



RESEARCH ARTICLE

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## A FUZZY SERVQUAL-BASED QFD FRAMEWORK FOR ENHANCING CALIBRATION SERVICES IN A REGIONAL METROLOGY LABORATORY

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### ARTICLE INFO

#### Article History

Received: March 18, 2026

Reviewed: April 18, 2026

Accepted: May 15, 2026

Published: September 30, 2026

#### Keywords:

Service Quality,  
Fuzzy SERVQUAL,  
Quality Function Deployment,  
Calibration Services,  
ISO/IEC 17025.

### ABSTRACT

Calibration laboratories operate within technically demanding and highly regulated environments, where service quality is shaped not only by measurement accuracy but also by customers' service experiences. Traditional service quality assessment approaches often struggle to capture the uncertainty and subjectivity inherent in customer and expert evaluations, particularly in technical services. This study proposes an integrated fuzzy SERVQUAL-based Quality Function Deployment (QFD) framework for improving calibration services in a regional metrology laboratory. A perception-based SERVQUAL instrument is employed to identify and weight customer requirements across the five SERVQUAL dimensions using triangular fuzzy numbers. These fuzzy importance weights are subsequently deployed into a fuzzy House of Quality to prioritize technical improvement actions aligned with ISO/IEC 17025 requirements. The proposed framework enables the systematic translation of customer perceptions into prioritized technical requirements while explicitly accounting for uncertainty in both customer feedback and expert judgments. By integrating fuzzy logic with SERVQUAL dimensions and QFD, the study provides a transparent and defensible decision-support tool for calibration laboratories seeking to enhance service quality, support risk-based thinking, and guide continuous improvement initiatives. The framework is designed to be replicable and adaptable to other technical service environments governed by quality management standards.



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### I. INTRODUCTION

Calibration laboratories are critical components of national quality infrastructure, supporting measurement accuracy, industrial safety, regulatory compliance, and technological development. As industries increasingly rely on precise measurements, calibration service providers face growing pressure to deliver accurate, timely, reliable, and customer-centered services while maintaining compliance with ISO/IEC 17025 standards [1]. In this context, service quality has become a strategic concern for calibration laboratories, particularly those operating in developing regions where resources, technical capacity, and service demand often compete. Despite the technical nature of calibration services, customer satisfaction remains a decisive factor influencing repeat patronage, trust, and institutional credibility. Clients evaluate calibration laboratories not only on measurement accuracy but also on responsiveness, reliability, communication clarity, turnaround time, and professionalism of personnel. These service attributes are inherently subjective and are typically expressed using linguistic judgments rather than precise numerical values. Consequently, calibration laboratories require systematic, analytically robust tools that can capture customer perceptions while translating them into actionable technical improvement strategies. Service quality measurement models, particularly SERVQUAL, have been widely employed across service industries to assess customer evaluations of service performance.

SERVQUAL conceptualizes service quality across five dimensions—Tangibles, Reliability, Responsiveness, Assurance, and Empathy—and was originally operationalized using expectation–perception gap scores [2]. However, subsequent research has raised concerns regarding the stability, interpretability, and reliability of expectation measurements, especially in technical and professional service environments where customers may lack sufficient domain knowledge to articulate normative expectations [3]. In response to these limitations, perception-based SERVQUAL approaches have gained increasing acceptance in service quality research. These approaches retain the SERVQUAL dimensional structure while focusing on customers’ actual service experiences rather than expectation–perception gaps. Empirical studies have demonstrated that perception-only models often yield stronger explanatory power, higher reliability, and clearer managerial implications, particularly in complex service systems [4] [5]. For technical services such as calibration, where performance is judged primarily through delivered outcomes and service interactions, perception-based evaluation provides a more realistic and operationally relevant representation of service quality. While SERVQUAL and its variants effectively identify and prioritize customer requirements, they do not inherently provide mechanisms for translating these requirements into technical or operational improvement strategies.

Quality Function Deployment (QFD) addresses this limitation by systematically transforming the “voice of the customer” into prioritized technical requirements through the House of Quality (HOQ). QFD has been successfully applied in manufacturing, healthcare, and service engineering contexts to align customer needs with design and operational decisions [6] [7] [8] [9]. In laboratory environments, QFD has shown promise in linking customer satisfaction drivers with technical performance indicators and quality system requirements [10]. Nevertheless, traditional QFD relies heavily on crisp numerical judgments, assuming that experts can precisely quantify the strength of relationships between customer requirements and technical attributes. In practice, expert assessments are also subjective and uncertain, particularly when dealing with complex systems governed by regulatory standards such as ISO/IEC 17025. Fuzzy logic, originally introduced by Zadeh in 1965, offers a mathematically rigorous framework for modeling such uncertainty by allowing partial membership and linguistic representation of judgments [11]. Integrating fuzzy logic into both SERVQUAL and QFD enhances the robustness, realism, and defensibility of service quality improvement models [12]. Although prior studies have applied fuzzy SERVQUAL or fuzzy QFD independently, limited research has integrated these methods within a unified framework specifically tailored to calibration services and ISO/IEC 17025 requirements. Moreover, existing laboratory-focused studies often emphasize technical compliance without explicitly incorporating customer perceptions into technical prioritization.

