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Evaluating Service Quality in Infant and Childcare Institutions: A Decision-Making Framework Using Interval Type-2 Fuzzy MCDM

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ABSTRACT

The study presents a comprehensive framework for evaluating service quality in public childcare institutions by employing an integrated Interval Type-2 Fuzzy Multi-Criteria Decision-Making (IT2F-MCDM) approach. This framework is designed to systematically address uncertainty inherent in human judgement by converting expert linguistic evaluations into Interval Type-2 Fuzzy Numbers (IT2FNs). Decision alternatives, represented by childcare institutions, and evaluation criteria, including safety, staff qualifications, emotional support, and infrastructural conditions, are identified through a combination of expert consultation and an extensive review of existing literature. Expert opinions are aggregated using the Fuzzy Weighted Averaging (FWA) operator, following the normalisation of criterion weights, which are likewise expressed in IT2FN form. The assessment process produces an overall fuzzy performance value for each childcare institution, derived from expert evaluations across the specified criteria. These fuzzy performance values are subsequently defuzzified into crisp scores using the centre-of-gravity technique, enabling more transparent interpretation and practical applicability of the results. Based on the resulting crisp values, childcare institutions are ranked according to their relative levels of service quality. To examine the robustness and stability of the proposed framework, a sensitivity analysis is performed by systematically varying the weights assigned to the evaluation criteria. This analysis provides insight into how changes in criterion importance influence institutional rankings. Furthermore, the reliability of the IT2F-MCDM results is verified through comparative analysis with established decision-making techniques, including Fuzzy TOPSIS and Fuzzy VIKOR. The consistency observed across these methods confirms the validity of the proposed approach. Overall, the framework functions as a dependable decision-support tool capable of assisting childcare administrators and policymakers in making evidence-based decisions aimed at enhancing service quality.

1. Introduction

Early childhood represents a critical developmental stage during which cognitive, social, and emotional capacities are shaped in ways that influence long-term developmental trajectories [8].

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Within this context, the standard of care delivered by infant and childcare institutions is of central importance for both families and the wider community [23]. The demand for public childcare services has risen markedly in recent decades, driven by urban expansion and increasing parental participation in the workforce across many societies [29]. These institutions extend well beyond custodial supervision, as they are responsible for fostering secure environments that support emotional nurturing during highly sensitive phases of child development. Nevertheless, public childcare institutions encounter substantial challenges in both maintaining and systematically evaluating service quality [26].

Comprehensive assessment of service quality in public childcare settings requires consideration of multiple interrelated dimensions, including physical infrastructure, hygiene practices, staff competence, emotional care provision, and institutional safety measures. The evaluation process is further complicated by the predominantly qualitative nature of these dimensions, which are difficult to observe and measure directly [27]. Conventional assessment approaches, such as survey instruments and checklist-based inspections, are often insufficient for capturing the nuanced and subjective aspects of perceived service quality [21]. In situations characterized by the presence of multiple concurrent factors, MCDM techniques offer a structured analytical framework that is more suitable for complex evaluative contexts [20]. Such methods have been widely adopted across service-oriented domains, including healthcare, education, and public services, due to their capacity to incorporate both quantitative indicators and qualitative judgements [22].

Despite their advantages, service quality assessments remain challenging because expert judgements are frequently expressed through imprecise linguistic terms, such as highly effective, moderate, or needs improvement. These subjective expressions cannot be adequately represented using conventional numerical scales or Type-1 fuzzy logic-based MCDM approaches [28]. Although Type-1 fuzzy sets allow for limited representation of uncertainty through fixed membership functions, they lack the flexibility required to fully model the variability inherent in human perception across different evaluators and contexts [24].

In response to these limitations, the present study proposes an advanced decision-making framework based on IT2F-MCDM for evaluating service quality in infant and childcare institutions. Expert linguistic assessments are systematically transformed into IT2FNs, enabling a more accurate representation of uncertainty associated with subjective evaluations. A multidisciplinary expert panel, informed by an extensive review of relevant literature, identifies key assessment criteria, including safety standards, emotional care provision, staff qualifications, and infrastructure quality. Expert judgements are aggregated using the FWA operator, with the relative importance of experts likewise modelled through IT2FNs. The resulting overall performance values for each institution are subsequently defuzzified using the centre-of-gravity method to obtain final ranking outcomes. To examine the stability of the proposed framework, a sensitivity analysis is undertaken by varying the weights assigned to evaluation criteria. Furthermore, the validity of the framework is assessed through comparative analysis with results generated using the Fuzzy TOPSIS and Fuzzy VIKOR methods. Collectively, this approach strengthens the reliability of service quality evaluation and offers a robust decision-support tool for administrators seeking to enhance childcare service provision.

2. Related Works

In recent years, the evaluation of service quality in public childcare institutions has attracted considerable attention from researchers. Various decision-making models and quality assessment frameworks have been developed to address the inherently subjective and multifaceted nature of this problem domain. Methodologies that fail to incorporate expert uncertainty often yield derivative or inaccurate evaluations, undermining the reliability of their findings. Fuzzy logic-based MCDM approaches, including Type-1 fuzzy sets and techniques such as Fuzzy AHP, Fuzzy TOPSIS, and Fuzzy VIKOR, have been widely applied to mitigate these issues. The emergence of IT2FS provides a more advanced mechanism, allowing experts to express uncertain and hesitant judgements with greater precision and depth. Evidence presented in Table 1 highlights the necessity of an IT2F-MCDM framework, as existing studies demonstrate methodological limitations, and the summary outlines the key approaches and benefits of previous research.

Table 1
Problem Formulation

Author(s)	Techniques Involved	Advantages	Disadvantages
Pragathi et al. [25]	Adaptive Decision-Making with Cognitive Computation	Enables dynamic behaviour analysis; high adaptability	Context-specific; not easily generalizable
Khambhati et al. [16]	Fuzzy AHP	Effectively separates urban and rural priorities; structured method	It depends heavily on subjective expert input
Gazi et al. [12]	Pentagonal Fuzzy DEMATEL	Captures complex interdependencies; suited for social metrics	Difficult interpretation and computationally intensive
Chaki et al. [7]	Intuitionistic Fuzzy Decision Framework	Models both uncertainty and hesitancy well	Sensitive to parameter settings; not intuitive
Yang et al. [36]	MCDM for Smart Healthcare Strategy	Supports long-term healthcare planning; strategic decision aid	Requires extensive and accurate data; less suitable for micro-level

Pragathi et al. [25] introduced an adaptive decision-making system employing reactive cognitive computation and real-time behavioural adaptation, offering valuable insights for improving service responsiveness in childcare institutions. The system analyses behavioural patterns in real time using reactive cognitive computation, allowing responses to changing individual characteristics. Decision quality is maintained through continuous behavioural updates, producing tailored solutions. However, the system's operational scope is limited, constraining its applicability across different populations and service domains. Khambhati et al. [16] developed a methodology for assessing public healthcare service quality in urban and rural areas using Fuzzy AHP. This approach evaluates healthcare services separately, considering features aligned with the specific needs of rural and urban communities. Fuzzy AHP provides a structured framework enabling experts to generate systematic decisions based on multiple criteria. Nonetheless, expert involvement can introduce judgmental biases, and evaluations remain affected by high levels of uncertainty or ambiguity.

