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An integrated fuzzy-VIKOR-DEMATEL-TOPSIS technique for assessing QoS factors of SOA

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ABSTRACT

Quality of service (QoS) is a very important concept in service-oriented architecture (SOA). While there is a growing body of study on QoS-based service selection based on SOA, there is little research on analyzing QoS factors from the viewpoints of IT workers and researchers. As a result, the purpose of the current study aims to offer an integrated fuzzy VIKOR-TOPSIS-DEMATEL approach framework for evaluating QoS factors of online services from the viewpoint of experts in a fuzzy environment. A numerical assessment of the QoS factors for a case firm in Ghana indicated that the suggested technique is appropriate for the problem. Furthermore, the technique outcomes divided QoS factors into cause-effect variables, ranked QoS factors, and lastly, suggested conflicting QoS factors. The results from the Fuzzy DEMATEL aspect of the proposed approach found integrity, availability, accessibility, compliance, documentation, latency, and adaptability as causal variables. While response time, cost/price, reliability, performance, security, reputation, throughput, best practices, success ability, encryption, portability, storage, and consistency are regarded as influential variables. The Fuzzy TOPSIS aspect of the technique found adaptability, documentation, consistency, transaction, and accessibility are the most ranked QoS factors of online services. The fuzzy VIKOR side of the proposed method discovers integrity, cost, and latency as incommensurable QoS factors. Finally, a sensitivity analysis was carried out, and the results show the model is robust. This study confirms the position of existing knowledge on sensitivity analysis in the QoS literature. In the issue of QoS factor evaluation, this work effectively blended three MCDM techniques. The study's shortcoming stems from its reliance on data from QoS specialists from only one developing nation (i.e. Ghana).

1. Introduction

SOA is a form of design for integrating business applications (Jain and Easo, 2012; Singh and Tyagi, 2017), which supports distributed systems (Lin et al., 2013), overcomes ownership limitations such as owning a physical structure, and heterogeneity (Gohar and Purohit, 2015). It can be implemented as a cloud service (Kumar et al., 2018; Maroc and Zhang 2020) and a web service (Al-Masri and Mahmoud 2008). Hence, it reaps the benefits of both cloud and web-based services. SOA does not only aid the dismantlement of silos and ensures the sharing of business resources across domains. But also, concerns about the quality of service (QoS) factors (Gohar and Purohit, 2015; Tong et al., 2021). Since then, QoS has emerged as the most accepted measure for distinguishing non-functional requirements across comparable web and cloud services (Ruiz and Rubira, 2016). It relates to the non-functional attributes of cloud and web services such as response time, availability, performance, and security among others (Sridevi et al., 2021; Tong et al., 2021; Sujith et al., 2018). Some merits of QoS include (1) the non-functional attribute guarantees that the service conforms to statutory and regulatory requirements, (2) they ensure the service's dependability, availability, and performance, (3) they guarantee a confident consumer involvement and the straightforwardness of usage of the service, and (4) they add to the advancement of the service's security rule, among others.

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Many scholars have taken an interest in QoS-based online services selection. Preserving the quality of their web and cloud services has been a top concern for service providers in recent times. Each scholar has a focus within the QoS research space. For instance, some are focusing on QoS composition (Liu and Zhang, 2017; Sujith et al., 2018; Vesyropoulos and Georgiadis, 2015; Zou et al., 2010). Others are also researching QoS Optimization (Beran et al., 2013; Mousa and Bentahar, 2016; Seghir and Khababa, 2021; Wang et al., 2015). Very few studies evaluated QoS factors (Choi and Jeong, 2014; Gao et al., 2009; Kumar and Kumar, 2016; Maheswari and Karpagam, 2018). To the best of our knowledge, to date, the QoS evaluation studies concerning online services are very limited. Furthermore, the few studies on QoS factor evaluation focused on either the cloud or web service, but not both. This research evaluates the QoS factors of both web and cloud services based on expert ratings of the QoS factors. On the other hand, fuzzy multi-criteria decision-making (MCDM) approaches were deployed. Thus, the current research put forward an integrated approach of fuzzy VIKOR, Fuzzy TOPSIS, and fuzzy DEMATEL approach to offer a consistent and systematic method for assessing the QoS elements by experts in a fuzzy environment. The uncertainty and subjective vagueness within the decision-making process are dealt with by fuzzy linguistic terms quantified on an interval scale [0–1] by triangular fuzzy numbers (Sangaiah et al., 2015). See Table 1 for the QoS factors and Table 2 for the linguistics terms. The contributions of the current research are as follows:

1. Development of a new approach called an integrated Fuzzy VIKOR, Fuzzy TOPSIS, and Fuzzy DEMATEL Approach. The Fuzzy DEMATEL aspect of the new approach develops a QoS model that represents QoS factors of online services. This is distinct from existing models (Liu et al., 2004; Zhang et al., 2012a; 2012b), which commonly use one, either a cloud or web service. Our model classifies both the web and cloud QoS factors into cause and effect groups. It offers a better interrelationship among the QoS factors and assigns weights to each QoS factor for the Fuzzy TOPSIS aspect of the approach to begin.
2. To optimally rank the QoS factors, the Fuzzy TOPSIS aspect of the approach receives weights from the fuzzy DEMATEL side and ranks the QoS factors in the QoS model based on the coefficient values obtain using the mathematical equations given in the Fuzzy TOPSIS steps.
3. The fuzzy VIKOR side of the study's method names the incommensurable QoS factors of online service. The study tests the robustness of the TOPIS ranking through sensitivity analysis.

The section that follows presents a review of the research on QoS factors for services. Section 3 delves into the theoretical underpinnings of fuzzy VIKOR, fuzzy DEMATEL, and fuzzy TOPSIS methods. Section 4 introduces an evaluation approach for addressing the QoS factors' evaluation as viewed by experts in an experienced way. Sections 5 and 6 will provide and discuss the outcomes of the scenario study analysis using fuzzy MCDM approaches. Finally, the investigation ends.

In this study, we extracted twenty-one (21) quality of service attributes of both web and cloud services that have different characteristics from literature (Chen et al., 2016; Ran, 2003) and asked experts to rate them.