This gap highlights the need for a holistic, customer-centered, and uncertainty-aware decision-support framework for calibration service improvement. To address this gap, this study proposes a Fuzzy SERVQUAL-Based Quality Function Deployment (QFD) framework for enhancing calibration services in a regional metrology laboratory. The framework employs perception-based SERVQUAL dimensions to identify and weight customer requirements, converts linguistic customer and expert judgments into triangular fuzzy numbers, and deploys these weights into a fuzzy House of Quality to prioritize technical improvement actions aligned with ISO/IEC 17025 standards. The contributions of this study are fourfold. First, it extends service quality assessment in calibration laboratories by adopting a perception-based SERVQUAL framework supported by fuzzy logic, addressing limitations of expectation-based gap models in technical service contexts. Second, it integrates fuzzy SERVQUAL outputs directly into a fuzzy QFD structure, enabling systematic translation of customer perceptions into prioritized technical requirements. Third, it aligns customer-driven improvement priorities with ISO/IEC 17025 technical and managerial requirements, supporting risk-based thinking and continuous improvement. Finally, it provides a replicable and transparent decision-support model that can be adopted by other calibration laboratories and technical service organizations.

## II. THEORETICAL REFERENCE

### II.1 FUZZY SERVICE QUALITY MEASUREMENT AND DEPLOYMENT OF CUSTOMER REQUIREMENTS

#### Using Quality Function Deployment (QFD)

Service quality has been widely recognized as a crucial factor to determine organizational performance and customer satisfaction across both commercial and technical service industries. The concept of service quality is commonly grounded in the expectation–perception paradigm, which holds that customers evaluate service quality by comparing their expectations prior to service delivery with their perceptions of the actual service received. One of the most influential models operationalizing this concept is the SERVQUAL framework developed by Parasuraman et al., in 1988. The SERVQUAL model measures service quality through five core dimensions: tangibles, reliability, responsiveness, assurance, and empathy [2]. These dimensions collectively represent the key aspects of service interactions that influence customer perceptions. In technical service settings such as calibration laboratories, service quality encompasses more than customer interaction; it also involves operational aspects related to measurement accuracy, technical expertise, and adherence to regulatory standards. These laboratories function within quality management systems guided by frameworks such as ISO/IEC 17025, which emphasize competence, impartiality, traceability, and controlled laboratory environments [1]. Consequently, service quality in metrology laboratories reflects both the technical performance of laboratory processes and the relational aspects of service delivery. While SERVQUAL provides a structured framework for measuring customer perceptions of service quality, its traditional form assumes precise quantitative evaluations from respondents. However, customer perceptions of service performance are often subjective and expressed in linguistic terms such as “agree,” “satisfied,” or “very satisfied.” To address this uncertainty, fuzzy set theory provides an effective approach for modeling imprecise human judgments [3] [12] [13]. Fuzzy logic enables linguistic variables to be represented through triangular fuzzy numbers, allowing researchers to capture the inherent vagueness in human perception and decision-making processes. In addition to measuring customer perceptions, organizations must translate these insights into actionable operational improvements. Quality Function Deployment (QFD) provides a systematic mechanism for transforming customer requirements into technical or operational specifications. Originally developed in Japanese manufacturing industries and popularized by Y.

Akao, QFD uses the House of Quality matrix to establish relationships between customer needs (WHATs) and technical responses (HOWs) [14]. This approach helps organizations prioritize improvement initiatives based on their relative impact on customer satisfaction. Integrating fuzzy SERVQUAL with QFD creates a robust decision-support framework capable of capturing uncertain customer perceptions while systematically translating these insights into prioritized technical actions. In this integrated framework, fuzzy SERVQUAL is used to determine the relative importance of service quality dimensions, while fuzzy QFD evaluates how technical and operational factors contribute to fulfilling customer expectations [12] [15] [16] [17]. The application of this integrated approach is particularly relevant in calibration laboratories, where service quality outcomes depend on both customer-oriented practices and strict technical processes. By combining perception-based measurement with structured operational deployment, the fuzzy SERVQUAL–QFD framework enables laboratories to align customer expectations with the technical requirements necessary to maintain high-quality measurement services.

### III. MATERIALS AND METHODS

The following subsections describe the research design, data collection procedure, fuzzy SERVQUAL analysis, and the application of fuzzy QFD for prioritizing technical service improvements.

#### III.1 RESEARCH DESIGN

This study adopts a quantitative, applied decision-support research design integrating perception-based SERVQUAL, fuzzy logic, and Quality Function Deployment (QFD) to systematically improve calibration services in a regional metrology laboratory. The methodology follows a two-stage analytical framework:

- (1) identification and prioritization of customer requirements using fuzzy SERVQUAL dimensions, and;
- (2) translation of these requirements into prioritized technical actions using fuzzy QFD.