Gazi et al. [12] applied the Pentagonal Fuzzy DEMATEL methodology to identify key factors influencing women's empowerment in the sports sector. Although their study pertains to a different domain, the methodological contribution is directly relevant: fuzzy DEMATEL allows the modelling of interdependent service quality factors and the analysis of causal relationships among criteria. In childcare institutions, this approach can support the identification and prioritisation of critical service components, such as caregiver competence, emotional support, and infrastructure. However, the authors note that the method's complexity during defuzzification presents interpretive challenges, potentially limiting practical use by non-expert stakeholders such as administrators or policymakers. Yang et al. [35] demonstrated the use of MCDM techniques in creating strategic evaluation models for long-term care, providing a methodological basis applicable to childcare service quality assessment. This approach enables decision-makers to develop strategic models aligned with national healthcare objectives and to inform future regulations. Nevertheless, the model requires extensive data inputs and struggles to capture distinct service levels, which may limit its applicability for immediate operational decisions.

While these evaluation methods offer specific advantages, they also exhibit limitations, highlighting the need for approaches capable of accurately assessing service quality within complex childcare systems. Decision-making processes are influenced by uncertainties in expert judgements, which may introduce biases. Techniques such as Fuzzy AHP and DEMATEL face practical challenges due to interpretive complexity and high computational demands. Systematic methods, although highly flexible, are often constrained by deployment limitations across diverse systems. To overcome these challenges, the proposed IT2F-MCDM framework provides a comprehensive solution for evaluating service quality in complex and uncertain childcare environments. By utilising IT2FNs, the framework enables experts to effectively manage uncertainty, producing reliable service quality assessments across multiple childcare settings. This framework offers public childcare administrators and policymakers a robust decision-support tool that reduces bias, simplifies complex planning processes, and adapts to high levels of uncertainty, thereby enhancing the overall quality and consistency of service evaluation.

3. IT2F-MCDM Decision-Making System Architecture

The IT2F-MCDM framework for evaluating service quality in public childcare institutions begins with the identification of decision alternatives, represented by childcare institutions, and the selection of evaluation criteria through a combination of expert consultations and literature review. The criteria encompass safety, staff qualifications, emotional support, and infrastructure. Experts express their judgements using predefined linguistic terms, which are subsequently transformed into IT2FNs to accurately capture uncertainty and imprecision in the assessments. Fuzzy evaluations are aggregated using the FWA operator, which accounts for both the credibility and relative importance of each expert. Criterion weights and evaluation values are represented as IT2FNs, and normalisation procedures ensure consistent and systematic assessments across all criteria.

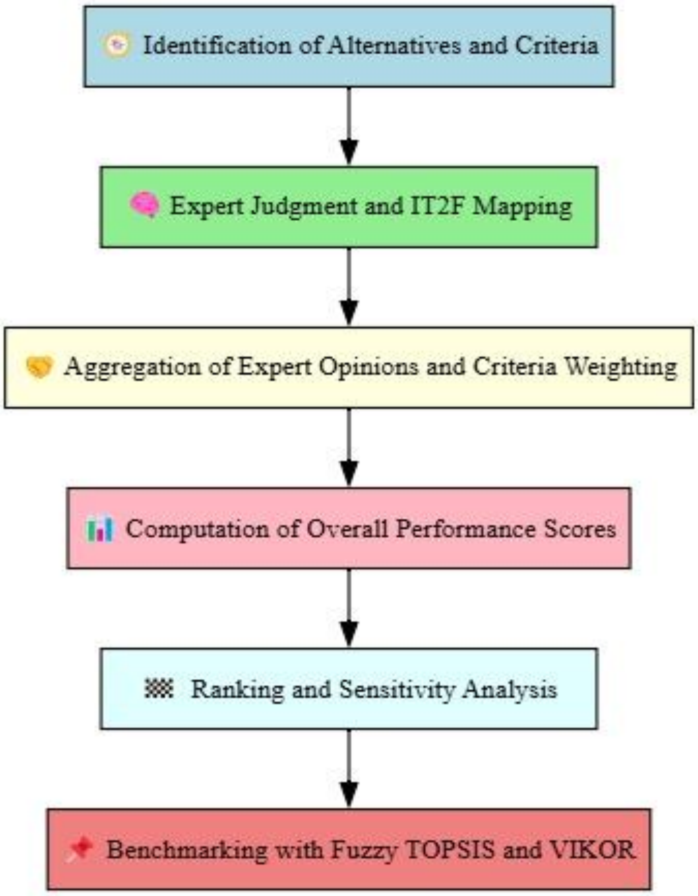

Fig.1: Proposed Flow Diagram

The overall performance of each institution is calculated by summing the weighted fuzzy evaluations, generating fuzzy performance scores that are then defuzzified into crisp values using the centre-of-gravity method. These crisp scores facilitate the ranking of alternatives from most advantageous to least desirable. To verify the robustness of the rankings, a sensitivity analysis is conducted by varying the criterion weights, ensuring the stability of the results under different scenarios. Furthermore, benchmarking the proposed IT2F-MCDM framework against Fuzzy TOPSIS and Fuzzy VIKOR confirms its effectiveness in managing expert uncertainty and delivering reliable service quality evaluations. The structural design of the framework is illustrated in Figure 1.