Table 1: Quality of service factors and definitions

QoS factors	Symbol	Description
Integrity	C1	Integrity is the extent to which a service accomplishes its process concerning Web Services Definition Language (WSDL) description and Service Level Agreement (SLA)
Transaction	C2	The transaction is connected to the process done on the ACID property, which includes features such as atomicity, consistency, isolation, and durability
Response Time	C3	The execution time between requests submitted and results received is measured by time quality
Cost	C4	Measures the price involved in requesting and executing a service
Reliability	C5	The capacity of a service to fulfill its needed activities for a certain amount of time correctly and consistently under specified conditions
Availability	C6	The status of a service to which a client may connect is referred to as availability.
Accessibility	C7	It denotes the scale at which a service request is met
Performance	C8	The amount of time it takes to perform a service request
Security	C9	Security involves the Confidentiality, Integrity, and Availability(CIA) of a service
Reputation	C10	It assesses the dependability of a service based on the user's experience with the service
Throughput	C11	Total number of invocations during a certain period
Compliance	C12	The degree to which a WSDL (Web Services Definition Language) specification is adhered to
Best Practices	C13	The degree to which a Web Service Interoperability industry consortium (WS-I) is adhered to
Documentation	C14	A measure of documentation (i.e. description tags) in WSDL
Success ability	C15	It is defined as the number of responses divided by the number of service requests
Latency	C16	A given request execution time duration
Encryption	C17	How secured is the digital data using one or more mathematical techniques, along with a password or "key" used to decrypt the information
Adaptability	C18	The ability of the system to assess other available resources that can still meet the request goal
Portability	C19	Whether or not a service can still be used in a different platform either than where it was originally developed
Storage	C20	Storage is the process of storing digital data in a data storage device using computing technology
Consistency	C21	Service consistency is an expectation of all service usages at all times; users want peace of mind and no unpleasant surprises

Table 2: Code, linguistic terms, and triangular fuzzy numbers

Code	Linguistic terms	L	M	U
1	Very Poor(VP)	0	0	0.25
2	Poor(P)	0	0.25	0.5
3	Fair(F)	0.25	0.5	0.75
4	Good(G)	0.5	0.75	1
5	Excellent(E)	0.75	1	1

2. Evaluation framework for QoS factors

Although some studies have employed the fuzzy VIKOR, fuzzy TOPSIS, and fuzzy DEMATEL methods for a variety of applications, no study has addressed the integration of these three techniques in the subject area of service selection to the superlative of our awareness. To measure QoS variables as viewed by experts, a combination of fuzzy DEMATEL and fuzzy TOPSIS with fuzzy VIKOR is proposed in this context. Fig. 1 demonstrates the development of the proposed framework for assessing the QoS elements of online and cloud services in a fuzzy environment. The basic steps of the fuzzy DEMATEL method used in this study are as follows:

- Step 1: Create a fuzzy decision matrix based on the respondents' subjective opinions. Use Likert's scale and its linked linguistic characteristics.
- Step 2: Produce the fuzzy normalized decision matrix.
- Step 3: Create the fuzzy total-relationship matrix.
- Step 4: Calculate the prominence and weights of the QoS factors.

The Fuzzy TOPSIS approach necessitates preliminary data on the relative distance of assessment criteria. This significance is conveyed by assigning weight to each criterion under consideration, wj. In this study, the fuzzy DEMATEL approach is used to compute the weightiness of each QoS factor. The following are the basic phases of the fuzzy TOPSIS technique employed in this study:

- Step 1: Create a fuzzy evaluation decision matrix.
- Step 2: Enter the weights acquired from the DEMATEL algorithm to compute the weighted normalized decision matrix.
- Step 3: FPIS and FNIS are used to calculate the best and worst evaluation values for each criterion.
- Step 4 Determine the relative proximity coefficient to the ideal solution and rank.

The Fuzzy VIKOR methodology requires basic information about the best and worst values of the evaluation factors. The best and worst values were calculated with the help of the Fuzzy TOPSIS method. The basic steps of the fuzzy VIKOR approach used in this study are as follows:

- Step 1: Compute the values and utilize the best and worst Fuzzy TOPSIS values.
- Step 2: Determine the VIKOR index (Q).
- Step 3: Provide a compromise solution. In this stage, a choice is made based on the descending order of the values R, S, and Q for the possibilities. Two requirements must be met, and a variety of compromise solutions might be provided in response to these two conditions.

Condition 1: Acceptable benefit: $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$ where $A^{(1)}$ is an option with first place and $A^{(2)}$ is the option ranked second in the ranking list by Q. m is the number of alternatives. Condition 2: Acceptable stability in decision making: The alternative $A^{(1)}$ must also be the best ranked by S or/and R.

- Step 4: The proposed methodology result is provided in Table 3 and the sensitivity analysis is offered in Fig. 2.

Table 3: QoS factors and fuzzy VIKOR

QoS factors	Fuzzy VIKOR
C1	C1
C2	
C3	
C4	C4
C5	
C6	
C7	
C8	
C9	
C10	
C11	
C12	
C13	
C14	
C15	
C16	C16
C17	
C18	
C19	
C20	
C21	

The authors provide a numerical example of how a hybrid Fuzzy DEMATEL, Fuzzy TOPSIS, and Fuzzy VIKOR are used to assess and rank twenty-one (21) QoS factors of online services. Data was collected from 21 individuals, including researchers and information technology professionals, who were familiar with the issues of web and cloud services and were identified and chosen based on their research and job profiles from Intercom Programming and Manufacturing Co. Ltd (IPMC), a Ghana-based Information Technology (IT) company providing IT services and education. The combined fuzzy DEMATEL–TOPSIS–VIKOR approach employed in this work gives a more precise and tangible way of dealing with cognitive uncertainty caused by the human perception in collective decision-making. As a result, the suggested integrated MCDM will enhance the quality of decision-making for QoS evaluation of web and cloud services in a fuzzy context. The weightiness between the criteria at the individual level is calculated using the fuzzy DEMATE approach, which employs fuzzy linguistic statements. The Fuzzy DEMATEL will develop a cause-and-effect QoS factors model. For effective QoS ranking, the fuzzy TOPSIS technique will be used to rank the QoS factors. Fuzzy VIKOR will also rank and establish the conflicting criteria in the study.

3. Data sources and demographics of experts

The study obtained data from Intercom Programming and Manufacturing Co. Ltd, a Ghana-based Information Technology Service and Education provider. The authors selected IPMC as the case organization for the study due to the good records the company has earned in providing both IT service and IT education. The educational backgrounds of experts who responded to the questionnaire were master and Ph.D. degree holders. 15 out of the 21 experts representing about 71.42% were holders of master's degrees. Whereas the remaining 6 experts were Ph.D. holders. On experience, the majority of the experts (13 out of 21) had 15 years and more working experience with online services. The remaining experts had between 6-14 years of work experience. Also, on age distribution, the respondents were dominated by adults between the age groups of 37-47 representing 17 whereas, the rest of the 4 experts were between the age groups of 48-65.

