means of strengthening and improving the quality of a firm's services and products [42]. The improvements that accrue in service and product quality are not the only benefits of superior internal services which have also been linked to lower employee turnover and higher productivity [24], lower waste and reduced costs [42], increased job satisfaction [22, 39], and more effective teamwork and communication [43]. There is also strong evidence which suggests that satisfied internal customers share positive links with satisfied external customers [20].

If external customer service is the business of servicing the customers of the company, then internal customer service is the act of providing services to those within an organization. A scholarly consensus has been reached suggesting that internal customer service not only has a major influence on external customer service satisfaction, but is also a key contributor to its quality of it [35]. Researchers agree that the internal workings of a firm, even if they are far removed from the actual point of service to customers, will ultimately have a significant impact on the eventual quality of the service provided [15]. The driving idea behind internal customer service, at its most basic, is that every person, in any organization, is akin to a customer, and thus has a customer that they serve. This idea led Johnston [35] to claim "there can be few, if any, individuals, processes and functions within organizations that could not be classified as being the providers and/or recipients of internal service" (p.211). Thus, every member of an organization is part of a value added service chain. As a result, the internal workings of an organization will have a large impact on the final customer. Understanding how internal service encounters are perceived and evaluated is crucial to improving on them. Those firms that are armed with understanding have an advantage in designing service processes, and will reap the benefits of improvements in these [2].

Service operations and improvement strategies in enterprises are essentially complex analytical processes. Several strategies have to be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often hard to quantify. To date, there have been no studies which adopt a rigorous methodology to find out how to select a best improvement strategy for internal service operations. Although internal service quality (ISQ) is always a key issue, it is hard to measure. Since numerical values cannot clearly express each considered criterion for the various internal service strategies, fuzziness is applicable. In imprecise environments, fuzzy logic is widely employed to deal with the problems of uncertainty, especially with problems related to subjective perception. Therefore, this study employed the fuzzy logic methodology to address the vagueness of human judgment. In addition, in the conventional approach to decision making, the criteria in the decision model are assumed to be independent of each other. However, in the complex system of the real world, the criteria are generally inter-related, and an individual has to deal with interdependent information to cope with complex situations with multi-goal/objectives. Traditional analytical methods which assume independent relationships with additive measures are thus inadequate for modeling such complex situations. Therefore, this research adopts fuzzy AHP and nonadditive fuzzy integral to evaluate each of the possible alternative strategies in a dynamic environment with multiple dimensions. The fuzzy AHP was applied to determine the weights of criteria from subjective judgment, and nonadditive integral technique was utilized to evaluate the performance of improvement strategies for internal service operations. In this article, we demonstrate that the fuzzy integral is a good means of evaluation, and appears to be more appropriate when the criteria are not independent of each other.

The rest of this paper is organized as follows. In Section 2, the prior literature is reviewed to form the dimensions and criteria of ISQ. Section 3 reviews the fuzzy MCDM methods, including the fuzzy AHP and nonadditive fuzzy integral. In Section 4, an empirical study is illustrated to show the effectiveness of the proposed model. Section 5 presents a discussion of the research findings and their managerial implication. Finally, the concluding remarks are presented in Section 6.

2. Literature Review of Internal Service Quality.

In MCDM approaches, the goal of the research needs to be categorized into distinct dimensions and criteria based on thorough support from the literature. The current study examined a finite set of alternative strategies to be evaluated in terms of multiple criteria. In this section, the literature on ISQ is reviewed, and the hierarchical structure of the dimensions and criteria and the alternative strategies are generated.

2.1. **Internal service quality.** Services exhibit specific characteristics that differentiate them from tangible products, and these have a significant impact on the study of services and determinants of service quality. Services are often conceptualized as performances rather than physical objects. Stated by Parasuraman et al. [49], services cannot be "counted, measured, inventoried, tested or verified" (p.42) prior to the sale of the service itself. This characteristic makes service quality an important and distinct area of study. Schneider and Bowen [57] noted that marketers need to emphasize not only the actual service delivery employees, but also the organizational context of the service experience as an important determinant of customer satisfaction, and their work began the study of internal customer service.

Internal customers have been described as any member of an organization who is supplied with services or products by any other person within the same organization [2, 20]. Internal customers are those who use the services provided by other internal departments. As stated by Heskett et al. [24], a good ISQ can directly raise employee satisfaction and increase the overall profit of an enterprise. The links that exist in the service profit-chain are illustrated in Figure 1. In order to improve ISQ, managers need to have a clear and well-defined idea of the attributes that affect internal customer satisfaction. Furthermore, they will need to be equipped with the knowledge that will allow them to control and measure these attributes [34].

Parasuraman et al. [49] identified ten factors of service quality which their later study [48] reduced to five. However, their work was focused on external customers, and was therefore not entirely suitable for further ISQ research. Reynoso and Moores's [54] study adapted the original dimensions to an internal setting, and proposed ten dimensions of ISQ.

2.2. **Internal service quality in Taiwan.** The definition and perception of service quality is not uniform across all cultures. As stated by Hofstead [25], "Management deals with a reality that is man-made. People build organizations according to their values, and societies are composed of institutions and organizations that reflect the dominant values within their culture" (p.81). Management, institutional character and culture cannot be disconnected from each other. Culture permeates into every aspect of an organization, and effective management requires an understanding of the cultural context in which it