3.1 Identification of Evaluation Criteria and Alternatives

The identification of decision alternatives and corresponding evaluation criteria constitutes the initial step in assessing service quality in infant and childcare institutions [13]. In this process, individual public childcare institutions are treated as alternatives, while the criteria represent key dimensions of service quality used for evaluation [16]. Selection of these criteria is informed by a combination of expert consultation and systematic review of relevant literature, ensuring a comprehensive basis for assessment. Existing institutional standards emphasise elements such as physical security, staff qualifications, emotional support, hygiene, and adequacy of facilities [32]. These established criteria function as operational measures for evaluating and comparing institutional performance. A formal representation of this problem would include two main elements: the set of alternatives $A = \{A_1, A_2, \dots, A_M\}$ as well as the set of evaluation criteria $C = \{C_1, C_2, \dots, C_N\}$. In this context, m denotes the number of childcare institutions, while n represents the number of evaluation dimensions. Organizing the assessment framework in this manner is essential for establishing a coherent link between the components of multi-criteria decision-making, thereby facilitating subsequent fuzzy-based evaluation and the ranking of available alternatives [14].

3.2 Expert Judgment and Interval Type-2 Fuzzy Mapping

The evaluation phase is grounded in expert assessments of childcare institution performance based on the predefined criteria. In practice, expert judgements are typically expressed using linguistic terms, ranging from "Very Poor" to "Poor," "Fair," "Good," and "Very Good." These descriptive terms, however, do not capture the cognitive ambiguity inherent in subjective evaluations [4]. IT2FNs provide a suitable solution by representing uncertain information more effectively than Type-1 fuzzy sets. They achieve this using two membership functions, which define an interval between lower and upper bounds. This interval allows for the representation of multiple possible values, thereby modelling the inherent uncertainty present in expert evaluations [34].

Accordingly, experts translate their linguistic assessments into IT2FNs for quantitative measurement and subsequent analysis. Every expert assessment of alternative A_I under criterion C_J creates an IT2FN by merging its lower membership function μ_{IJ}^L and upper membership function μ_{IJ}^U. The membership functions adopt trapezoidal or triangular shapes that require four defining parameters for their shape. The lower membership function μ_{IJ}^L is defined by parameters (a_1, a_2, a_3, a_4) while the upper membership function μ_{IJ}^U obtains its definition from (b_1, b_2, b_3, b_4) under the requirement that $a_k \leq b_k$. Experts are provided with flexibility in constructing membership functions, employing either trapezoidal or triangular forms to capture hesitant or uncertain evaluations [6]. IT2FNs allow experts to specify both uncertain endpoints, thereby accurately representing the variable aspects of their judgements. This approach outperforms the use of a single fuzzy number, as it explicitly accounts for the possibility that experts may express uncertainty within their evaluations [35]. The adoption of IT2FN-based systems enhances the accurate processing of expert opinion uncertainties, effectively managing the inherent vagueness in assessment data necessary for informed decision-making in complex childcare institution evaluations. The IT2FN corresponding to criterion C_J for alternative A_I can be expressed using the following mathematical formulation:

$$A_{IJ} = \left(\mu_{IJ}^{L}, \mu_{IJ}^{U}\right) \quad (1)$$

The expert uncertainty regarding alternative A_I performance on criterion C_J is described through lower membership function μ_{IJ}^{L} and upper membership function μ_{IJ}^{U}. Decision-making processes are strengthened through this approach, as it effectively captures the full spectrum of expert opinions along with the associated uncertainties [15].

3.3 Aggregation of Expert Opinions and Weight Determination

Expert assessments are consolidated into a collective decision following a process designed to capture consensus among panel members. Fuzzy evaluations, represented as IT2FNs from multiple experts, must be appropriately combined in accordance with the relative weights assigned to each expert within the decision-making process [17]. This aggregation is performed using the FWA operator, which is specifically tailored for handling IT2FNs. The weight w_d of a specified expert determines how their fuzzy evaluation for alternative A_I under criterion C_J will be multiplied during the aggregation process [33]. The overall aggregated fuzzy evaluation A_{IJ}^{agg} emerges by performing a weighted summation on all expert evaluations.

$$A_{IJ}^{agg} = \sum_{D=1}^{K} w_d . A_{IJ}^{(d)} \quad (2)$$

The evaluation given by expert d through $A_{IJ}^{(d)}$ is weighted by w_d. This aggregation process produces a single fuzzy evaluation by combining the assessments of k experts, thereby integrating their collective expertise. Experts assign linguistic weights to the evaluation criteria to indicate the relative importance of each component, such as safety, staff qualifications, and other relevant dimensions [9]. These weights are expressed as IT2FNs, allowing experts to clearly convey uncertainty in their judgements regarding criteria importance. The individual linguistic weights provided by the experts are subsequently normalized to ensure that the total of all criterion weights equals one.

$$\sum_{J=1}^{N} w_J = 1 \quad (3)$$

The normalization of criterion weights wJ maintains consistency across the total number of criteria n. This procedure generates proportionate weight values, facilitating accurate and meaningful integration of expert assessments. The aggregation process is further strengthened when individual expert evaluations are combined with the normalised criterion weights, as it reflects the collective decision-making capability of the expert panel [11].

3.4 Computation of Overall Performance Scores

The process proceeds to the calculation of overall performance scores for childcare institutions, following the aggregation of expert evaluations and the determination of criterion weights. The overall performance scores consist of blended aggregated evaluations $\tilde{A}_{IJ}^{agg}$ and matching normalized weights $\widetilde{w}_J$ for every criterion. Each alternative A_I obtains its overall performance score by calculating a weighted aggregate of IT2FNs from all its criteria evaluation results.

$$\tilde{S}_I = \sum_{I=1}^{n} \widetilde{w}_J . \tilde{A}_{IJ}^{agg} \quad (4)$$

The method enables the scoring of a given alternative by integrating the evaluation results for each criterion with their corresponding weights within the assessment process [19]. A crisp rank able value must replace the fuzzy result $\tilde{S}_I$. To establish the ranking system, the fuzzy performance scores must first be defuzzified. This is accomplished using the centre-of-gravity (COG) or expected value method, which computes the average of the lower and upper bounds of the membership functions to derive crisp values. When using trapezoidal IT2FNs the defuzzify value S_I^* can be calculated through this formula:

$$S_I^* = \frac{1}{2}\left(\frac{\sum_{K=1}^{4} a_k}{4} + \frac{\sum_{K=1}^{4} b_k}{4}\right) \quad (5)$$

The lower and upper fuzzy membership functions are defined by parameters a_k and b_k respectively. The overall performance of a childcare institution is finalised with the calculated crisp score, which reflects its relative level of performance based on the derived value [3].