4. Theoretical basis

The current work suggested an integration of Fuzzy VIKOR, Fuzzy TOPSIS, AND Fuzzy DEMATEL methodology for evaluating SOA factors in a fuzzy environment from the perspective of experts. First, we used the fuzzy DEMATEL approach to develop the QoS factors' cause and effect models and then determined the weights of the criteria. Thirdly, to determine the rank and relevance of the qualities, we used fuzzy TOPSIS. and finally, fuzzy VIKOR was used to determine the incommensurable QoS factors. The theoretical foundation of the proposed methodology is shown in Fig. 3.

4.1. Fuzzy DEMATEL

The DEMATEL technique collects shared information to identify the causal linkages between QoS criteria (Büyüközkan and Çifçi, 2012; Jassbi et al., 2011; Sangaiah et al., 2015). Several studies (Seker and Zavadskas, 2017; Seleem et al., 2020; Soner, 2021) have recently employed fuzzy DEMATEL for factors evaluation, interrelationships among criteria, and coping with human vagueness and idiosyncratic ambiguity within decision-making procedures through the application of fuzzy set theory (Sangaiah et al., 2015). In addition, in the literature, a DEMATEL technique has been effectively implemented in a variety of fields of application (Atthirawong et al., 2018; Dalvi-Esfahani et al., 2019; Hemati and Alroaia, 2012; Pandey et al., 2019; Pechová, 2015; Peleckis, 2021; Sangaiah et al., 2015; Tabrizi et al., 2016) in the area of operations research (MCDM) problems. Similarly, this research combines Fuzzy Set Theory with DEMATEL with other Fuzzy MCDM techniques to develop an integrated Fuzzy Multi-Criteria Decision-Making Method for evaluating the QoS factors of online services. In this paper, the Fuzzy DEMATEL technique and associated computational procedure for data analysis are summarized in Fig. 3 and the steps section.

4.2. Fuzzy TOPSIS

With its excellent computing efficiency and comprehensibility, Fuzzy TOPSIS, one of the fuzzy MCDM approaches, has been widely utilized to compute the relative significance of alternatives and solve real decision-making issues (Sangaiah et al., 2015). Furthermore, TOPSIS has been used in previous research to handle MCDM issues (Afful-Dadzie et al., 2014a; Lin et al., 2019; Ortiz-Barrios et al., 2021; Rhimi et al., 2016; Safari et al., 2012; Thasni et al., 2020). Similarly, the primary concept behind utilizing Fuzzy TOPSIS in this research is to compute ideal solutions (best values realistic of criteria) and negative ideal solutions (worst values realistic of criteria) for grading the QoS factors of online services. The operating technique for the Fuzzy TOPSIS approach and associated data analysis are given in Fig. 3 and the steps section

4.3. Fuzzy VIKOR

The Fuzzy VIKOR method was first developed by Opricovic et al. (2004) and has been applied to rank the alternatives in a fuzzy environment. Since then, the fuzzy VIKOR has been used alone or with other methods. The Fuzzy VIKOR approach was employed and efficiently deployed to tackle a broad variety of MCDM issues (Ayouni et al., 2021; Balin et al., 2020; Jing et al., 2018; Meksavang et al., 2019). In this paper, the Fuzzy VIKOR method is modified and applied with other fuzzy MCDM methods to evaluate the QoS factors of web and cloud services. The modified steps of the Fuzzy VIKOR method are depicted in Fig. 3 and the steps section.

4.4. The fuzzy MCDM methods equations

- Step 1: Create a fuzzy direct-relationship matrix. The initial step of the fuzzy DEMATEL analysis builds a fuzzy decision matrix A, based on the influence values collected from the experts. Initial Matrix Z of QoS factors $(Ci, j = 1,2,3 \ldots \ldots . . , n)$ and the respondents $(R^i, i=1,2,3 \ldots \ldots \ldots ., m)$ were asked to share their subjective judgments about the importance weights of each QoS factor using the linguistic scale (1-5) in Table 2.

The initial fuzzy decision matrix is as follows;

$$Z = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array}\begin{array}{c} \begin{array}{ccccc} R^1 & R^2 & R^3 & \dots & R^m \end{array} \\ \begin{bmatrix} \tilde{\alpha}_1^1 & \tilde{\alpha}_1^2 & \tilde{\alpha}_1^3 & \dots & \tilde{\alpha}_1^m \\ \tilde{\alpha}_2^1 & \tilde{\alpha}_2^2 & \tilde{\alpha}_2^3 & \dots & \tilde{\alpha}_2^m \\ \tilde{\alpha}_3^1 & \tilde{\alpha}_3^2 & \tilde{\alpha}_3^3 & \dots & \tilde{\alpha}_3^m \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{\alpha}_n^1 & \tilde{\alpha}_n^2 & \tilde{\alpha}_n^3 & \dots & \tilde{\alpha}_n^m \end{bmatrix} \end{array},$$

$$i = 1,2,\dots,m;\ j = 1,2,\dots,n \qquad (1)$$

In this decision matrix, m denotes the number of respondents and n is the number of influential factors, and $\tilde{a}_j^i = \left(La_{j,}^i Ma_{j,}^i Ua_{j,}^i\right)$ represents lower bound (L), middle bound (M), upper bound (U) of a triangular fuzzy number (TFN), and fuzzy degree of impact as assessed by ith respondents for jth influential factor.

The direct relation matrix Z is generated by taking the arithmetic mean of all of the experts' judgments given in Table 4.