The methodological structure is intentionally designed to support ISO/IEC 17025-aligned service improvement, where customer satisfaction, technical competence, and operational effectiveness must be jointly considered.

#### III.2 PERCEPTION-BASED SERVQUAL FRAMEWORK

##### *III.2.1 Rationale for Using a Perception-Only SERVQUAL Approach*

This study adopts a perception-based SERVQUAL framework, rather than the traditional expectation–perception gap model [2]. Although the SERVQUAL gap approach has been widely used, subsequent research has highlighted several limitations associated with measuring customer expectations, particularly in technical and professional service environments such as calibration laboratories. Prior studies have shown that expectations are often unstable, context-dependent, and difficult for respondents to articulate, especially when customers lack full technical knowledge of the service process [3] [12] [13]. In highly technical services, customers tend to evaluate service quality primarily based on actual service experience, rather than abstract or idealized expectations. Consequently, perception-based SERVQUAL approaches—sometimes referred to as SERVPERF-type or performance-only models—have demonstrated higher reliability, stronger explanatory power, and clearer managerial interpretability in service quality assessment [3] [4] [5] [12]. Moreover, in the context of QFD, the primary requirement is not the computation of service gaps but the relative importance of customer requirements, which can be effectively derived from perception-based evaluations. Accordingly, this study employs SERVQUAL dimensions as structured customer requirement categories, reflecting customers' actual experiences with calibration services. This approach preserves the theoretical foundation of SERVQUAL while enhancing methodological suitability for fuzzy modeling and QFD integration.

##### *III.2.2 SERVQUAL Dimensions and Instrument Design*

The SERVQUAL instrument was structured around the five canonical dimensions:

- **Tangibles** – physical facilities, equipment condition, and visual appearance
- **Reliability** – accuracy, consistency, and dependability of calibration results
- **Responsiveness** – timeliness, speed of service, and willingness to assist
- **Assurance** – technical competence, credibility, and confidence conveyed by staff
- **Empathy** – individualized attention and understanding of customer needs

Survey items were adapted to the calibration service context to ensure relevance and clarity. Respondents evaluated each item based solely on actual service experience, using linguistic rating scales.

#### III.3 FUZZIFICATION OF CUSTOMER RESPONSES

##### *III.3.1 Linguistic Variables and Triangular Fuzzy Numbers (TFNs)*

To capture uncertainty and subjectivity in customer evaluations, linguistic ratings were converted into triangular fuzzy numbers (TFNs). Each linguistic term was represented as:

$$\tilde{A} = (l, m, u)$$

where:

- $l$  = the lower bound (minimum possible value)
- $m$  = the most likely or mean value
- $u$  = the upper bound (maximum possible value)

The linguistic responses in the SERVQUAL questionnaire were transformed into Triangular Fuzzy Numbers (TFNs) as presented in Table 1. The assigned values follow the Saaty's 1–9 importance scale [18], which is widely used in fuzzy multi-criteria decision-making methods to convert qualitative judgments into quantitative representations while capturing uncertainty in human perceptions.

Table 1: SERVQUAL questionnaire scales and its corresponding TFNs.

| Linguistic Term            | TFNs      |
|----------------------------|-----------|
| Strongly disagree          | (1, 1, 3) |
| Disagree                   | (1, 3, 5) |
| Neither agree nor disagree | (3, 5, 7) |
| Agree                      | (5, 7, 9) |
| Strongly agree             | (7, 9, 9) |

Source: [19].

This representation captures uncertainty by allowing partial membership across values rather than forcing precise numeric scores, hence, accommodates vagueness inherent in human judgment, consistent with fuzzy set theory [11].

### III.3.2 Aggregation of Customer Responses

Let  $\tilde{x}_{ijk}$  denote the fuzzy response of respondent  $i$  to item  $j$  under SERVQUAL dimension  $k$ . The aggregated fuzzy score for item  $j$ ,  $\tilde{X}_{jk}$ , is computed as:

$$\tilde{X}_{jk} = \frac{1}{n} \sum_{i=1}^n \tilde{x}_{ijk}$$

where  $n$  is the number of respondents. For each SERVQUAL dimension  $k$ , the aggregated fuzzy score,  $\tilde{S}_k$ , is obtained by averaging its four items:

$$\tilde{S}_k = \frac{1}{4} \sum_{j=1}^4 \tilde{X}_{jk}$$

### III.3.3 Defuzzification Of Servqual Scores

To convert fuzzy SERVQUAL scores into crisp values usable in QFD, the centroid (center-of-area) method was applied:

$$S_k = \frac{l_k + m_k + u_k}{3}$$

Where  $(l_k, m_k, u_k)$  represents the TFN of SERVQUAL dimension  $k$ .

### III.3.4 Normalization of Customer Importance Weights

The relative importance weight of each customer requirement (WHAT) is calculated as:

$$w_k = \frac{S_k}{\sum_{k=1}^5 S_k}$$

Where:

$w_k$  = normalized importance weight of SERVQUAL dimension  $k$

$$\sum w_k = 1$$

These weights serve as the customer importance ratings, which serve as direct inputs to the QFD phase.