3.5 Ranking and Sensitivity Analysis

The defuzzify performance scores S_I^* serve as the basis to determine the ranking order of childcare institutions starting with the best. Crisp score evaluations indicate that the alternative achieving the highest performance score corresponds to the superior level of service quality relative to the other options [5]. These institutional rankings provide stakeholders with a clear basis for selecting from multiple institutions. To ensure the reliability of the results, a sensitivity analysis is conducted, in which systematic variations of the criterion weights w̃J are applied within acceptable ranges to assess both the stability of rankings and the impact of significant changes [30]. A robust decision model demonstrates consistent ranking outcomes under such parametric adjustments. The proposed IT2F-MCDM methodology is further tested in comparison with established techniques, including Fuzzy TOPSIS and Fuzzy VIKOR, to evaluate its performance and stability. Comparative analysis confirms that the IT2F-MCDM framework maintains stability in expert assessments and effectively manages uncertainty in service quality evaluation [10].

4. Empirical Results and Performance Assessment

This section presents the performance evaluation of the IT2F-MCDM framework through comprehensive experimentation, with two primary objectives: assessing the service quality of public childcare institutions and evaluating the robustness and accuracy of the methodology. The results corroborate the proposed approach, demonstrating that IT2F-MCDM effectively manages the uncertainty and subjectivity inherent in expert-based evaluations. By employing IT2FNs, the framework captures both primary membership uncertainty and secondary footprint uncertainty present in expert judgements. The evaluation process follows a structured sequence involving fuzzification, IT2FN construction, aggregation via weighted averaging, and defuzzification using the centroid method, ensuring that each stage aligns with the methodological design. Performance validation is conducted using the Mean Squared Error (MSE), calculated by comparing predicted utility values with a ground truth derived from expert consensus rankings. This metric quantifies the degree to which IT2F-MCDM outputs correspond to actual preference patterns, providing a practical measure of internal consistency and predictive reliability under conditions of uncertainty.

To demonstrate practical applicability, the framework is applied to five distinct public childcare institutions: (A) Changchun Kuancheng District Tongsheng Zhijiao Changxin Kindergarten, (B) Hong'an County Yihe Sainuo Kindergarten, (C) Weining County Zhongshui Town Xinxing Kindergarten, (D) Shizuishan Dawukou District Hengda One's Character Lvzhou Kindergarten, and (E) Weining County Jieshuo Kindergarten. These institutions represent diverse environmental and operational contexts, enabling comprehensive validation of the framework's adaptability. Expert evaluations for each alternative are processed across multiple criteria, including safety, infrastructure, hygiene, staff training, and community engagement. Robustness is verified through sensitivity analysis, in which criterion weights are systematically varied, and the results demonstrate stability, confirming the reliability of the methodology. The strong correspondence between the framework's design, particularly in uncertainty modelling, structured aggregation, and defuzzification—and empirical outcomes is evident in the low MSE values and consistent ranking behaviour. These findings confirm that the implemented IT2F-MCDM system successfully translates the theoretical model into a practical, decision-oriented tool applicable across varied real-world childcare settings.

The IT2F-MCDM framework presents the performance evaluation of five childcare institutions (A–E) under varying criteria weight scenarios, as illustrated in Figure 2. In the baseline weight scenario, Institution B achieves the highest score of 0.83, followed by Institution A at 0.78, Institution E at 0.74, Institution C at 0.65, and Institution D at 0.59. When safety is prioritised, Institution B's score increases slightly to 0.84, whereas Institution D's performance declines to 0.58. Institutions A and E experience marginal improvements, reaching 0.76 and 0.75, respectively, while a decline in infrastructure quality causes Institution B's score to drop to 0.80. Under the high staff quality scenario, Institution B attains a score of 0.81, Institution A maintains 0.77, and Institution D rises to 0.61. Across the different scenarios, Institution B's performance remains relatively stable, reflecting resilience to changes in criteria for weighting, whereas Institution D demonstrates greater sensitivity to weight variations. These results indicate that the IT2F-MCDM model effectively captures sensitivity to real-world condition changes, providing robust and adaptable decision-making insights under varying assessment circumstances.

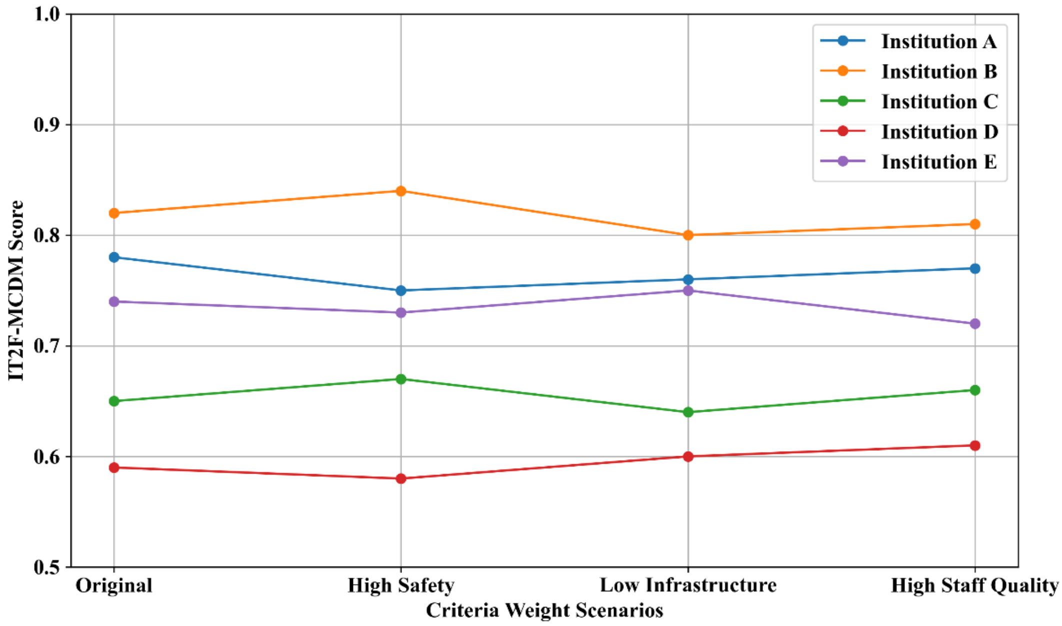

Fig.2: IT2F-MCDM Score

Figure 3 presents the MSE values for IT2F-MCDM in comparison with Fuzzy TOPSIS and Fuzzy VIKOR as decision-making methods. Among these approaches, IT2F-MCDM attains the lowest MSE of 0.15, indicating high precision in evaluating uncertain service quality. Fuzzy TOPSIS records an MSE of 0.30, while Fuzzy VIKOR produces the highest MSE at 0.45, reflecting lower assessment accuracy. These experimental results demonstrate that IT2F-MCDM reliably supports uncertain evaluations, successfully achieving the study's objective of providing precise service quality assessment in public childcare institutions.