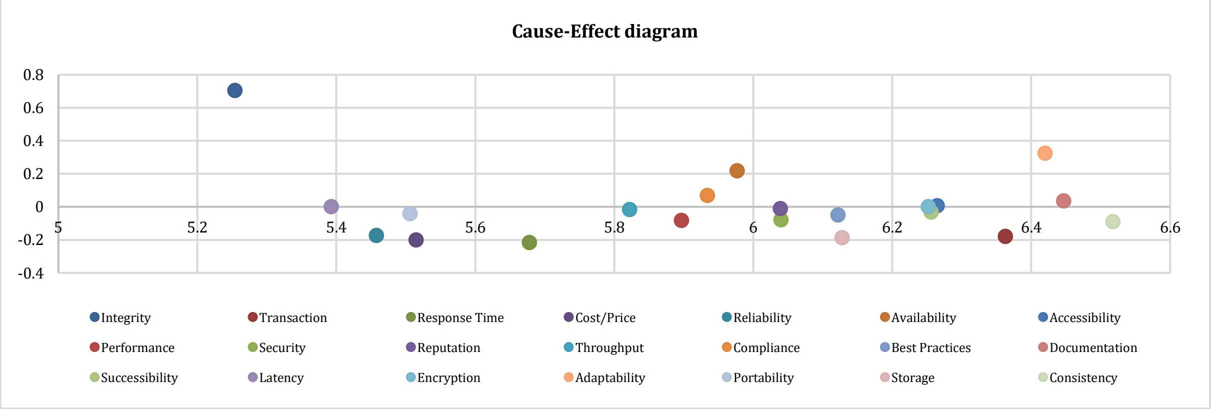

Fig. 1: Cause-effect model diagram of QoS factors from fuzzy DEMATEL

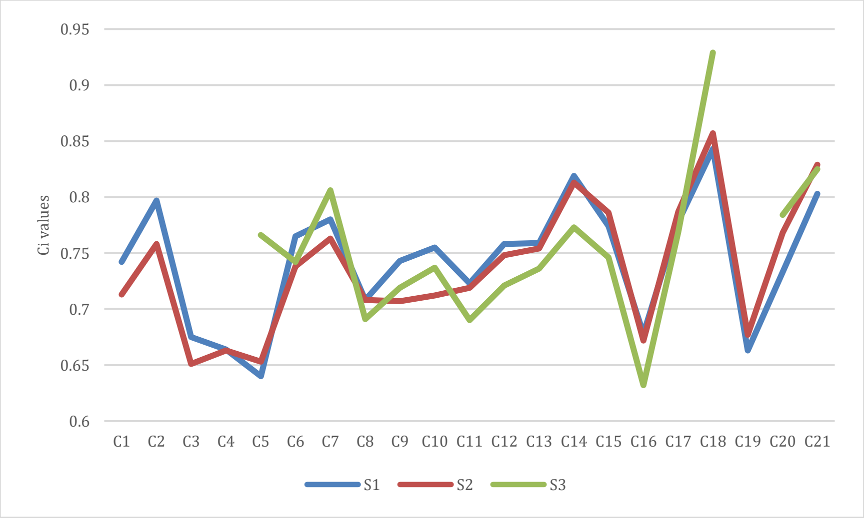

Fig. 2: Sensitivity analysis result on the proposed method

Table 4: Direct-relation matrix z (mean)

	C1	C2	C3	...	C21
C1	(0.000,0.000,0.000)	(0.321,0.571,0.798)	(0.274,0.512,0.726)	...	(0.286,0.536,0.786)
C2	(0.131,0.298,0.536)	(0.000,0.000,0.000)	(0.381,0.619,0.821)	...	(0.286,0.536,0.786)
C3	(0.107,0.298,0.548)	(0.262,0.500,0.714)	(0.000,0.000,0.000)	...	(0.321,0.571,0.821)
C4	(0.119,0.298,0.548)	(0.226,0.452,0.667)	(0.405,0.643,0.845)	...	(0.357,0.607,0.857)
C5	(0.155,0.357,0.583)	(0.262,0.500,0.714)	(0.333,0.583,0.798)	...	(0.310,0.560,0.810)
C6	(0.143,0.345,0.595)	(0.274,0.512,0.738)	(0.190,0.405,0.655)	...	(0.298,0.548,0.774)
C7	(0.167,0.357,0.607)	(0.440,0.679,0.857)	(0.298,0.536,0.762)	...	(0.345,0.595,0.821)
C8	(0.202,0.393,0.619)	(0.298,0.536,0.750)	(0.298,0.548,0.762)	...	(0.357,0.607,0.857)
C9	(0.179,0.357,0.595)	(0.393,0.643,0.845)	(0.202,0.429,0.667)	...	(0.369,0.619,0.857)
C10	(0.167,0.345,0.583)	(0.429,0.679,0.869)	(0.250,0.464,0.690)	...	(0.298,0.548,0.798)
C11	(0.155,0.345,0.583)	(0.381,0.631,0.821)	(0.190,0.417,0.667)	...	(0.274,0.512,0.762)
C12	(0.179,0.357,0.595)	(0.417,0.667,0.845)	(0.167,0.381,0.631)	...	(0.310,0.536,0.786)
C13	(0.143,0.333,0.583)	(0.524,0.774,0.952)	(0.262,0.500,0.738)	...	(0.357,0.583,0.798)
C14	(0.214,0.417,0.667)	(0.452,0.690,0.869)	(0.321,0.560,0.774)	...	(0.345,0.583,0.833)
C15	(0.286,0.500,0.702)	(0.464,0.714,0.893)	(0.226,0.476,0.726)	...	(0.381,0.619,0.833)
C16	(0.179,0.357,0.607)	(0.155,0.369,0.607)	(0.143,0.345,0.583)	...	(0.369,0.619,0.845)
C17	(0.131,0.310,0.560)	(0.464,0.702,0.881)	(0.333,0.560,0.750)	...	(0.333,0.583,0.810)
C18	(0.333,0.536,0.738)	(0.417,0.655,0.845)	(0.357,0.607,0.821)	...	(0.393,0.643,0.857)
C19	(0.214,0.405,0.643)	(0.143,0.333,0.583)	(0.202,0.381,0.607)	...	(0.357,0.607,0.857)
C20	(0.107,0.286,0.536)	(0.369,0.607,0.798)	(0.393,0.631,0.821)	...	(0.417,0.667,0.857)
C21	(0.155,0.321,0.571)	(0.321,0.571,0.810)	(0.369,0.619,0.845)	...	(0.000,0.000,0.000)