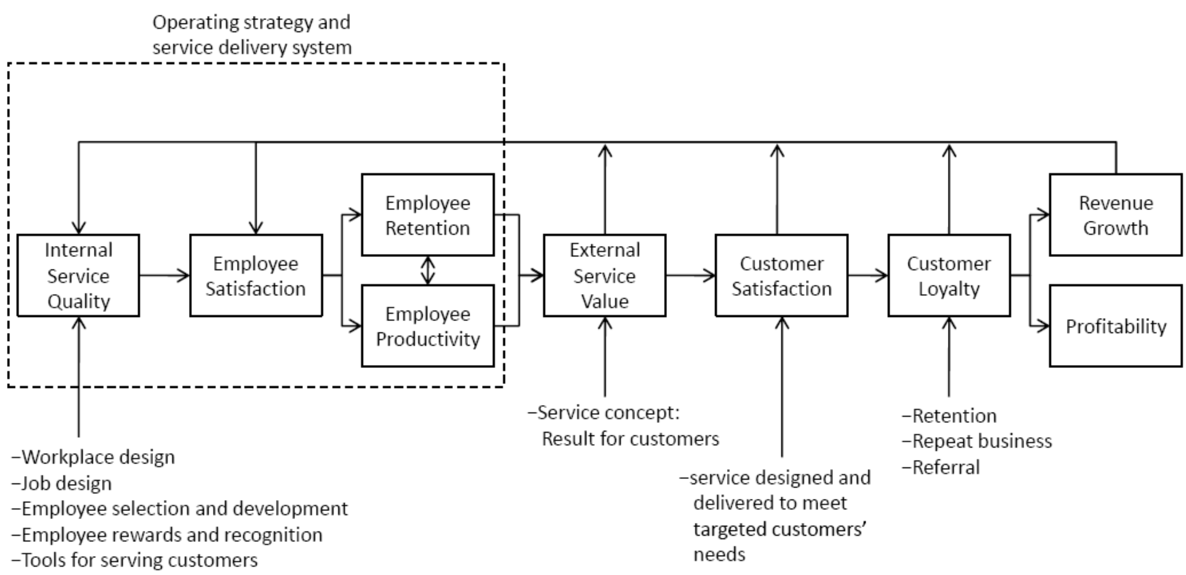

Figure 1. The links in the service profit-chain (source: Heskett et al. [24])

exists. Each regional branch of a global firm will have its own cultural context, and this will distinguish that branch's internal service operations from its counterparts.

The realization that service quality attributes are not consistent across cultures is important. This suggests that managers must base their management decisions upon culturally specific information sources. Solely relying on research from the West may not be appropriate for managers in the East, and vice versa. The studies from Raajpoot [51] and Winstead [66] have shown the research conducted on Western internal customers may be lacking in very important contributing attributes for non-Western settings.

The study of internal service quality in Taiwan is a newly developing field. Stanworth et al. [60] conducted a qualitative study to establish the attributes determining internal customer service. A follow up study conducted by Owen [47] extracted a clear factor structure from Stanworth et al.'s [60] list, and has been validated by Reeder [53]. Details of these dimensions and definitions of the criteria are summarized in Table 1.

2.3. **Alternative strategies for improving internal service quality.** Scholars have worked on uncovering various strategies to improve service quality. Gap theory [41] contends that the size of the gap between what a customer expects and what they receive is the key determinant of customer satisfaction. Therefore, those internal service providers that are best able to match customer expectations with the actual service provided will enjoy higher levels of perceived service quality and internal customer satisfaction, and this in turn can increase the profit of an organization.

Following Heskett et al. [24], five strategic alternatives are adopted in this study, namely workplace design [58, 59], job design [6], employee selection and development [12], employee rewards and recognition [3, 22], and tools for serving customers [16, 22]. These strategic alternatives have shown to have a significant impact on the success of internal service quality.

Workplace design includes the design of buildings (e.g., layout and appearance), their interiors (e.g., rooms and furniture), and the surrounding outdoor areas [38]. The design of work and living environments can support or constrain the internal operation behavior. Becker [4] stated that workplace design contributes to organizational effectiveness not only in work tasks (e.g., work quantity and quality, and style of work), but also acts as a catalyst for organizational outcomes (e.g., absenteeism and turnover). Becker [4] also treated workplace design as a strategic tool for achieving both short- and long-term organizational goals.

A job is defined as a set of tasks designed to be performed by one employee [21, 28, 67]. Grant [19] further stated jobs are designed with elaborate relational architectures that affect employees' interpersonal interactions and connections. In addition, numerous studies (e.g., [37, 61, 64, 67]) have found that, as Grant [19] writes, "jobs structure the nature and content of employees' relationships with coworkers by configuring particular patterns of interaction, cooperation, and collaboration" (p.395).

Employee selection is finding the applicants who have the skills and abilities necessary to do a particular job. London [40] defined employee development as courses, workshops, seminars, and assignments that influence personal and professional growth. Development opportunities are focused on skills, behaviors, and abilities that are necessary for long-term personal effectiveness, and that contribute to the firm's ability to remain competitive by providing high-quality goods and services to its customers [44].

Employee rewards and recognition are defined as "rewarding and recognizing employees who provide superior service and take a personal interest in resolving customer problems, celebrating top service accomplishments, and making it clear that delivering excellent service is important in advancement decisions" [33] (p.837). In internal service operations,