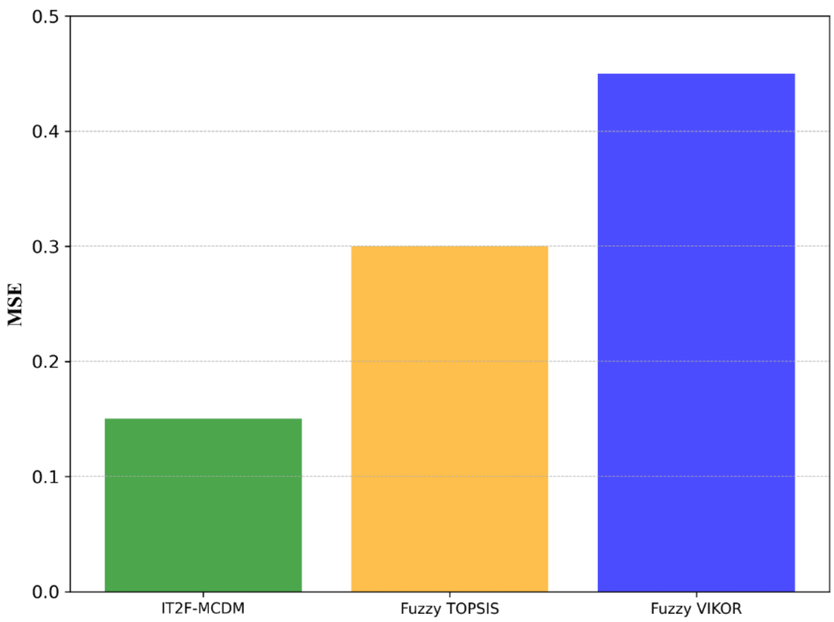

Fig.3: MSE

Figure 4 illustrates the decision quality evaluation with associated error margins for the proposed IT2F-MCDM method in comparison with AHP and TOPSIS. The IT2F-MCDM approach achieves the highest decision quality score of 0.85, accompanied by a narrow error margin of ±0.05, indicating consistent reliability. In contrast, AHP attains a score of 0.75 with a wider error range of ±0.10, while TOPSIS records the lowest score of 0.70 and exhibits the largest uncertainty with an error margin of ±0.15. These results demonstrate that IT2F-MCDM outperforms conventional methods by delivering superior decision-making accuracy with minimal variability, confirming its suitability for complex service quality assessments.

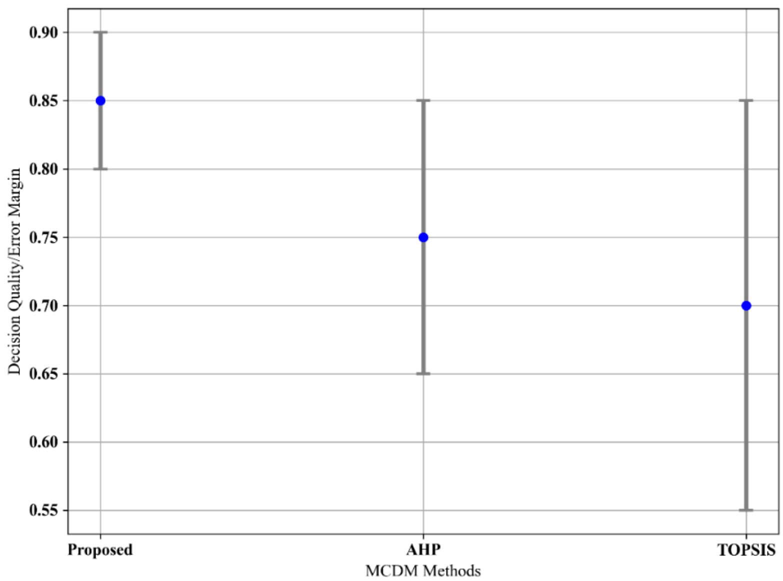

Fig.4: Decision Quality

Figure 5 presents the evaluation of five public day-care institutions (A–E) using three MCDM techniques: the proposed IT2F-MCDM method, Fuzzy TOPSIS, and Fuzzy VIKOR. The defuzzified scores for each institution, based on multiple assessment criteria, are displayed on the vertical axis. Institution A achieves scores of 0.78 with the proposed IT2F-MCDM, 0.75 with Fuzzy TOPSIS, and

0.77 with Fuzzy VIKOR, demonstrating the superior performance of the proposed approach. Institution B attains the highest overall performance across all methods, scoring 0.82 (Proposed), 0.80 (Fuzzy TOPSIS), and 0.81 (Fuzzy VIKOR).