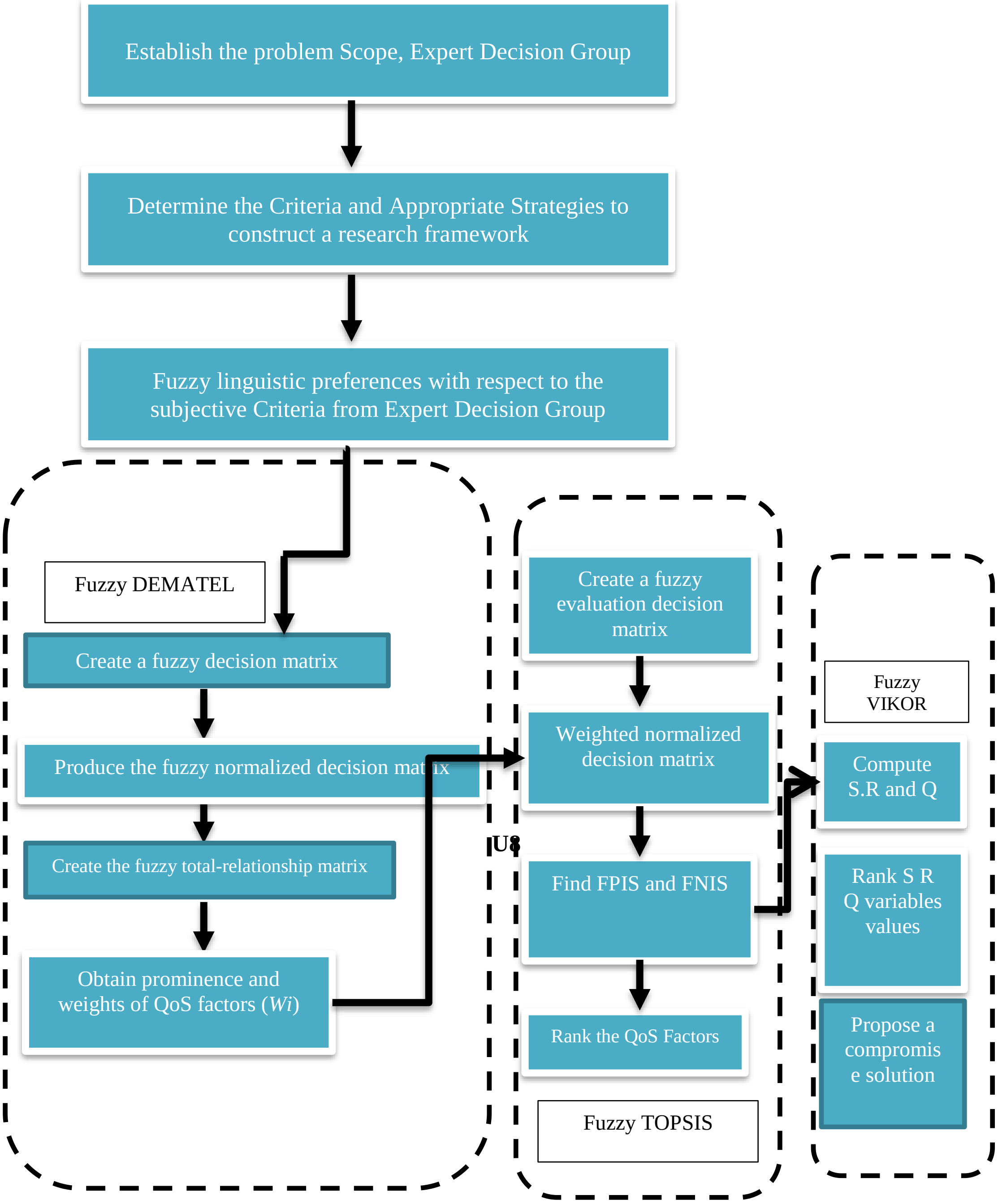

Fig. 3: Proposed method framework adapted from Sangaiah et al. (2015)

- Step 2: Normalize the fuzzy direct-relationship matrix. The following formula may be used to compute the normalized fuzzy direct-relation matrix:

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \tag{2}$$

where,

$$r = \max_{i,j}\left\{\max_{i}\sum_{j=1}^{n} u_{ij}, \max_{j}\sum_{i=1}^{n} u_{ij}\right\} \quad i,j \in \{1,2,3,\dots,n\}$$

The normalized fuzzy relationship matrix $\tilde{x}_{ij}$ is shown in Table 5.

- Step 3: Calculate the fuzzy total-relation matrix. In this step, the fuzzy total-relation matrix is calculated by the following formula:

$$\tilde{T} = \lim_{k\to+\infty}(\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k) \tag{3}$$

If each member of the fuzzy total-relation matrix is written as $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$, it can be calculated as follows:

$$[l''_{ij}] = x_l \times (I - x_l)^{-1} \tag{4}$$
$$[m''_{ij}] = x_m \times (I - x_m)^{-1} \tag{5}$$
$$[u''_{ij}] = x_u \times (I - x_u)^{-1} \tag{6}$$

In other words, the normalized matrix's inverse is calculated first, then subtracted from the Identity matrix I, and finally multiplied by the resulting matrix. The fuzzy direct-relation matrix is shown in Table 6.

Table 5: Normalized fuzzy relationship matrix $\tilde{x}_{ij}$

	C1	C2	C3	...	C21
C1	(0.000,0.000,0.000)	(0.019,0.035,0.048)	(0.017,0.031,0.044)	...	(0.017,0.033,0.048)
C2	(0.008,0.018,0.033)	(0.000,0.000,0.000)	(0.023,0.038,0.050)	...	(0.017,0.033,0.048)
C3	(0.006,0.018,0.033)	(0.016,0.030,0.043)	(0.000,0.000,0.000)	...	(0.019,0.035,0.050)
C4	(0.007,0.018,0.033)	(0.014,0.027,0.041)	(0.025,0.039,0.051)	...	(0.022,0.037,0.052)
C5	(0.009,0.022,0.035)	(0.016,0.030,0.043)	(0.020,0.035,0.048)	...	(0.019,0.034,0.049)
C6	(0.009,0.021,0.036)	(0.017,0.031,0.045)	(0.012,0.025,0.040)	...	(0.018,0.033,0.047)
C7	(0.010,0.022,0.037)	(0.027,0.041,0.052)	(0.018,0.033,0.046)	...	(0.021,0.036,0.050)
C8	(0.012,0.024,0.038)	(0.018,0.033,0.046)	(0.018,0.033,0.046)	...	(0.022,0.037,0.052)
C9	(0.011,0.022,0.036)	(0.024,0.039,0.051)	(0.012,0.026,0.041)	...	(0.022,0.038,0.052)
C10	(0.010,0.021,0.035)	(0.026,0.041,0.053)	(0.015,0.028,0.042)	...	(0.018,0.033,0.048)
C11	(0.009,0.021,0.035)	(0.023,0.038,0.050)	(0.012,0.025,0.041)	...	(0.017,0.031,0.046)
C12	(0.011,0.022,0.036)	(0.025,0.041,0.051)	(0.010,0.023,0.038)	...	(0.019,0.033,0.048)
C13	(0.009,0.020,0.035)	(0.032,0.047,0.058)	(0.016,0.030,0.045)	...	(0.022,0.035,0.048)
C14	(0.013,0.025,0.041)	(0.027,0.042,0.053)	(0.019,0.034,0.047)	...	(0.021,0.035,0.051)
C15	(0.017,0.030,0.043)	(0.028,0.043,0.054)	(0.014,0.029,0.044)	...	(0.023,0.038,0.051)
C16	(0.011,0.022,0.037)	(0.009,0.022,0.037)	(0.009,0.021,0.035)	...	(0.022,0.038,0.051)
C17	(0.008,0.019,0.034)	(0.028,0.043,0.054)	(0.020,0.034,0.046)	...	(0.020,0.035,0.049)
C18	(0.020,0.033,0.045)	(0.025,0.040,0.051)	(0.022,0.037,0.050)	...	(0.024,0.039,0.052)
C19	(0.013,0.025,0.039)	(0.009,0.020,0.035)	(0.012,0.023,0.037)	...	(0.022,0.037,0.052)
C20	(0.006,0.017,0.033)	(0.022,0.037,0.048)	(0.024,0.038,0.050)	...	(0.025,0.041,0.052)
C21	(0.009,0.019,0.035)	(0.019,0.035,0.049)	(0.022,0.038,0.051)	...	(0.000,0.000,0.000)