## III.4 IDENTIFICATION OF TECHNICAL REQUIREMENTS

The technical requirements (HOWs) were identified through a combination of ISO/IEC 17025:2017 clauses, laboratory's Quality Management System (QMS) and operational documents and expert consultations with calibration personnel and quality managers. These represent key operational factors influencing service quality, and as follows:

- Short Lead Time – Timely release of calibration results to meet customer and operational requirements.
- High Customer Satisfaction – Overall fulfillment of customer expectations through reliable and responsive service.
- Accuracy of Results – Delivery of reliable and traceable calibration measurements.
- Confidentiality of Data – Protection of customer information and calibration records.
- Impartiality of Personnel – Objective and unbiased performance of calibration activities.

- Preventive Maintenance of Equipment – Regular maintenance to ensure consistent equipment performance.
- Accreditation Compliance – Continuous adherence to ISO/IEC 17025 requirements.
- Training and Competency Development – Ongoing development of personnel skills and qualifications.
- Environmental Condition Control (Temperature, RH) – Monitoring and control of conditions affecting measurement validity.

### III.5 FUZZY QUALITY FUNCTION DEPLOYMENT (QFD)

#### III.5.1 Construction of the Fuzzy House of Quality (HOQ)

The fuzzy House of Quality (HOQ) was constructed to map customer requirements (WHATs) to technical requirements (HOWs). Experts assessed the strength of relationships using linguistic terms (e.g., weak, moderate, strong), mapped to TFNs, as presented in table 2.

Table 2: Relationship levels and its corresponding fuzzy Numbers.

| Relationship | TFN       |
|--------------|-----------|
| Weak (W)     | (1, 3, 5) |
| Moderate (M) | (3, 5, 7) |
| Strong (S)   | (5, 7, 9) |

Source: [19].

#### III.5.2 Fuzzy Relationship Matrix

Let  $\hat{r}_{kj}$  represent the fuzzy relationship between customer requirement  $k$  and technical requirement  $j$ . The fuzzy technical importance rating (F-TIR) for technical requirement  $j$  was calculated as:

$$T\hat{I}R_j = \sum_{k=1}^5 w_k \otimes \hat{r}_{kj}$$

Where  $\otimes$  denotes fuzzy multiplication.

#### III.5.3 Defuzzification of Technical Importance Ratings

Each fuzzy technical importance rating was defuzzified using the centroid method to obtain crisp TIR values:

$$TIR_j = \frac{l_j + m_j + u_j}{3}$$

This value represents the overall contribution of a technical requirement to customer satisfaction.

#### III.5.4 Normalization of Technical Importance Ratings

To allow comparison and prioritization, TIRs were normalized as follows:

$$RW_j = \frac{TIR_j}{\sum_{j=1}^m TIR_j}$$

where:

$RW_j$  = relative weight of technical requirement  $j$

$m$  = number of technical requirements

The normalization of the Technical Importance Ratings highlights the relative contribution of each technical requirement within the overall improvement framework. The ranking results reflect how strongly each technical factor influences service quality. It provides a systematic representation of how technical elements interact to drive overall calibration service quality improvement.

## IV. RESULTS AND DISCUSSIONS

This section presents the structure of analytical outputs derived from the fuzzy SERVQUAL and fuzzy QFD framework. Results are expressed in terms of fuzzy importance weights, technical importance ratings, and priority rankings. The interpretation focuses on relative importance rather than service quality gaps, consistent with the perception-based framework adopted in this study.

### IV.1 PROFILE OF RESPONDENTS

The study gathered responses from 42 customers of the Metrology Laboratory. The demographic distribution indicates that the majority of respondents were male (64%) and within the 25–35 age bracket (38%). Most participants had 5–10 years of work experience and were primarily assigned to marketing and sales functions (24%). This profile suggests that the respondents possess relevant professional exposure and organizational involvement, enabling them to provide informed evaluations of the laboratory's calibration services.

## IV.2 FUZZY SERVQUAL RESULTS

The fuzzy SERVQUAL analysis produced aggregated Triangular Fuzzy Numbers (TFNs), which were subsequently defuzzified to obtain crisp importance values for each service quality dimension. The computed crisp values and normalized relative importance scores provide a clear prioritization of customer-perceived service quality dimensions in the Metrology Laboratory. As can be seen in table 3, Empathy obtained the highest crisp value (7.9722) with a relative importance of 0.20098 among the five dimensions. This finding suggests that customers highly value individualized attention, clear communication, and the laboratory's ability to understand and address specific calibration requirements. In the context of metrology services, where technical procedures can be complex and compliance-driven, clients appear to appreciate service providers who demonstrate flexibility, accessibility, and customer-oriented engagement. This result implies that strengthening consultation processes and improving communication channels may significantly enhance overall service perception.