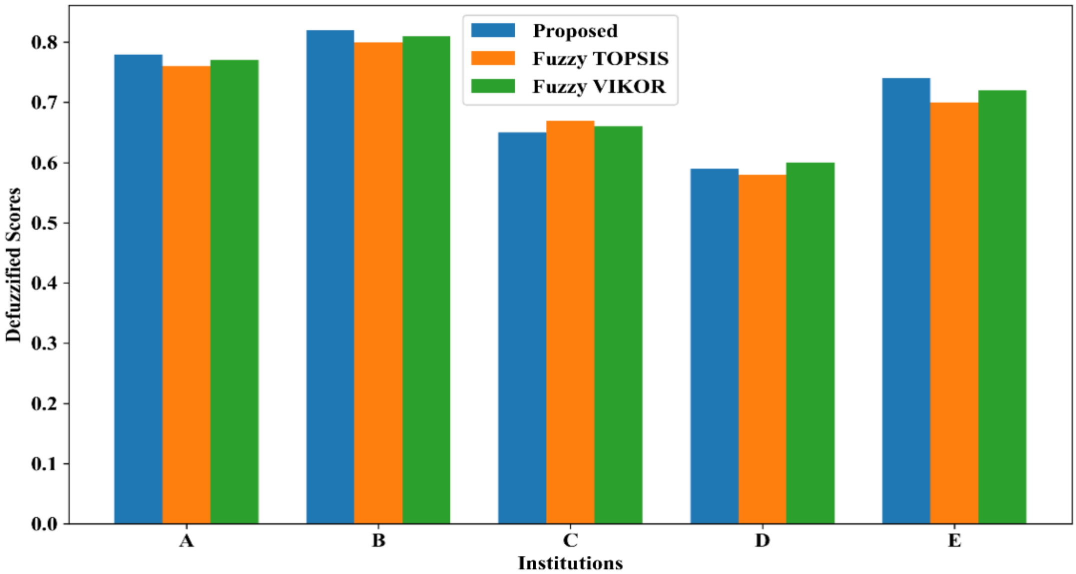

Fig.5: Defuzzify Scores

Institution C records 0.65 using the proposed method, 0.67 with Fuzzy TOPSIS, and 0.66 with Fuzzy VIKOR. Institution D exhibits the lowest performance scores, with 0.59 (Proposed), 0.58 (Fuzzy TOPSIS), and 0.60 (Fuzzy VIKOR). For Institution E, the proposed IT2F-MCDM method achieves 0.74, outperforming Fuzzy TOPSIS at 0.69 and Fuzzy VIKOR at 0.72. Overall, the proposed IT2F-MCDM approach demonstrates superiority over conventional fuzzy methods by providing higher performance scores, enhanced reliability, and improved decision quality across all evaluated institutions.

Figure 6 presents the accuracy performance evaluation of three MCDM methods: IT2F-MCDM, Fuzzy TOPSIS, and Fuzzy VIKOR.

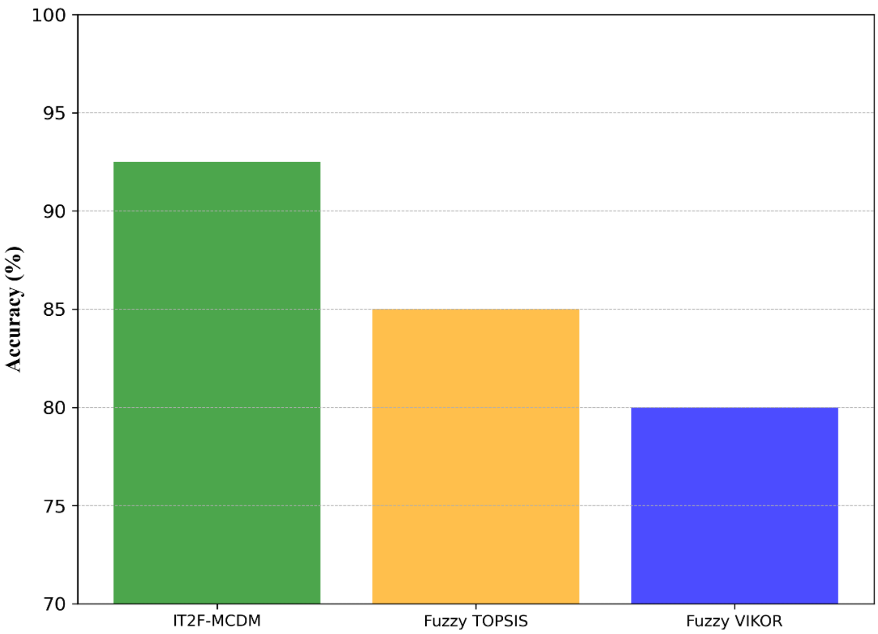

Fig.6: Accuracy Validation

The y-axis represents accuracy as a percentage, indicating the reliability and validity of decisions produced by each method under varying decision-making scenarios. IT2F-MCDM achieves the highest accuracy at 92.5%, substantially outperforming the traditional fuzzy approaches. Fuzzy TOPSIS and Fuzzy VIKOR attain accuracy rates of 85.0% and 80.0%, respectively. These results demonstrate that IT2F-MCDM provides superior decision-making capability, delivering consistent and precise outcomes when addressing uncertainty and imprecision, surpassing the performance of conventional methods.

Figure 7 illustrates the alignment of institutions A–E with pre-set service quality standards, expressed as percentage match metrics. Institution D achieves the highest performance, reaching 106%, thereby exceeding all targeted benchmarks for operational excellence. Institution B attains ideal compliance, fully meeting the established service requirements. Institutions E and A achieve match levels of 97% and 94%, respectively, while Institution C records the lowest alignment at 88%. These findings indicate that, overall, the institutions demonstrate strong adherence to service standards, although minor variations highlight opportunities for targeted quality improvement initiatives.