TABLE 1. Definition of Taiwanese ISQ dimensions and criteria

Dimension	Criteria	Definition
Attitude (D_1)	Chin-chieh (Friendly) (C_{11})	Provides help with a kind and pleasant countenance.
	Ke-chi (Polite) (C_{12})	Uses a polite and gentle manner when asking a favour or explaining something; does not use a commanding voice.
	Ji-ji (positive/proactive) (C_{13})	Helps solve problems voluntarily; is willing to have problems or errors pointed out or be corrected by others.
	Patience (C_{14})	Does not become impatient, even if required to explain things or is asked for clarification multiple times.
Consideration (D_2)	Considerate (C_{21})	Makes careful considerations and advises of alternative solutions if the task cannot currently be solved.
	Help each other (C_{22})	Supports me when I have problems, helping me to satisfy my customers' needs.
	Professional knowledge (C_{23})	Provides expertise and detailed data to me when needed, and gives a reasonable explanation when a promise cannot be met or when a request cannot be accommodated.
	Cooperation (C_{24})	Shows a cooperative attitude which helps coordinate tasks and allows them to be completed smoothly.
	External efficiency (C_{25})	Completes tasks quickly and makes the external customer/supplier very satisfied, thus making my job more enjoyable.
	Bureaucracy (C_{26})	Formal rules, policies and procedures are emphasized, while also allowing for special circumstances.
Shared Understanding (D_3)	Competent (C_{31})	The service providing department possesses the ability to understand and deal with issues without causing problems.
	Shows empathy (C_{32})	Understands my difficulties and encourages and assists rather than blames me.
	Consensus (C_{33})	Though has a different opinion than mine, we can still reach a common consensus and I feel my point of view is heard.
Promise (D_4)	Internal efficiency (C_{41})	Finishes tasks on time and does not cause delays with regard to the next step.
	Responsible (C_{42})	Are responsible and diligent in terms of their work and the data/information they provide me.
	Reliability (C_{43})	Finishes tasks and achieves my requirements.
Working Atmosphere (D_5)	Harmony (C_{51})	Helps to develop a harmonious atmosphere that envelops the whole working environment, even when there are fierce discussions.
	Emotional Stability (C_{52})	Has a high emotional quotient and does not lose his/her temper or get angry because of increasing work load.
Relationship (D_6)	Personal connection (C_{61})	Has a professional as well as personal relationship with me, improving our relationship at work.
	Exchange thoughts (C_{62})	Shares or exchanges their work abilities and experiences selflessly with others.
Accessible (D_7)	Accessible (C_{71})	Though they are busy, they are able to help when needed.
	Work Load (C_{72})	Though they are busy, they still have a positive attitude towards me.
Shared Objectives (D_8)	Common goal (C_{81})	Understands that we share a common goal within the company.
	Common vision (C_{82})	Understands that our mission is to make a great effort for the company together.
Effectiveness (D_9)	Discussions (C_{91})	Conducts meetings and discusses issues effectively.
	Time (C_{92})	Does not waste my or other people's time.

Source: Adapted from Reeder [53], p.6-7; Owen [47], p.6; and Stanworth et al. [60], p.8-12.

this definition can also be applied inter-organizationally. Rewards and recognition can communicate to employees that quality service is important to the organization, which is most predictive aspect of customer satisfaction and overall satisfaction with services [33]. Hansen et al. [23] stated that "only when recognition and reward are treated as two distinct phenomena will the effectiveness of employee motivation initiatives be improved" (p.64).

Customer service tools are highly valued in operations management, both in practice and the literature. They are tools for serving customers more effectively and efficiently, and can be used to enhance customer satisfaction. Such tools are supported by state-of-the-art technologies, such as data mining [5, 27] and net-based systems [50]. Internal customer service tools are thus becoming an integral part of many enterprises, which use them as a strategic tool to raise the efficiency of internal operations and ultimately achieve company goals.

Based on this review of the literature, the alternative ISQ improvement strategies adopted in this research are summarized as follows: ($S1$) workplace design, ($S2$) job design, ($S3$) employee selection and development, ($S4$) employee rewards and recognition, and ($S5$) tools for serving customers.

3. **Fuzzy Measurement and Fuzzy Integral.** Fuzzy MCDM has been widely used to deal with decision making problems involving multiple criteria evaluation and the selection of alternatives. The practical applications reported in the literature [10, 13, 31, 32, 46, 68] have shown several advantages in handling qualitative criteria. The AHP [55, 56] is one of most common methods that have been adopted to solve decision-making problems. In this approach, a pairwise comparison of relative importance based on expert judgments is used to evaluate the related hierarchical system and weights, where each criterion's importance within the hierarchy is determined by its weight. Later, the fuzzy AHP [7] applied fuzzy logic to resolving fuzzy linguistic scale problems to allow analysis of the opinion expressed by survey respondents. Previous studies have proven the efficiency of fuzzy AHP. For example, Hsieh et al. [26] used fuzzy AHP for tender selection in public office buildings.

The concept of the fuzzy integral, introduced by Sugeno [62], can be applied to multi-attribute assessment, which in the discrete case is merely a kind of distorted mean [18]. A synthesis on the use of fuzzy integral as an aggregation operator in MCDM was later presented by Grabisch [17]. The distinguishing feature of a fuzzy integral is that it is able to represent a certain kind of interaction between criteria, ranging from redundancy (negative interaction) to synergy (positive interaction), which overcomes the limitation of modeling dependent criteria as independent sets [17]. This approach has been applied in various fields, such as wood quality evaluation [30], analysis of public attitudes towards the use of nuclear energy [45], evaluation of printed color images [63], design of speakers [29], analysis of human reliability [65], assessing the performances of organizational transformation via communities of practice [11], and planning of industrial green engineering investment [10].

In traditional multiple criteria evaluation approaches, each criterion must be independent of the others. Consequently, the interactions and mutual influences among the criteria in a real system cannot be handled by the concept of traditional additive measures alone. Therefore, to assess ISQ criteria and alternative strategies, it is more appropriate to apply a fuzzy integral model in which it is not necessary to assume additivity and independence. Moreover, fuzzy measures and fuzzy integrals can analyze the human evaluation process and help decision makers in identifying preference structures. In the subsections below, the conventional AHP method, fuzzy logic concept, and fuzzy integral are introduced.

3.1. **Determination of evaluation criteria weights by AHP.** Saaty [56] originally introduced the AHP to systematically cope with complex problems in social systems. He used the principal eigenvector of the comparison matrix to find the comparative weights among the criteria of the hierarchy systems. If we wish to compare a set of n criteria pairwise according to their relative importance (weights), then denote the criteria by $C_1, C_2, \ldots, C_n$ and their weights by $w_1, w_2, \ldots, w_n$. If $\boldsymbol{w} = (w_1, w_2, \ldots, w_n)^T$ is given, the pairwise comparisons may be represented by matrix $\boldsymbol{A}$ of the following formulation:

$$(\boldsymbol{A} - \lambda_{\max} I)\boldsymbol{w} = 0 \tag{1}$$

Equation (1) denotes that $\boldsymbol{A}$ is the matrix of pairwise comparison values derived by intuitive judgement for ranking order. The procedure for AHP can be summarized in four steps, as follows:

Step 1: Set up the decision system by decomposing the problem into a hierarchy of interrelated elements.