Table 3: Customer Importance Ratings Computation.

| Dimension      | Question No. | Fuzzy Numbers |          |          | Crisp Values ( | Customer Importance Weights |
|----------------|--------------|---------------|----------|----------|----------------|-----------------------------|
|                |              | Lower         | Middle   | Upper    |                |                             |
| Tangible       | 1            | 6.619048      | 8.571429 | 8.761905 | 7.928571429    | 0.19987995                  |
|                | 2            | 6.47619       | 8.428571 | 8.809524 |                |                             |
|                | 3            | 6.52381       | 8.47619  | 8.809524 |                |                             |
|                | 4            | 6.47619       | 8.428571 | 8.761905 |                |                             |
|                | AVERAGE      | 6.52381       | 8.47619  | 8.785714 |                |                             |
| Reliability    | 5            | 6.47619       | 8.428571 | 8.761905 | 7.924603175    | 0.19977991                  |
|                | 6            | 6.52381       | 8.47619  | 8.809524 |                |                             |
|                | 7            | 6.52381       | 8.47619  | 8.809524 |                |                             |
|                | 8            | 6.52381       | 8.47619  | 8.809524 |                |                             |
|                | AVERAGE      | 6.511905      | 8.464286 | 8.797619 |                |                             |
| Responsiveness | 9            | 6.52381       | 8.47619  | 8.761905 | 7.876984127    | 0.19857943                  |
|                | 10           | 6.428571      | 8.380952 | 8.714286 |                |                             |
|                | 11           | 6.47619       | 8.47619  | 8.809524 |                |                             |
|                | 12           | 6.380952      | 8.333333 | 8.761905 |                |                             |
|                | AVERAGE      | 6.452381      | 8.416667 | 8.761905 |                |                             |
| Assurance      | 13           | 6.619048      | 8.571429 | 8.809524 | 7.964285714    | 0.20078031                  |
|                | 14           | 6.428571      | 8.380952 | 8.761905 |                |                             |
|                | 15           | 6.571429      | 8.52381  | 8.809524 |                |                             |
|                | 16           | 6.666667      | 8.619048 | 8.809524 |                |                             |
|                | AVERAGE      | 6.571429      | 8.52381  | 8.797619 |                |                             |
| Empathy        | 17           | 6.571429      | 8.571429 | 8.857143 | 7.972222222    | 0.20098039                  |
|                | 18           | 6.52381       | 8.47619  | 8.809524 |                |                             |
|                | 19           | 6.52381       | 8.47619  | 8.761905 |                |                             |
|                | 20           | 6.619048      | 8.619048 | 8.857143 |                |                             |
|                | AVERAGE      | 6.559524      | 8.535714 | 8.821429 |                |                             |

Source: Authors (2026)

Assurance ranked second (7.9643; relative importance = 0.20078), indicating that customers place substantial importance on staff competence, credibility, and professionalism. Calibration services inherently require a high level of technical expertise, accuracy, and adherence to ISO/IEC 17025 standards. The high ranking of assurance reflects the critical role of trust and confidence in measurement services, where even minor inaccuracies may have significant operational implications for clients. Continuous training, competency validation, and strict compliance with accreditation requirements therefore remain central to sustaining customer confidence. The Tangible (7.9286; 0.19988) and Reliability (7.9246; 0.19978) dimensions followed closely in ranking. The tangible dimension reflects the importance of well-maintained equipment, organized facilities, and professional documentation, while reliability emphasizes consistent and accurate service delivery. The near-equal importance of these two dimensions suggests that customers expect both physical evidence of technical capability and dependable performance outcomes. For a metrology laboratory, this underscores the necessity of preventive maintenance, proper environmental control, and systematic quality assurance procedures. Responsiveness recorded the lowest crisp value (7.8769; 0.19858), although the difference compared to other dimensions is minimal. This indicates that while prompt service and timely communication are important, customers may prioritize competence, accuracy, and personalized attention slightly more than speed alone.

In technical services such as calibration, clients may accept reasonable processing times provided that results are accurate and professionally delivered. The narrow range of relative importance values (0.1986 to 0.2010) suggests that customers view service quality as a multidimensional construct in which all five SERVQUAL dimensions contribute meaningfully to overall satisfaction. The fuzzy modeling approach effectively captured the inherent uncertainty in linguistic survey responses while producing a quantitative ranking suitable for decision-making. These normalized weights were subsequently utilized in the fuzzy QFD phase to translate customer-driven priorities into technical improvement strategies within the House of Quality framework.