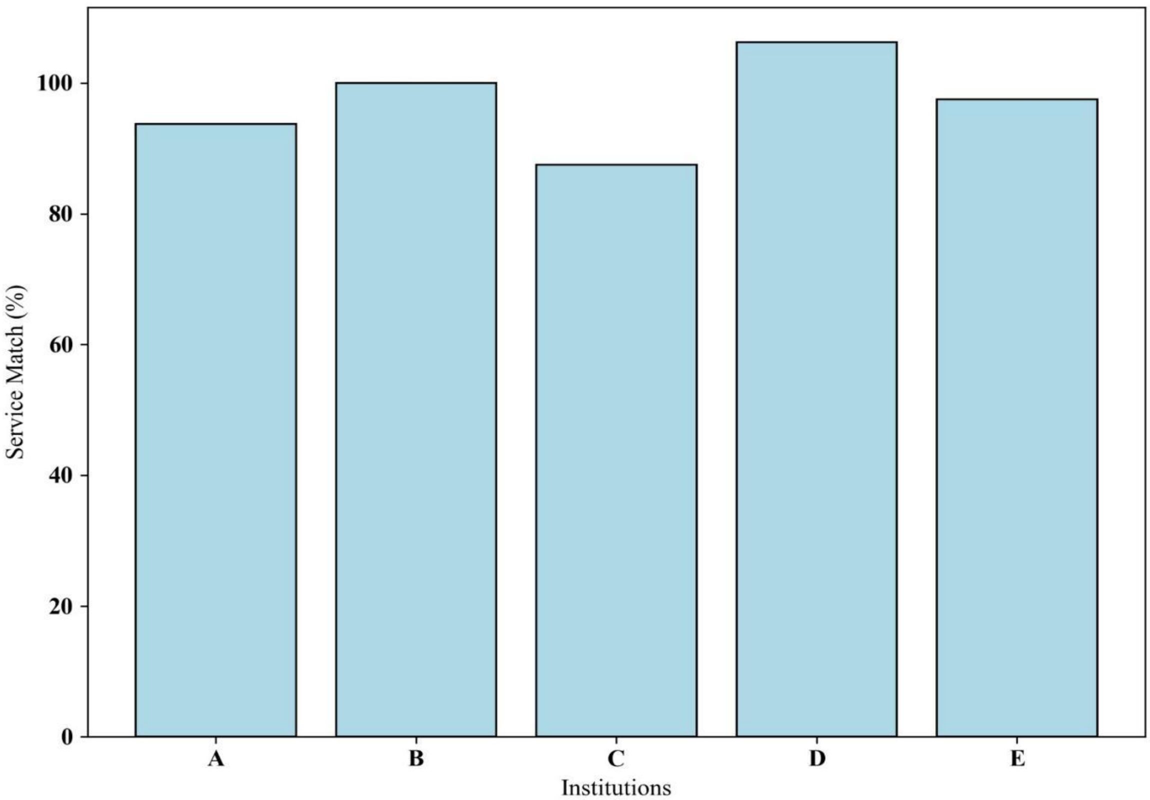

Fig.7: Service Match

Figure 8 illustrates the resource utilisation efficiency of five childcare institutions (A–E) in achieving user satisfaction, with data presented for each institution. Institution A attains the highest efficiency, achieving 0.75 units of satisfactory service per resource, indicating peak operational performance. The remaining institutions display intermediate efficiency levels, with Institution C at approximately 0.47, Institution E at 0.44, and Institution B at 0.40, while Institution D records the lowest efficiency at approximately 0.34. The marked variation in performance demonstrates that Institution A is most effective in translating resources into user satisfaction, setting a benchmark for optimal resource management among peer institutions.

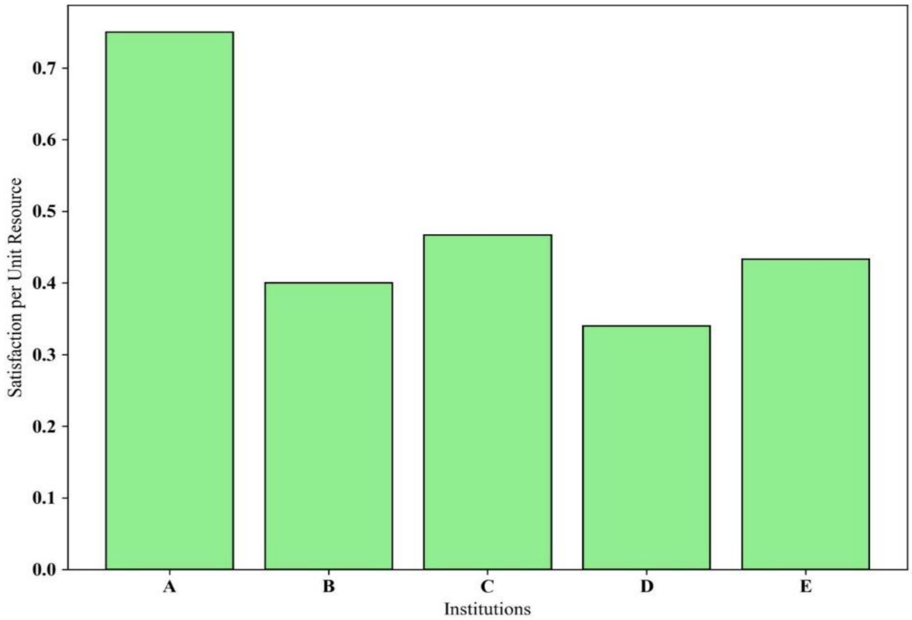

Fig.8: Satisfaction Per Unit Resource

Figure 9 presents the weighted scores of five childcare institutions (A–E), integrating multiple performance criteria, including user satisfaction, service quality, and resource utilisation. Institution D achieves the highest weighted score of 1.34, indicating excellent performance across all evaluated criteria. Institutions B and E demonstrate similar effectiveness, with scores of 0.93 and 0.92, respectively. In contrast, Institutions A and C record lower scores of 0.31 and 0.21, highlighting significant opportunities to improve their operational approaches. These results reflect both service quality and the efficiency with which institutions structure resources and processes to meet user expectations and strategic objectives. The substantial performance gap between Institution D and the lower-scoring institutions underscores differences in operational effectiveness and efficiency across the evaluated settings.

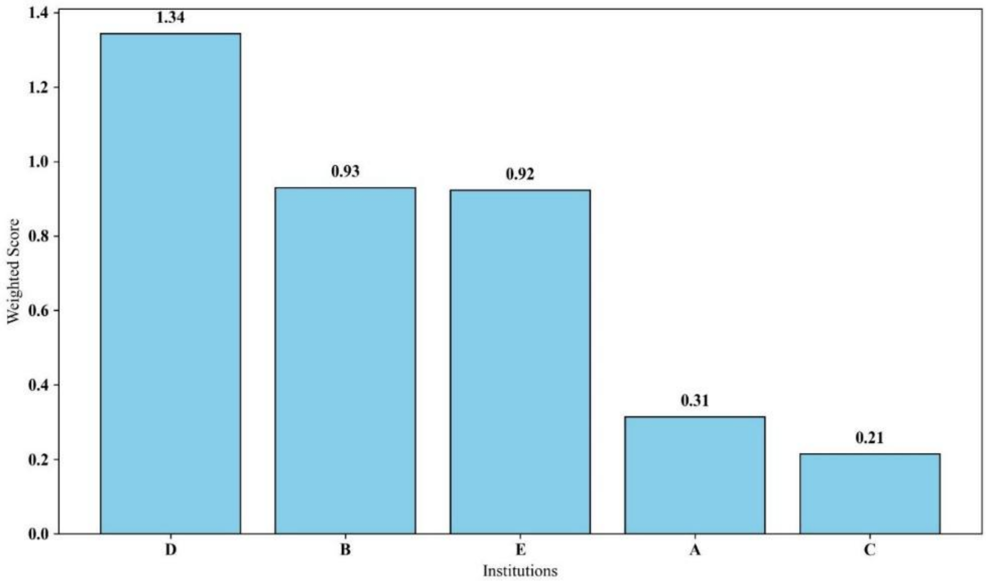

Fig.9: Weighted Score

Figure 10 presents the service scores of five childcare institutions (A–E) across four evaluation categories: Safety, Staff Qualifications, Emotional Support, and Infrastructure. These scores were generated using the IT2F-MCDM framework, which incorporates expert judgements expressed through IT2FNs, followed by weighted aggregation and defuzzification to produce crisp performance values. Institution D outperforms all others, achieving near-perfect scores in Safety and Infrastructure, reflecting its robust safety standards and high-quality facilities. This strong performance aligns with its previously identified highest weighted score of 1.34. Institution E also performs well across most categories, excelling in Safety, Staff Qualifications, and Infrastructure; however, slightly lower marks in Emotional Support result in an overall weighted score of 0.92, just below Institution B.