Step 2: Generate input data consisting of pairwise comparative evaluations of decision elements.

Step 3: Synthesize the judgement and estimate the relative weight.

Step 4: Determine the aggregate weights of the decision elements to arrive at a set of ratings for the alternatives/strategies.

The evaluators choose a performance value for each participating expert based on their subjective judgements. This way of estimating the achievement level of each criterion in each strategy can use the fuzzy theory method to handle the fuzzy environment.

Since Zadeh [69] first proposed the fuzzy set theory and Bellman and Zadeh [1] subsequently described various decision making methods in fuzzy environments, an increasing number of studies have dealt with uncertain, fuzzy problems by applying fuzzy set theory. Similarly, this study utilizes fuzzy decision making theory, considering the possible fuzzy subjective judgements during the evaluation process.

According to Dubois and Prade [14], a fuzzy number $\widetilde{A}$ is a fuzzy subset of a real number, and its membership function is $\mu_{\widetilde{A}}(x) : R \to [0, 1]$, where x represents the criterion and is described by the following characteristics: (1) $\mu_{\widetilde{A}}(x)$ is a continuous mapping from R to the closed interval $[0, 1]$; (2) $\mu_{\widetilde{A}}(x)$ is a convex fuzzy subset; and (3) $\mu_{\widetilde{A}}(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\widetilde{A}}(x) = 1$.

According to the characteristics of triangular fuzzy numbers and the extension principle put forward by Zadeh [69], the operational laws of two triangular fuzzy numbers, $\widetilde{A} = (a_1, a_2, a_3)$ and $\widetilde{B} = (b_1, b_2, b_3)$, 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 $\ominus$:

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

3. Multiplication of two fuzzy numbers $\otimes$:

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

4. Multiplication of any real number k and a fuzzy number:

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

5. Division of two fuzzy numbers $\oslash$:

$$(a_1, a_2, a_3) \oslash (b_1, b_2, b_3) = (a_1/b_3, a_2/b_2, a_3/b_1) \tag{6}$$

It is not possible for conventional quantification to express reasonably those situations that are overtly complex or hard to define, and thus the notion of a linguistic variable is necessary in such cases [70]. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language, and we use this kind of expression to compare two ISQ criteria by linguistic variables in a fuzzy environment, such as extreme importance, very strong importance, strong importance, moderate importance, and equal importance with respect to a fuzzy five-level scale.

Buckley [7] was the first to investigate fuzzy weights and the fuzzy utility for the AHP technique, extending AHP by the geometric mean method to derive the fuzzy weights. In Saaty [56], if $\boldsymbol{A} = [a_{ij}]$ is a positive reciprocal matrix, then the geometric mean of each row r_i can be calculated as $r_i = (\prod_1^m a_{ij})^{1/m}$. Saaty defined $\lambda_{\max}$ as the largest eigenvalue of $\boldsymbol{A}$ and the weight w_i as the component of the normalized eigenvector corresponding to $\lambda_{\max}$, where $w_i = r_i/(r_1 + r_2 + \cdots + r_m)$.

Buckley [7] considered a fuzzy positive reciprocal matrix $\widetilde{A} = [\widetilde{a}_{ij}]$, extending the geometric mean technique to define the fuzzy geometric mean of each row $\widetilde{r}_i$ and fuzzy weight $\widetilde{w}_i$ corresponding to each criterion as follows:

$$\begin{aligned} \widetilde{r}_i &= (\widetilde{a}_{i1} \otimes \cdots \otimes \widetilde{a}_{im})^{1/m} \\ \widetilde{w}_i &= (\widetilde{r}_i \oplus \cdots \oplus \widetilde{r}_m)^{-1} \end{aligned} \tag{7}$$

3.2. **Obtaining synthetic utility value.** Sugeno [62] introduced the concepts of the fuzzy measure and fuzzy integral, generalizing the usual definition of a measure by replacing the usual additive property with a weaker requirement, i.e., the monotonicity property with respect to set inclusion.

Definition 3.1. *Let X be a measurable set that is endowed with properties of σ-algebra, where $\aleph$ is all subsets of X. A fuzzy measure g, defined on the measurable space $(X, \aleph)$, is a set function $g : \aleph \to [0, 1]$, which satisfies the following properties: (1) $g(\phi) = 0$, $g(X) = 1$ (boundary conditions); (2) $\forall A, B \in \aleph$ if $A \subseteq B$ then $g(A) \le g(B)$ (monotonicity); (3) for every sequence of subsets of X, if either $A_1 \subseteq A_2 \subseteq \cdots$ or $A_1 \supseteq A_2 \supseteq \cdots$, then $\lim_{i\to\infty} g(A_i) = g(\lim_{i\to\infty} A_i)$ (continuity).*

As in the above definition, $(X, \aleph, g)$ is said to be a fuzzy measure space. Furthermore, as a consequence of the monotonicity condition, we can obtain

$$\begin{cases} g(A \cup B) \ge \max\{g(A), g(B)\} \\ g(A \cap B) \le \min\{g(A), g(B)\} \end{cases} \tag{8}$$

while the two strict cases of measure g as

$$\begin{cases} g(A \cup B) = \max\{g(A), g(B)\} \\ g(A \cap B) = \min\{g(A), g(B)\} \end{cases} \tag{9}$$

are called the possibility measure and necessity measure, respectively.

Definition 3.2. *Let $(X, \aleph, g)$ be a fuzzy measure space. The Choquet integral of a fuzzy measure $g : \aleph \to [0, 1]$ with respect to a simple function h is then defined by*

$$\int h(x) \cdot dg \cong \sum_{i=1}^{n} [h(x_i) - h(x_{i-1})] \cdot g(A_i) \tag{10}$$

where $h(x_{(0)}) = 0$.