#### IV.3 FUZZY QFD RESULTS

The fuzzy QFD analysis translated the normalized customer importance ratings derived from the fuzzy SERVQUAL phase into prioritized technical requirements through the fuzzy House of Quality. The defuzzified Technical Importance Ratings (TIRs) and their normalized weights provide a clear hierarchy of improvement priorities for the metrology laboratory. Among the nine technical requirements evaluated (see Table 4), Accreditation of Laboratory and Training of Personnel emerged as the highest-priority improvement areas, each obtaining the highest normalized weight (0.1345). The crisp TIR values (8.2763 and 8.2745, respectively) indicate that these factors exert the strongest overall influence on customer satisfaction across all SERVQUAL dimensions. This result suggests that customers' perceptions—particularly under Empathy and Assurance, which were ranked highest in the SERVQUAL phase—are strongly driven by visible technical competence, formal accreditation status, and staff capability. In the context of calibration services governed by ISO/IEC 17025, accreditation and personnel competency serve as tangible indicators of credibility and measurement reliability. Therefore, investments in sustaining accreditation compliance and enhancing staff technical training are expected to yield the most significant improvements in perceived service quality. The second-tier priorities include High Customer Satisfaction (0.1246) and Preventive Maintenance of Equipment (0.1182).

Although "High Customer Satisfaction" appears conceptually broad, its strong linkage across all SERVQUAL dimensions indicates that systematic customer feedback mechanisms and service monitoring processes play a critical integrative role. Meanwhile, preventive maintenance directly supports Reliability and Tangibles by ensuring equipment accuracy, minimizing downtime, and sustaining measurement traceability. Given that calibration services fundamentally depend on equipment performance, this finding reinforces the operational necessity of structured maintenance programs aligned with quality management requirements. Moderate priorities were observed for Impartiality of Officers (0.1101) and Short Lead Time (0.1008). The importance of impartiality reflects the regulatory emphasis on objectivity and ethical conduct in laboratory operations. Customers appear sensitive to fairness and transparency in calibration reporting, which aligns strongly with Assurance and Reliability dimensions. Short lead time, while important, received comparatively lower weighting than technical competence-related factors. This suggests that clients of calibration laboratories may tolerate reasonable turnaround times provided that results remain accurate, traceable, and professionally delivered. In highly technical services, precision and compliance appear to outweigh speed alone. Lower-ranked technical requirements include Accuracy of Result (0.0991), Maintaining Environmental Conditions (0.0912), and Confidentiality of Result (0.0870).

Although these factors received relatively lower normalized weights, their scores remain substantial and should not be interpreted as unimportant. Rather, the narrow distribution of weights across all nine technical requirements indicates that customers perceive service quality as a multidimensional construct in which multiple technical elements contribute simultaneously. The slightly lower ranking of environmental control and confidentiality may reflect customers' limited visibility into these internal processes, even though they remain critical for ISO/IEC 17025 compliance and measurement validity. The fuzzy QFD results demonstrate that customer-driven service improvement in calibration laboratories is strongly anchored in institutional credibility and technical competence. Accreditation compliance and continuous personnel development form the core strategic priorities, supported by structured maintenance systems and customer-oriented management practices. The relatively balanced distribution of normalized weights (ranging from 0.0870 to 0.1345) further indicates that improvement efforts should remain holistic rather than narrowly focused on a single operational factor. The integration of fuzzy SERVQUAL with fuzzy QFD successfully captured uncertainty in both customer perceptions and expert judgments while producing a defensible, quantitative prioritization of technical actions. By explicitly linking customer expectations to ISO-aligned operational factors, the framework provides laboratory managers with a transparent basis for resource allocation, risk-based thinking, and continuous improvement planning.

Table 4: Fuzzy Relationship Matrix and Technical Importance Ratings in the House of Quality.

| Dimension                            | CIR        | Short Lead Time                  |        |        | High Customer Satisfaction      |        |        | Accuracy of Result                         |        |        |
|--------------------------------------|------------|----------------------------------|--------|--------|---------------------------------|--------|--------|--------------------------------------------|--------|--------|
|                                      |            | lower                            | middle | upper  | lower                           | middle | upper  | lower                                      | middle | upper  |
| <b>Tangible</b>                      | 0.1999     | 0.5996                           | 0.9994 | 1.3992 | 0.5996                          | 0.9994 | 1.3992 | 0.9994                                     | 1.3992 | 1.7989 |
| <b>Reliability</b>                   | 0.1998     | 0.9989                           | 1.3985 | 1.7980 | 1.2444                          | 1.7421 | 2.2399 | 1.2444                                     | 1.7421 | 2.2399 |
| <b>Responsiveness</b>                | 0.1986     | 0.9929                           | 1.3901 | 1.7872 | 1.2569                          | 1.7597 | 2.2625 | 0.1986                                     | 0.5957 | 0.9929 |
| <b>Assurance</b>                     | 0.2008     | 0.6023                           | 1.0039 | 1.4055 | 1.0039                          | 1.4055 | 1.8070 | 1.2556                                     | 1.7578 | 2.2601 |
| <b>Empathy</b>                       | 0.2010     | 1.0049                           | 1.4069 | 1.8088 | 1.2544                          | 1.7561 | 2.2578 | 0.2010                                     | 0.6029 | 1.0049 |
| Technical Importance Ratings (Fuzzy) |            | 4.1987                           | 6.1987 | 8.1987 | 5.3592                          | 7.6628 | 9.9664 | 3.8989                                     | 6.0978 | 8.2967 |
| Crisp Values                         |            | 6.1987                           |        |        | 7.6628                          |        |        | 6.0978                                     |        |        |
| <b>Normalized Weight</b>             |            | <b>0.1008</b>                    |        |        | <b>0.1246</b>                   |        |        | <b>0.0991</b>                              |        |        |
| <b>Dimension</b>                     | <b>CIR</b> | <b>Confidentiality of Result</b> |        |        | <b>Impartiality of Officers</b> |        |        | <b>Preventive Maintenance of Equipment</b> |        |        |