Table 6: Fuzzy total-relation matrix $\tilde{T}$

	C1	C2	C3	...	C21
C1	(0.000,0.000,0.000)	(0.019,0.035,0.048)	(0.017,0.031,0.044)	...	(0.017,0.033,0.048)
C2	(0.008,0.018,0.033)	(0.000,0.000,0.000)	(0.023,0.038,0.050)	...	(0.017,0.033,0.048)
C3	(0.006,0.018,0.033)	(0.016,0.030,0.043)	(0.000,0.000,0.000)	...	(0.019,0.035,0.050)
C4	(0.007,0.018,0.033)	(0.014,0.027,0.041)	(0.025,0.039,0.051)	...	(0.022,0.037,0.052)
C5	(0.009,0.022,0.035)	(0.016,0.030,0.043)	(0.020,0.035,0.048)	...	(0.019,0.034,0.049)
C6	(0.009,0.021,0.036)	(0.017,0.031,0.045)	(0.012,0.025,0.040)	...	(0.018,0.033,0.047)
C7	(0.010,0.022,0.037)	(0.027,0.041,0.052)	(0.018,0.033,0.046)	...	(0.021,0.036,0.050)
C8	(0.012,0.024,0.038)	(0.018,0.033,0.046)	(0.018,0.033,0.046)	...	(0.022,0.037,0.052)
C9	(0.011,0.022,0.036)	(0.024,0.039,0.051)	(0.012,0.026,0.041)	...	(0.022,0.038,0.052)
C10	(0.010,0.021,0.035)	(0.026,0.041,0.053)	(0.015,0.028,0.042)	...	(0.018,0.033,0.048)
C11	(0.009,0.021,0.035)	(0.023,0.038,0.050)	(0.012,0.025,0.041)	...	(0.017,0.031,0.046)
C12	(0.011,0.022,0.036)	(0.025,0.041,0.051)	(0.010,0.023,0.038)	...	(0.019,0.033,0.048)
C13	(0.009,0.020,0.035)	(0.032,0.047,0.058)	(0.016,0.030,0.045)	...	(0.022,0.035,0.048)
C14	(0.013,0.025,0.041)	(0.027,0.042,0.053)	(0.019,0.034,0.047)	...	(0.021,0.035,0.051)
C15	(0.017,0.030,0.043)	(0.028,0.043,0.054)	(0.014,0.029,0.044)	...	(0.023,0.038,0.051)
C16	(0.011,0.022,0.037)	(0.009,0.022,0.037)	(0.009,0.021,0.035)	...	(0.022,0.038,0.051)
C17	(0.008,0.019,0.034)	(0.028,0.043,0.054)	(0.020,0.034,0.046)	...	(0.020,0.035,0.049)
C18	(0.020,0.033,0.045)	(0.025,0.040,0.051)	(0.022,0.037,0.050)	...	(0.024,0.039,0.052)
C19	(0.013,0.025,0.039)	(0.009,0.020,0.035)	(0.012,0.023,0.037)	...	(0.022,0.037,0.052)
C20	(0.006,0.017,0.033)	(0.022,0.037,0.048)	(0.024,0.038,0.050)	...	(0.025,0.041,0.052)
C21	(0.009,0.019,0.035)	(0.019,0.035,0.049)	(0.022,0.038,0.051)	...	(0.000,0.000,0.000)

- Step 4: Defuzzify to obtain crisp values. To achieve a precise value of the total-relation matrix, the CFCS approach developed by Opricovic et al. (2004) was applied. The following are the steps of the CFCS method:

$$l_{ij}^{n}=\frac{(l_{ij}^{t}-\min l_{ij}^{t})}{\Delta_{\min}^{\max}} \tag{7}$$

$$m_{ij}^{n}=\frac{(m_{ij}^{t}-\min l_{ij}^{t})}{\Delta_{\min}^{\max}} \tag{8}$$

$$u_{ij}^{n}=\frac{(u_{ij}^{t}-\min l_{ij}^{t})}{\Delta_{\min}^{\max}} \tag{9}$$

So that,

$$\Delta_{\min}^{\max}=\max u_{ij}^{t}-\min l_{ij}^{t} \tag{10}$$

Calculating the upper and lower bounds of normalized values:

$$l_{ij}^{s}={m_{ij}^{n}}\Big/{(1+m_{ij}^{n}-l_{ij}^{n})} \tag{11}$$

$$u_{ij}^{s}={u_{ij}^{n}}\Big/{(1+u_{ij}^{n}-l_{ij}^{n})} \tag{12}$$

Crisp values are produced via the CFCS algorithm. Total normalized crisp values are calculated:

$$x_{ij}=\frac{[l_{ij}^{s}(1-l_{ij}^{s})+u_{ij}^{s}\times u_{ij}^{s}]}{[1-l_{ij}^{s}+u_{ij}^{s}]} \tag{13}$$

- Step 5: Set the threshold value. To calculate the internal relations matrix, the threshold value must be acquired. As a result, partial relationships are ignored, and the network relationship map (NRM) is drawn. Only relations with matrix T values larger than the threshold value are shown in the NRM. It is sufficient to compute the average values of the matrix T to compute the threshold value for relations. After determining the threshold intensity, any values in matrix T that are less than the threshold value are set to zero (Table 7). That is, the previously indicated causal relationship is ignored. The threshold value in this investigation was 0.1420. All matrix T values that are less than 0.1420 are set to zero. That is, the previously indicated causal relationship is ignored. The model of relevant relationships is shown in Table 7.