From the start of the application of fuzzy measures and fuzzy integrals to multiple criteria evaluation problems, it has been thought there was dependence between criteria. Keeney and Raiffa [36] advocated the multi-attribute multiplicative utility function, called the nonadditive multiple criteria evaluation technique, to refine situations that do not conform to the assumption of independence between criteria [8, 9, 52]. In this paper, we apply Keeney's [36] nonadditive multiple criteria evaluation technique using Choquet integrals to derive the fuzzy synthetic utilities of each strategy for criteria, as follows.

Let g be a fuzzy measure that is defined on a power set $P(x)$ and satisfies Definition 3.1 above. The following characteristic is evidently,

$$\begin{aligned}&\forall A, B \in P(X), \quad A \cap B = \phi \\ &\Rightarrow g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B) \quad \text{for} \quad -1 \leq \lambda \leq \infty \end{aligned} \tag{11}$$

where set $X = x_1, x_2, \ldots, x_n$, and the density of fuzzy measure $g_i = g_\lambda(\{x_i\})$ can be formulated as follows:

$$\begin{aligned} g_\lambda(\{x_1, x_2, \cdots, x_n\}) &= \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i1} \cdot g_{i2} + \cdots + \lambda^{n-1} \cdot g_1 \cdot g_2 \cdots g_n \\ &= \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda \cdot g_i) - 1 \right| \quad \text{for} \ -1 \leq \lambda \leq \infty \end{aligned} \tag{12}$$

For an evaluation case with two criteria, A and B, one of three cases as following will be sustained, based on the above properties:

Case 1: if $\lambda > 0$, i.e., $g_\lambda(A \cup B) > g_\lambda(A) + g_\lambda(B)$, then this implies A and B have a multiplicative effect.

Case 2: if $\lambda = 0$, i.e., $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B)$, then this implies A and B have an additive effect.

Case 3: if $\lambda < 0$, i.e., $g_\lambda(A \cup B) < g_\lambda(A) + g_\lambda(B)$, then this implies A and B have a substitutive effect.

Let h be a measurable set function defined on the fuzzy measurable space $(X, \aleph)$, and suppose that $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$, then the fuzzy integral of fuzzy measure $g(\cdot)$ with respect to $h(\cdot)$ can be defined as follows [30]:

$$\begin{aligned} \int h(x) \cdot dg &= h(x_n) \cdot g(H_n) + [h(x_{n-1}) - h(x_n)] \cdot g(H_{n-1}) + \cdots + [h(x_1) - h(x_2)] \cdot g(H_1) \\ &= h(x_n) \cdot [g(H_n) - g(H_{n-1})] + h(x_{n-1}) \cdot [g(H_{n-1}) - g(H_{n-2})] \\ &\quad + \cdots + h(x_1) \cdot g(H_1) \end{aligned} \tag{13}$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \ldots, H_n = \{x_1, x_2, \ldots, x_n\} = X$. In addition, if $\lambda = 0$ and $g_1 = g_2 = \cdots = g_n$, then $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ is not necessary. The basic concept of Choquet integral (Equation (13)) is illustrated in Figure 2.

On the other hand, the result of the fuzzy synthetic decisions reached by each alternative is a fuzzy number. Therefore, it is necessary that the nonfuzzy ranking method for fuzzy numbers be employed during the comparison of the strategies. The defuzzification procedure has been used to locate the best nonfuzzy performance (BNP) value. Methods of defuzzified fuzzy ranking generally include the mean of maximal, center of area (COA), and α-cut [71]. Utilizing the COA method to determine the BNP is simple and practical, and there is no need to introduce the preferences of any evaluators. The BNP value of the triangular fuzzy number (LR_i, MR_i, UR_i) can be found with the following equation:

$$BNP_i = [(UR_i - LR_i) + (MR_i - LR_i)]/3 + LR_i, \ \forall i \tag{14}$$

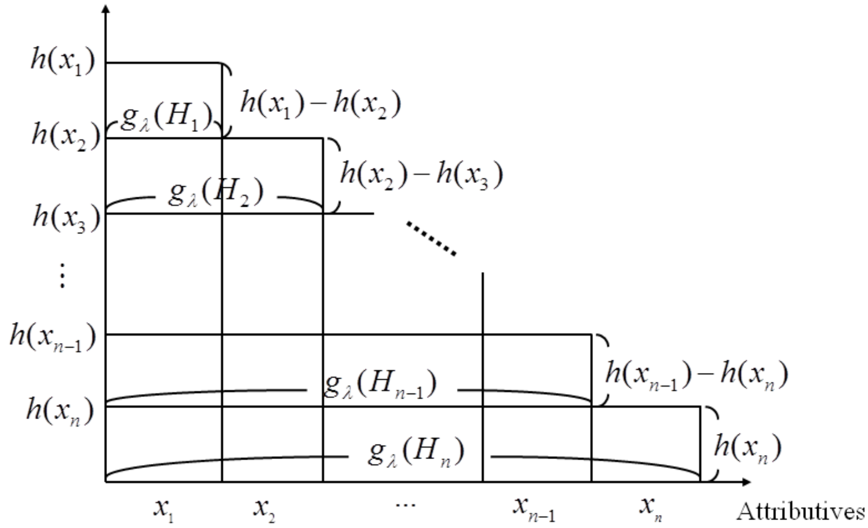

Figure 2. The basic concept of the Choquet integral

For these reasons, the COA method is used in this paper to rank the order of importance of each criterion. According to the value of the derived BNP, the evaluation of each ISQ strategy can then proceed.

Since the criteria are not necessarily mutually independent, the nonadditive fuzzy integral technique is applied in this paper to find the synthetic utilities of ISQ strategies, and to observe the order of the synthetic utilities with different λ values.

4. **Empirical Study: Case of a Semiconductor Manufacturer in Taiwan.**

The semiconductor industry is very competitive where employees need to be highly cooperative while working under intensive pressure. The employees in this industry often work overtime and have heavy task-loads, and thus increasing the efficiency of internal services has attracted more attention among these companies. An empirical case from a major Taiwanese semiconductor manufacturer undertaking ISQ improvement strategy selection is used in this work to show the practicability and usefulness of the proposed method, where 120 valid questionnaires were successfully collected. We integrate the subjective judgments obtained from these to develop the fuzzy criteria weights with respect to the fuzzy geometric mean method, as in Equation (7). We then derive the final fuzzy weights and nonfuzzy BNP values corresponding to each criterion, as shown in Table 2.