|                                      |        | lower                       | middle | lower   | middle                | upper  | upper   | lower                                | middle | upper  |
|--------------------------------------|--------|-----------------------------|--------|---------|-----------------------|--------|---------|--------------------------------------|--------|--------|
| <b>Tangible</b>                      | 0.1999 | 0.1999                      | 0.5996 | 1.2588  | 1.7623                | 2.2658 | 0.9994  | 0.2518                               | 0.7553 | 1.2588 |
| <b>Reliability</b>                   | 0.1998 | 0.5993                      | 0.9989 | 1.2444  | 1.7421                | 2.2399 | 1.3985  | 0.7466                               | 1.2444 | 1.7421 |
| <b>Responsiveness</b>                | 0.1986 | 0.5957                      | 0.9929 | 0.7542  | 1.2569                | 1.7597 | 1.3901  | 1.2569                               | 1.7597 | 2.2625 |
| <b>Assurance</b>                     | 0.2008 | 1.2556                      | 1.7578 | 0.7534  | 1.2556                | 1.7578 | 2.2601  | 1.2556                               | 1.7578 | 2.2601 |
| <b>Empathy</b>                       | 0.2010 | 0.6029                      | 1.0049 | 0.7526  | 1.2544                | 1.7561 | 1.4069  | 0.7526                               | 1.2544 | 1.7561 |
| Technical Importance Ratings (Fuzzy) |        | 3.2535                      | 5.3542 | 7.4549  | 4.7633                | 7.2713 | 9.7793  | 4.2635                               | 6.7715 | 9.2795 |
| Crisp Values                         |        | 5.3542                      |        |         | 6.7715                |        |         | 7.271                                |        |        |
| <b>Normalized Weight</b>             |        | <b>0.0870</b>               |        |         | <b>0.1101</b>         |        |         | <b>0.118</b>                         |        |        |
| Dimension                            | CIR    | Accreditation of Laboratory |        |         | Training of Personnel |        |         | Maintaining Environmental Conditions |        |        |
|                                      |        | lower                       | middle | upper   | lower                 | middle | upper   | lower                                | middle | upper  |
| <b>Tangible</b>                      | 0.1999 | 1.2588                      | 1.7623 | 2.2658  | 0.7553                | 1.2588 | 1.7623  | 1.2588                               | 1.7623 | 2.2658 |
| <b>Reliability</b>                   | 0.1998 | 1.2444                      | 1.7421 | 2.2399  | 1.2444                | 1.7421 | 2.2399  | 1.2444                               | 1.7421 | 2.2399 |
| <b>Responsiveness</b>                | 0.1986 | 1.2569                      | 1.7597 | 2.2625  | 1.2569                | 1.7597 | 2.2625  | 0.2514                               | 0.7542 | 1.2569 |
| <b>Assurance</b>                     | 0.2008 | 1.2556                      | 1.7578 | 2.2601  | 1.2556                | 1.7578 | 2.2601  | 0.2008                               | 0.6023 | 1.0039 |
| <b>Empathy</b>                       | 0.2010 | 0.7526                      | 1.2544 | 1.7561  | 1.2544                | 1.7561 | 2.2578  | 0.2509                               | 0.7526 | 1.2544 |
| Technical Importance Ratings (Fuzzy) |        | 5.7683                      | 8.2763 | 10.7843 | 5.7665                | 8.2745 | 10.7825 | 3.2062                               | 5.6135 | 8.0208 |
| Crisp Values                         |        | 8.2763                      |        |         | 8.2745                |        |         | 5.6135                               |        |        |
| <b>Normalized Weights</b>            |        | <b>0.1345</b>               |        |         | <b>0.1345</b>         |        |         | <b>0.0912</b>                        |        |        |

Source: Authors (2026).

## V. CONCLUSIONS

This study proposes a fuzzy SERVQUAL-based QFD framework for enhancing calibration services in a regional metrology laboratory. By adopting a perception-based SERVQUAL approach and integrating fuzzy logic with QFD, the framework addresses limitations of traditional crisp models and provides a transparent, customer-centered decision-support tool aligned with ISO/IEC 17025 requirements. The framework enables calibration laboratories to systematically prioritize technical improvement actions based on customer perceptions while accounting for uncertainty inherent in service evaluation. Findings indicate that customer perceptions of calibration service quality are strongly influenced by institutional credibility and personnel competence. Fuzzy QFD analysis identified accreditation compliance and personnel training as the most influential technical requirements affecting overall service quality. These results highlight the importance of maintaining rigorous accreditation standards, strengthening personnel competency programs, and implementing structured operational management practices in calibration laboratories. Future research may extend the framework through multi-laboratory comparisons, longitudinal analysis, or integration with additional multi-criteria decision-making techniques.