Table 7: Crisp values

	C1	C2	C3	...	C21
C1	0	0.156	0	...	0.156
C2	0	0	0.151	...	0.161
C3	0	0.143	0	...	0.149
C4	0	0	0	...	0.148
C5	0	0	0	...	0.145
C6	0	0.158	0	...	0.161
C7	0	0.168	0.148	...	0.165
C8	0	0.151	0	...	0.157
C9	0	0.161	0	...	0.161
C10	0	0.164	0	...	0.158
C11	0	0.157	0	...	0.152
C12	0	0.163	0	...	0.157
C13	0	0.169	0.143	...	0.161
C14	0	0.173	0.153	...	0.169
C15	0	0.169	0.145	...	0.166
C16	0	0	0	...	0.15
C17	0	0.169	0.149	...	0.164
C18	0	0.176	0.16	...	0.177
C19	0	0	0	...	0.151
C20	0	0.158	0.148	...	0.163
C21	0	0.166	0.156	...	0

- Step 6: Create a causal relationship diagram based on the final output. The following step is to compute the sum of each row and column of T. (in step 4). The sum of rows (D) and columns (R) is computed as follows:

$$D = \sum_{j=1}^{n} T_{ij} \tag{14}$$

$$R = \sum_{i=1}^{n} T_{ij} \tag{15}$$

$$Wij = \frac{[(D+R)^2+(D-R)^2]^1}{2} \tag{16}$$

Then, D and R may be used to determine the values of D+R and D-R, where D+R represents the degree of significance of factor I in the overall system and D-R represents the net impact that factor I brings to the system (Table 8).

The fuzzy TOPSIS method steps:

- Step 1: Make a normalized decision matrix. Based on the positive and negative ideal solutions, a normalized choice matrix may be derived via the following relation:

$$\tilde{r}_{ij} = c_j^* = \max_i c_{ij};\ \text{Positive ideal solution} \tag{17}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right);\ a_j^- = \min_i a_{ij};\ \text{Solution with a negative ideal (Table 9)} \tag{18}$$

- Step 2: Construct the weighted normalized decision matrix. The weighted normalized decision matrix may be generated by multiplying the weight of each criterion in the normalized fuzzy decision matrix by the following formula (Table 10).

$$\tilde{v}_{ij} = \tilde{r}_{ij} . \tilde{w}_{ij} \tag{19}$$

where, $\tilde{w}_{ij}$ indicates the weight of criteria c_j

- Step 3: Calculate the fuzzy positive ideal solution (FPIS, A*) and the fuzzy negative ideal solution (FNIS, A-).

Table 8: QoS factors, R, D D+R, D-R, and weight statistics

QoS Factors	R	D	D+R	D-R	*Wi*
Integrity	2.275	2.979	5.254	0.704	0.042285
Transaction	3.271	3.092	6.363	-0.179	0.050777
Response Time	2.948	2.731	5.678	-0.217	0.047709
Cost/Price	2.858	2.657	5.515	-0.201	0.049975
Reliability	2.816	2.642	5.458	-0.173	0.047044
Availability	2.88	3.097	5.977	0.217	0.048185
Accessibility	3.129	3.136	6.265	0.007	0.048173
Performance	2.99	2.908	5.897	-0.082	0.046442
Security	3.059	2.981	6.04	-0.078	0.047338
Reputation	3.024	3.015	6.039	-0.01	0.048836
Throughput	2.92	2.902	5.822	-0.017	0.051428
Compliance	2.932	3.002	5.934	0.069	0.049904
Best Practices	3.085	3.036	6.122	-0.049	0.04302
Documentation	3.206	3.241	6.447	0.035	0.049872
Success ability	3.144	3.112	6.256	-0.032	0.051277
Latency	2.696	2.697	5.393	0.001	0.048905
Encryption	3.126	3.126	6.252	0	0.051999
Adaptability	3.048	3.372	6.42	0.324	0.042285
Portability	2.774	2.732	5.506	-0.042	0.050777
Storage	3.158	2.971	6.128	-0.187	0.047709
Consistency	3.305	3.214	6.518	-0.091	0.049975

Table 9: Normalized decision matrix $\tilde{r}_{ij}$

	C1	C2	C3	...	C21
C1	(0.000,0.000,0.000)	(0.330,0.596,0.836)	(0.320,0.597,0.847)	...	(0.320,0.611,0.903)
C2	(0.180,0.377,0.705)	(0.000,0.000,0.000)	(0.473,0.750,0.986)	...	(0.334,0.625,0.917)
C3	(0.147,0.377,0.722)	(0.266,0.519,0.747)	(0.000,0.000,0.000)	...	(0.389,0.680,0.972)
C4	(0.164,0.394,0.738)	(0.240,0.468,0.697)	(0.473,0.750,1.000)	...	(0.389,0.680,0.972)
C5	(0.197,0.459,0.771)	(0.279,0.532,0.760)	(0.375,0.666,0.917)	...	(0.334,0.625,0.917)
C6	(0.180,0.427,0.771)	(0.279,0.532,0.772)	(0.209,0.459,0.750)	...	(0.292,0.583,0.861)
C7	(0.247,0.508,0.853)	(0.468,0.722,0.912)	(0.334,0.611,0.875)	...	(0.375,0.666,0.945)
C8	(0.278,0.508,0.820)	(0.317,0.570,0.798)	(0.292,0.583,0.847)	...	(0.403,0.694,0.986)
C9	(0.247,0.475,0.803)	(0.431,0.697,0.912)	(0.209,0.473,0.750)	...	(0.417,0.708,1.000)
C10	(0.230,0.459,0.787)	(0.456,0.722,0.937)	(0.278,0.527,0.805)	...	(0.348,0.639,0.931)
C11	(0.213,0.459,0.787)	(0.393,0.659,0.862)	(0.236,0.501,0.792)	...	(0.320,0.597,0.889)
C12	(0.262,0.508,0.836)	(0.481,0.747,0.924)	(0.195,0.445,0.736)	...	(0.348,0.611,0.903)
C13	(0.197,0.459,0.803)	(0.545,0.811,1.000)	(0.292,0.555,0.833)	...	(0.389,0.653,0.917)
C14	(0.295,0.558,0.902)	(0.456,0.710,0.899)	(0.375,0.653,0.889)	...	(0.389,0.666,0.958)
C15	(0.394,0.672,0.950)	(0.481,0.747,0.950)	(0.222,0.513,0.805)	...	(0.459,0.736,0.986)
C16	(0.247,0.475,0.820)	(0.152,0.380,0.633)	(0.167,0.403,0.680)	...	(0.445,0.736,0.986)
C17	(0.180,0.394,0.738)	(0.456,0.710,0.912)	(0.348,0.611,0.847)	...	(0.389,0.680,0.945)
C18	(0.459,0.722,1.000)	(0.393,0.633,0.849)	(0.362,0.653,0.917)	...	(0.431,0.722,0.972)
C19	(0.278,0.525,0.853)	(0.114,0.291,0.557)	(0.195,0.389,0.653)	...	(0.417,0.708,1.000)
C20	(0.131,0.344,0.689)	(0.393,0.646,0.849)	(0.431,0.708,0.945)	...	(0.473,0.764,1.000)
C21	(0.180,0.377,0.722)	(0.354,0.620,0.873)	(0.417,0.708,0.986)	...	(0.000,0.000,0.000)