To determine the performance value of each strategy, the evaluators can define their own individual range for the linguistic variables employed in this paper according to their subjective judgements within a fuzzy scale. This is because when facing a dynamic environment, the anticipated performance values of unquantifiable criteria cannot be specified with qualitative numerical data in a qualitative evaluation pertaining to the possible achievement value of each strategy.

Let $\widetilde{h}_{ij}^{k}$ represent the fuzzy performance score given by the kth evaluator with regard to the ith strategy under the jth criterion. Since the perception of each evaluator varies according to individual experience and knowledge, and the definitions of linguistic variables also vary, we employ the fuzzy geometric mean method to integrate the fuzzy performance score $\widetilde{h}_{ij}$ for m evaluators.

$$\widetilde{h}_{ij} = \left(\widetilde{h}_{ij}^{1} \otimes \cdots \otimes \widetilde{h}_{ij}^{m}\right)^{1/m} \tag{15}$$

Furthermore, we employ the COA defuzzification procedure to compute the BNP values of fuzzy performance score $\widetilde{h}_{ij}$, as shown in Table 3.

TABLE 2. Weighted dimensions and criteria of internal service quality

Dimensions/Criteria	Local weight	Global weight	BNP (ranking)
Attitude (D_1)	(0.019,0.081,0.325)		0.142
Chin-Chieh (C_{11})	(0.036,0.203,0.512)	(0.001,0.016,0.166)	0.061 (19)
Ke-qi (C_{12})	(0.031,0.127,0.384)	(0.001,0.010,0.125)	0.045 (20)
Positive (C_{13})	(0.102,0.247,0.668)	(0.002,0.022,0.217)	0.080 (12)
Patience (C_{14})	(0.058,0.263,0.599)	(0.001,0.021,0.195)	0.072 (17)
Consideration (D_2)	(0.017,0.061,0.203)		0.094
Considerate (C_{21})	(0.021,0.119,0.415)	(<0.000,0.007,0.084)	0.031 (25)
Help Each Other (C_{22})	(0.019,0.156,0.455)	(0.001,0.010,0.096)	0.036 (21)
Professional Knowledge (C_{23})	(0.023,0.170,0.436)	(<0.000,0.010,0.089)	0.033 (23)
Cooperation (C_{24})	(0.020,0.159,0.467)	(<0.000,0.008,0.078)	0.035 (22)
External Efficiency (C_{25})	(0.025,0.137,0.385)	(<0.000,0.008,0.078)	0.029 (26)
Bureaucracy (C_{26})	(0.017,0.128,0.431)	(<0.000,0.008,0.087)	0.032 (24)
Shared Understanding (D_3)	(0.033,0.120,0.307)		0.153
Competent (C_{31})	(0.049,0.263,0.718)	(0.002,0.032,0.220)	0.085 (10)
Empathy (C_{32})	(0.041,0.257,0.699)	(0.001,0.031,0.215)	0.082 (11)
Consensus (C_{33})	(0.053,0.298,0.733)	(0.002,0.036,0.225)	0.088 (9)
Promise (D_4)	(0.019,0.098,0.319)		0.145
Internal Efficiency (C_{41})	(0.048,0.189,0.667)	(0.001,0.019,0.213)	0.077 (15)
Responsible (C_{42})	(0.062,0.401,0.823)	(0.001,0.039,0.263)	0.101 (5)
Reliable (C_{43})	(0.066,0.292,0.745)	(0.001,0.029,0.238)	0.089 (8)
Working Atmosphere (D_5)	(0.023,0.075,0.217)		0.105
Harmony (C_{51})	(0.121,0.471,0.927)	(0.003,0.035,0.201)	0.080 (13)
Emotional Stability (C_{52})	(0.098,0.489,0.914)	(0.002,0.037,0.198)	0.079 (14)
Relationship (D_6)	(0.015,0.061,0.266)		0.114
Professional Connection (C_{61})	(0.157,0.304,0.985)	(0.002,0.019,0.262)	0.094 (7)
Exchange Thoughts (C_{62})	(0.122,0.549,0.961)	(0.002,0.033,0.256)	0.097 (6)
Accessibility (D_7)	(0.013,0.069,0.208)		0.097
Accessibility (C_{71})	(0.89,0.482,0.865)	(0.001,0.033,0.180)	0.071 (18)
Work Load (C_{72})	(0.187,0.437,0.941)	(0.002,0.030,0.196)	0.076 (16)
Shared Objectives (D_8)	(0.042,0.140,0.381)		0.188
Common Goal (C_{81})	(0.139,0.395,0.897)	(0.006,0.055,0.342)	0.134 (3)
Common Vision (C_{82})	(0.178,0.488,0.936)	(0.006,0.068,0.357)	0.144 (1)
Effectiveness (D_9)	(0.039,0.159,0.331)		0.176
Discussions (C_{91})	(0.104,0.421,0.879)	(0.004,0.067,0.291)	0.121 (4)
Time (C_{92})	(0.153,0.502,0.978)	(0.006,0.080,0.324)	0.137 (2)

The synthetic utilities of each strategy using different λ values are conducted, as shown in Table 4. Figure 3 shows the comparison of alternative strategies to improve ISQ.

5. **Discussion.** In this section, the results of the assessment hierarchy model, weights or relative importance assigned to dimensions and criteria, final ranking of Choquet integral, and practical implication are discussed.