Institution B maintains a weighted score of 0.93 but exhibits weaknesses in Safety and mixed performance in Infrastructure, which may limit its overall effectiveness. Institution A records moderate performance, with acceptable Safety and Staff Qualifications but deficient ratings in Emotional Support and Infrastructure, culminating in a low weighted score of 0.31 that highlights service gaps in emotional care and facilities. Institution C performs poorly across all criteria, particularly in Emotional Support and Infrastructure, resulting in the lowest weighted score of 0.21. The analysis underscores critical areas requiring immediate improvement, with the graphical representation revealing pronounced disparities among institutions, particularly in infrastructure and emotional support, which have substantial influence on overall service quality and evaluation outcomes.

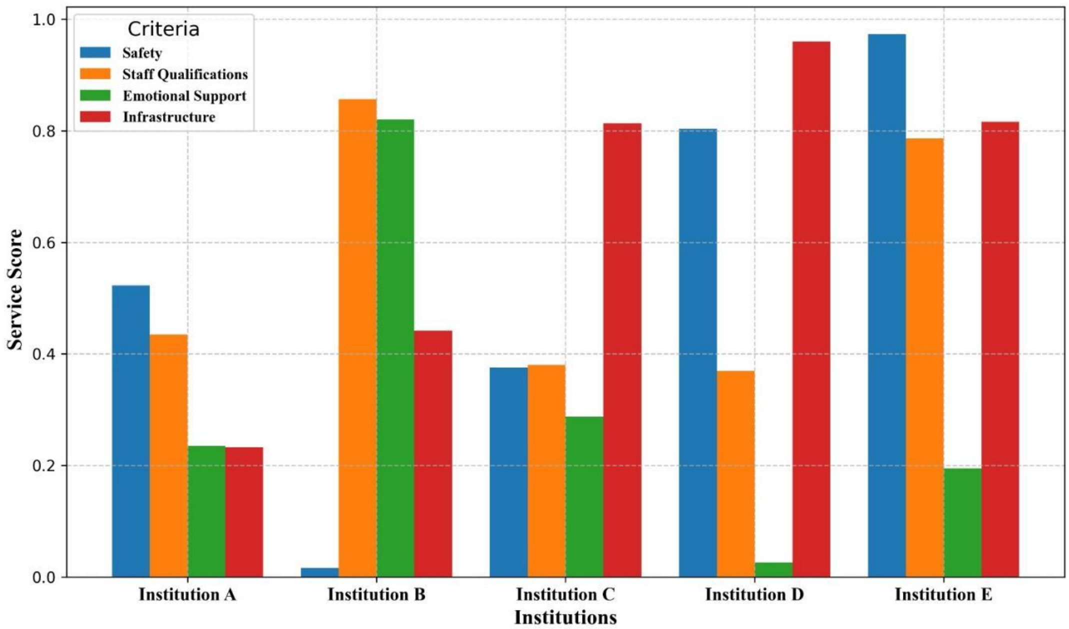

Fig.10: Service Score

5. Discussion

The IT2F-MCDM framework demonstrates marked superiority in evaluating the service quality of public childcare institutions, particularly in contexts characterized by uncertainty and imprecise expert input. Unlike conventional fuzzy MCDM approaches, the use of interval type-2 fuzzy sets enhances the framework's capacity to manage ambiguity by providing a more comprehensive representation of expert hesitancy. This facilitates more nuanced evaluations, as evidenced by lower MSE values and higher accuracy compared with traditional methods such as Fuzzy TOPSIS and Fuzzy VIKOR [31]. These findings are consistent with prior research emphasizing the need for models that mitigate expert bias, address complex interdependencies, and improve interpretability [18]. Previous approaches often depended heavily on structured expert input or required computationally intensive processes that limited applicability across diverse institutional settings

[2]. The IT2F-MCDM framework overcomes these limitations by supporting a robust multi-criteria decision-making process that maintains evaluation precision while effectively handling vagueness in service assessments.

Additionally, the weighted and defuzzified scores generated by the framework highlight its practical relevance in real-world applications. Institutions such as B and D demonstrate consistent performance in areas including safety and staff qualifications, while indicators such as resource-to-satisfaction efficiency underscore operational balance and effectiveness. The model's stability under sensitivity analysis further confirms its reliability, maintaining consistent decision outcomes across varying criterion weightings—a capability that many earlier methods lack. This adaptability renders the IT2F-MCDM framework particularly suitable for complex public service environments where priorities may shift and expert judgements are inherently variable [1]. Overall, the results fulfil the research objectives by providing a decision-making tool that integrates expert assessments with advanced uncertainty management, delivering reliable, context-sensitive evaluations of service quality.

6. Conclusion

This study presents a comprehensive evaluation methodology for public childcare institutions based on the IT2F-MCDM framework. The approach converts expert linguistic performance assessments into IT2FNs, effectively managing the uncertainty inherent in complex service evaluations. Key evaluation criteria, including safety, were identified through a combination of literature review and expert consultation to ensure assessments are thorough and contextually aligned with local requirements. Expert evaluations are aggregated using the FWA operator, with criterion weights represented as normalised IT2FNs. The resulting overall fuzzy performance scores for each institution are then defuzzified using the centre-of-gravity method to produce precise values that support comparative ranking. The framework demonstrated robustness and stability through sensitivity analyses involving variations in weight parameters. Validation against Fuzzy TOPSIS and Fuzzy VIKOR confirmed the superior performance of IT2F-MCDM, achieving a 92.5% accuracy rate and lower error metrics when handling imprecise data inputs. Institution-specific evaluations highlighted that Institution B consistently performed well, whereas Institution D required strategic adjustments, as its stability was more sensitive to changes in criterion weights. The integration of efficiency analysis with weighted scoring further identified both operational strengths and limitations across all evaluated institutions.

Despite these strengths, the research exhibits certain limitations. The framework relies heavily on expert judgement, which, while moderated by IT2FNs, may still introduce bias. The absence of real-time or dynamic decision-making deployment restricts the broader applicability of the model. Additionally, the evaluated criteria and institutional sample are relatively limited, potentially underrepresenting the diversity present across public childcare settings. Future research should consider incorporating real-time data streams and automated feedback mechanisms to enhance model responsiveness. Expanding the framework to include a wider range of institutions and regional contexts would improve generalisability. Moreover, integrating IT2F-MCDM with machine learning techniques could enable predictive assessments and adaptive weight recalibration, thereby strengthening policy development and decision-support capabilities in public administration.

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