## VI. AUTHOR'S CONTRIBUTION

**Conceptualization:** Angelie S. Abao, Ronald A. Pangan and Consorcio S. Namoco, Jr.

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## VII. ACKNOWLEDGMENTS

The authors would like to thank University of Science and Technology of Southern Philippines and Department of Science and Technology – Region X for the assistance and support in conducting the study.

## VIII. REFERENCES

- [1] International Organization for Standardization, ISO/IEC 17025:2017 – General Requirements for the Competence of Testing and Calibration Laboratories. Geneva, Switzerland: ISO, 2017.
- [2] A. Parasuraman, V. A. Zeithaml, and L. L. Berry, "SERVQUAL: A multiple-item scale for measuring consumer perceptions of service quality," *Journal of Retailing*, vol. 64, no. 1, pp. 12–40, 1988.

- [3] R. L. Taylor and J. J. Cronin Jr., “Measuring service quality: A reexamination and extension,” *Journal of Marketing*, vol. 56, no. 3, pp. 55–68, 1992.
- [4] A. I. Maghsoodi, A. Saghaei, and A. Hafezalkotob, “Service quality measurement model integrating an extended SERVQUAL model and a hybrid decision support system,” *European Research on Management and Business Economics*, vol. 25, no. 3, pp. 151–164, 2019.
- [5] S. Singh and S. S. Jasial, “Moderating effect of perceived trust on service quality–student satisfaction relationship: Evidence from Indian higher management education institutions,” *Journal of Marketing for Higher Education*, vol. 31, no. 2, pp. 280–304, 2021.
- [6] C. P. Govers, “What and how about quality function deployment (QFD),” *International Journal of Production Economics*, vol. 46–47, pp. 575–585, 1996.
- [7] H. Liu, “Fuzzy quality function deployment: A review,” *Expert Systems with Applications*, vol. 36, no. 4, pp. 8991–9000, 2009.
- [8] I. J. Cho, Y. J. Kim, and C. J. Kwak, “Application of SERVQUAL and fuzzy quality function deployment to service improvement in service centres of electronics companies,” *Total Quality Management & Business Excellence*, vol. 27, no. 3–4, pp. 368–381, 2016.
- [9] M. A. Beheshtinia and M. Farzaneh Azad, “A fuzzy QFD approach using SERVQUAL and Kano models under budget constraint for hotel services,” *Total Quality Management & Business Excellence*, vol. 30, no. 7–8, pp. 808–830, 2019.
- [10] F. J. Silva and J. M. Mendes, “Service quality assessment in laboratory services: A SERVQUAL approach,” *International Journal of Quality & Reliability Management*, vol. 34, no. 7, pp. 1040–1055, 2017.
- [11] L. A. Zadeh, “Fuzzy sets,” *Information and Control*, vol. 8, no. 3, pp. 338–353, 1965.
- [12] M. R. Aneesh, J. Dileepal, M. A. Abraham, “An Integrated Fuzzy Weighted SERVQUAL - QFD Approach for Service Quality Improvement”, *International Journal of Engineering Research*, Volume No.3, Issue No.12, pp : 774-776 , (2014)
- [13] S. Behdioğlu, E. Acar, & H. A. Burhan, “Evaluating service quality by fuzzy SERVQUAL: A case study in a physiotherapy and rehabilitation hospital,” *Total Quality Management & Business Excellence*, vol. 30, no. 3–4, pp. 301–319, 2019.
- [14] Y. Akao, *Quality Function Deployment: Integrating Customer Requirements into Product Design*. Cambridge, MA: Productivity Press, 1990.
- [15] W. Ho, P. K. Dey, and M. Lockström, “Strategic sourcing: A combined QFD and AHP approach in manufacturing,” *Supply Chain Management: An International Journal*, vol. 16, no. 6, pp. 446–461, 2011.
- [16] S. R. Surtiningtyas and S. T. Saputra, “Employing fuzzy-weighted SERVQUAL, refined Kano, IPA, and QFD to assess service quality in vocational higher education,” *Jurnal Kependidikan*, vol. 9, no. 1, pp. 272–286, 2023.
- [17] J. B. G. Junior, H. R. Hékis, J. A. F. Costa “Application of the QFD-fuzzy-SERVQUAL methodology as a quality planning tool at the surgical centre of a public teaching hospital,” *BMC Medical Informatics and Decision Making*, vol. 22, no. 1, pp. 1–12, 2022.
- [18] Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill.
- [19] R. Nagpal, “Rank university websites using fuzzy AHP and fuzzy TOPSIS approach on usability,” *International Journal of Information Engineering and Electronic Business*, vol. 7, no. 1, pp. 29–36, 2015.