5.1. **Results.** This research has outlined a multiple criteria model for assessing ISQ alternative strategies (see Table 1). Instead of qualitatively assessing the issue of ISQ, this research provides a practical quantitative model and approach for research institutes and enterprises to conduct their own ISQ assessment in a service-based economy. Based on previous studies [47, 53, 60], various important dimensions and criteria were selected. We utilized pairwise comparison in the first level to establish the relative importance of the nine dimension constructions, and then repeated this in the second level for criteria-weighting, which concludes the fuzzy AHP weights. Among the nine dimensions, Shared Objective (D_8) shows the highest weighting, and its criteria, Common Goal (C_{81}) and Common Vision (C_{82}), were ranked numbers 1 and 3, respectively (see Table 2).

Table 3. BNP values of fuzzy performance score with respect to criteria

Dimensions/Criteria	**Global Weight**	$S1$	$S2$	$S3$	$S4$	$S5$
Attitude (D_1)						
Chin-Chieh (C_{11})	0.061	1.213	2.173	4.156	6.693	1.595
Ke-qi (C_{12})	0.045	1.069	2.351	4.286	5.017	1.457
Positive (C_{13})	0.080	1.354	3.549	4.159	4.219	1.198
Patience (C_{14})	0.072	1.233	4.098	3.956	5.194	1.105
Consideration (D_2)						
Considerate (C_{21})	0.031	1.975	1.934	3.617	3.165	1.482
Help Each Other (C_{22})	0.036	2.064	3.582	3.924	4.760	1.546
Professional Knowledge (C_{23})	0.033	1.297	4.267	3.497	3.055	1.684
Cooperation (C_{24})	0.035	1.938	2.565	2.961	3.191	1.815
External Efficiency (C_{25})	0.029	2.517	5.248	2.165	4.092	5.482
Bureaucracy (C_{26})	0.032	1.261	2.839	2.107	3.982	2.749
Shared Understanding (D_3)						
Competent (C_{31})	0.085	1.013	5.281	3.628	4.025	3.158
Empathy (C_{32})	0.082	1.142	3.974	3.503	3.801	1.464
Consensus (C_{33})	0.088	1.574	4.956	2.921	3.475	4.547
Promise (D_4)						
Internal Efficiency (C_{41})	0.077	5.385	5.184	3.581	6.297	6.145
Responsible (C_{42})	0.101	2.081	4.394	4.395	3.854	1.859
Reliable (C_{43})	0.089	1.916	3.195	4.269	3.173	1.687
Working Atmosphere (D_5)						
Harmony (C_{51})	0.080	4.795	2.681	3.121	3.076	1.482
Emotional Stability (C_{52})	0.079	4.871	2.167	2.613	2.195	1.105
Relationship (D_6)						
Personal Connection (C_{61})	0.094	3.276	2.614	2.972	2.514	1.241
Exchange Thoughts (C_{62})	0.097	2.845	1.937	2.195	2.167	1.178
Accessibility (D_7)						
Accessibility (C_{71})	0.071	5.762	3.271	1.922	3.859	3.596
Work Load (C_{72})	0.076	1.084	4.658	1.073	1.135	6.524
Shared Objectives (D_8)						
Common Goal (C_{81})	0.134	1.021	4.352	4.610	3.016	2.145
Common Vision (C_{82})	0.144	1.132	4.197	4.095	3.845	2.068
Effectiveness (D_9)						
Discussions (C_{91})	0.121	4.675	2.548	2.581	3.194	1.548
Time (C_{92})	0.137	2.517	3.816	1.695	1.584	5.864

Table 4. Synthetic utilities with λ values

Str.	λ													
	−1.0	−0.5	0.0	0.5	1.0	3.0	5.0	10.0	20.0	40.0	100.0	150.0	200.0	SAW
$S1$	6.094	4.137	3.876	3.534	3.192	2.817	2.695	2.473	2.119	1.856	1.552	1.204	0.895	3.955
$S2$	6.307	4.216	4.051	3.721	3.425	3.112	3.019	2.881	2.475	2.107	1.817	1.511	1.197	3.826
$S3$	6.851	4.633	4.269	3.972	3.614	3.348	2.978	2.704	2.362	2.009	1.736	1.453	1.084	4.261
$S4$	7.029	4.812	4.532	4.194	3.856	3.527	3.391	3.013	2.891	2.518	2.210	1.972	1.638	4.517
$S5$	5.872	4.129	3.924	3.628	3.308	2.920	2.754	2.538	2.250	1.912	1.695	1.374	0.997	3.614

In the Choquet integral, the properties of substitution between criteria were represented by the λ value, which ranged from -1 to a positive infinite value (∞). The different λ values represent the variations of the synthetic utilities. For each strategy, the synthetic utilities decrease with respect to λ. Situations where $\lambda < 0$ are substitutive effect cases; for example, where $\lambda = -1$ the fuzzy synthetic utilities are outranked: $S4 \succ S3 \succ S2 \succ S1 \succ S5$. In an additive effect case where $\lambda = 0$, the fuzzy synthetic utilities are outranked: $S4 \succ S3 \succ S2 \succ S5 \succ S1$. Finally, when $\lambda > 0$, there are multiplicative effect

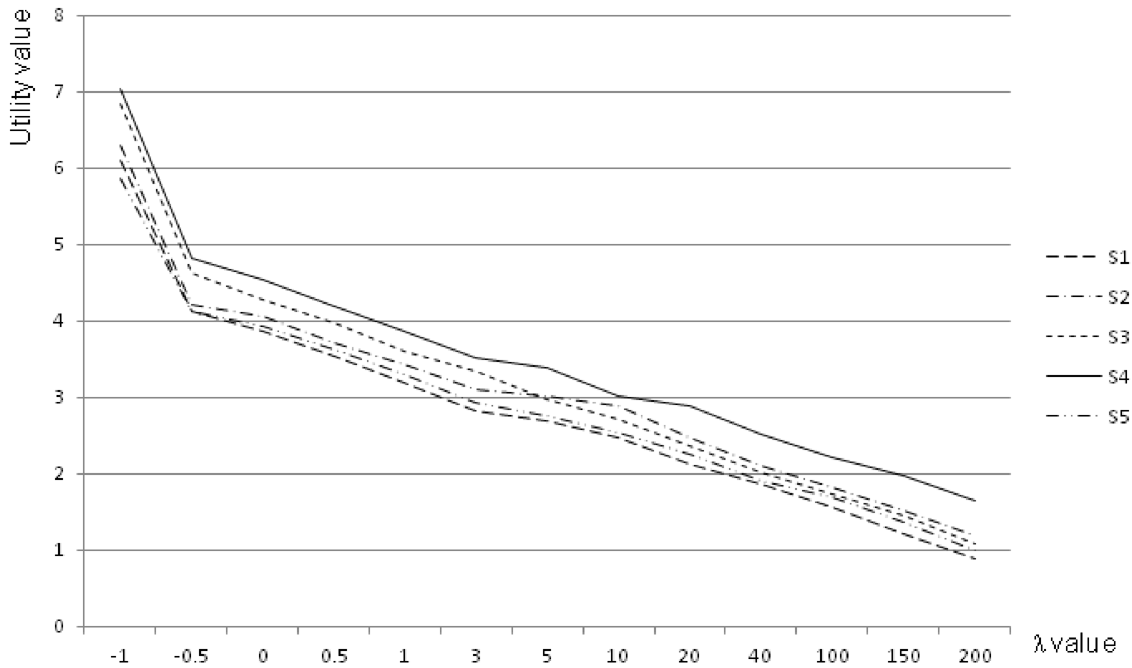

FIGURE 3. Effective values of alternative strategies to improve ISQ

cases, for example where $\lambda = 5$, we have different outranking fuzzy synthetic utilities: $S4 \succ S2 \succ S3 \succ S5 \succ S1$ (see Table 4 and Figure 3).

In addition, if the criteria are independent in a fuzzy environment, obtaining the fuzzy synthetic utilities by the simple additive weight (SAW) method is traditionally undertaken. This method is especially appropriate to employ in independent criteria situations. In this paper, we also compute the fuzzy synthetic utilities by the SAW method, and obtain a different outranking as follows: $S4 \succ S3 \succ S1 \succ S2 \succ S5$.

It is recommended that criteria with high weights and high anticipated performance values should be the focus of any improvement efforts. In the dimension of attitude (D_1), see Table 3 for example, positive (C_{13}) has the highest weight. Among the five strategies, employee rewards and recognition ($S4$) has the highest anticipated performance value. Previous scholars [23, 33] found that rewards and recognition can highly motivate employees to improve their services, which is consistent with the finding in this work and being evaluated high by the employees in the surveyed company.

Evaluating and planning the strategies and criteria in the service operations or in other practical MCDM problems can result in a vast body of data that are often inaccurate or uncertain and come from the subjective judgement by various stakeholders. Moreover, despite the correlation between different criteria, the conventional MCDM methods are based on the assumption of independence among criteria within the evaluating system, with the subsequent decision making activities being performed in an additive process. However, in such complex MCDM problems, the criteria are not independent. Therefore, we demonstrate in this work that the nonadditive fuzzy integral is more appropriate for real-world MCDM problems.

5.2. **Implications.** When substitutive, additive, and multiplicative criteria are considered, the strategy of employee rewards and recognition ($S4$) outperforms other approaches. Service team building should thus be well-planned strategically. The chain of internal services required to offer the end service normally spans multiple functions [3], and organizations must actively work at fostering teamwork across these, and rewarding and recognizing employees in various parts of the service chain is shown to be the best strategy in semiconductor industry under the Taiwanese context in this study.

In addition, the strategies of employee selection and development ($S3$) and job design ($S4$) also have a significantly impact on the improvement of ISQ. Human resources professionals may thus work with operations managers and employees to (1) design the employee selection, reward and recognition systems that create the values and culture of the organization; (2) provide training that is both task- and attitude-enhancing; and (3) conduct a task analysis by examining various jobs and determining the related responsibilities, and discussing with staff on how their position may directly or indirectly affect both internal and external service quality.

6. **Concluding Remarks.** ISQ is key to improving customer satisfaction. Although many authors assert that ISQ creates organizational profit, there has been relatively little systematic study on the linkage between ISQ criteria and carious improvement strategies, since many organizations find the measurement systems that they use have difficulty tracking the benefits associated with the execution of internal service operations. This research thus attempted to develop a way to assess ISQ key criteria and preferred alternatives.

In the real world, most criteria have inter-dependent or interactive characteristics, and so they cannot be evaluated by conventional additive measures. To evaluate human subjective judgements, like ISQ, there must be better methods to distinguish the preferences by applying a fuzzy integral model instead of traditional SAW, in which it is not necessary to assume additivity and independence. This paper also gives examples of ISQ with the hierarchical structure of the Choquet integral model.

This research has established a multi-objective and multi-criteria model of a preferred ISQ improvement strategy to increase effectiveness, conducted a literature survey, interviewed experts and practitioners in related fields regarding internal service operations, and used pairwise comparisons to draw up first-tier priorities. In our assessment hierarchy model, we first examined critical elements suggested by the literature and experts, and analyzed the internal service activities in nine dimensions and 26 criteria. We identified five specific alternative strategies associated with ISQ and linked to the above dimensions and criteria. Finally, we concluded with the results and discussions on the criteria weights and rankings of the alternatives.

This work aimed to help in understanding the critical dimensions and criteria that facilitate successful deployment of a strategy for ISQ improvement, and then evaluate strategy alternatives that lead to enhanced internal customer satisfaction. The contributions of this paper can be summarized as follows: (1) By employing fuzzy logic, the decision making methodology eliminates the assumption of criteria independence; (2) After analyzing the survey results, this work provides insight into the importance and ranking of criteria in ISQ management; (3) Instead of qualitative assessment of the ISQ issue, this work provides a practical quantitative approach for practitioners to conduct ISQ assessments and select operations strategies. As this study only focuses on single strategy performance evaluation, future research may develop hybrid MCDM models to assist decision makers in better optimizing and suggesting an overall improvement strategy.

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