Table 10: Fuzzy weighted normalized decision matrix $\tilde{v}_{ij}$

	C1	C2	C3	....	C21
C1	(0.000,0.000,0.000)	(0.017,0.030,0.042)	(0.014,0.027,0.038)	....	(0.017,0.032,0.047)
C2	(0.008,0.016,0.030)	(0.000,0.000,0.000)	(0.021,0.034,0.045)	....	(0.017,0.033,0.048)
C3	(0.006,0.016,0.031)	(0.014,0.026,0.038)	(0.000,0.000,0.000)	....	(0.020,0.035,0.051)
C4	(0.007,0.017,0.031)	(0.012,0.024,0.035)	(0.021,0.034,0.045)	....	(0.020,0.035,0.051)
C5	(0.008,0.019,0.033)	(0.014,0.027,0.039)	(0.017,0.030,0.042)	....	(0.017,0.033,0.048)
C6	(0.008,0.018,0.033)	(0.014,0.027,0.039)	(0.009,0.021,0.034)	....	(0.015,0.030,0.045)
C7	(0.010,0.021,0.036)	(0.024,0.037,0.046)	(0.015,0.028,0.040)	....	(0.019,0.035,0.049)
C8	(0.012,0.021,0.035)	(0.016,0.029,0.041)	(0.013,0.026,0.038)	....	(0.021,0.036,0.051)
C9	(0.010,0.020,0.034)	(0.022,0.035,0.046)	(0.009,0.021,0.034)	....	(0.022,0.037,0.052)
C10	(0.010,0.019,0.033)	(0.023,0.037,0.048)	(0.013,0.024,0.036)	....	(0.018,0.033,0.048)
C11	(0.009,0.019,0.033)	(0.020,0.033,0.044)	(0.011,0.023,0.036)	....	(0.017,0.031,0.046)
C12	(0.011,0.021,0.035)	(0.024,0.038,0.047)	(0.009,0.020,0.033)	....	(0.018,0.032,0.047)
C13	(0.008,0.019,0.034)	(0.028,0.041,0.051)	(0.013,0.025,0.038)	....	(0.020,0.034,0.048)
C14	(0.012,0.024,0.038)	(0.023,0.036,0.046)	(0.017,0.030,0.040)	....	(0.020,0.035,0.050)
C15	(0.017,0.028,0.040)	(0.024,0.038,0.048)	(0.010,0.023,0.036)	....	(0.024,0.038,0.051)
C16	(0.010,0.020,0.035)	(0.008,0.019,0.032)	(0.008,0.018,0.031)	....	(0.023,0.038,0.051)
C17	(0.008,0.017,0.031)	(0.023,0.036,0.046)	(0.016,0.028,0.038)	....	(0.020,0.035,0.049)
C18	(0.019,0.031,0.042)	(0.020,0.032,0.043)	(0.016,0.030,0.042)	....	(0.022,0.038,0.051)
C19	(0.012,0.022,0.036)	(0.006,0.015,0.028)	(0.009,0.018,0.030)	....	(0.022,0.037,0.052)
C20	(0.006,0.015,0.029)	(0.020,0.033,0.043)	(0.020,0.032,0.043)	....	(0.025,0.040,0.052)
C21	(0.008,0.016,0.031)	(0.018,0.031,0.044)	(0.019,0.032,0.045)	....	(0.000,0.000,0.000)

The alternatives' FPIS and FNIS can be defined as follows:

A^* A^-

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*\} = \left\{\left(\max_j v_{ij} \,|\, i \in B\right), \left(\min_j v_{ij} \,|\, i \in C\right)\right\} \tag{20}$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\} = \left\{\left(\min_j v_{ij} \,|\, i \in B\right), \left(\max_j v_{ij} \,|\, i \in C\right)\right\} \tag{21}$$

where, $\tilde{v}_i^*$ is the max value of i for all the alternatives and $\tilde{v}_1^-$is the min value of i for all the alternatives. B and C represent the positive and negative ideal solutions, respectively (Table 11).

- Step 4: Determine the distance between each option and the fuzzy positive ideal solution A*as well as the distance between each alternative and the fuzzy negative ideal solution. A-The distances between each option and FPIS and FNIS are estimated as follows:

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad i = 1,2,\ldots,m \tag{22}$$
$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad i = 1,2,\ldots,m \tag{23}$$

When given two triangular fuzzy integers, d is the distance between them, (a_1, b_1, c_1) and (a_2, b_2, c_2). The following formula may be used to determine the distance between the two:

$$d_v(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \tag{24}$$

Note that $d(\tilde{v}_{ij}, \tilde{v}_j^*)$ and $d(\tilde{v}_{ij}, \tilde{v}_j^-)$ are crisp numbers (Table 12).

Table 11: The QoS factors, positive, and negative ideal solutions

	Positive ideal	Negative ideal
Integrity	(0.019,0.031,0.042)	(0.000,0.000,0.000)
Transaction	(0.028,0.041,0.051)	(0.000,0.000,0.000)
Response Time	(0.021,0.034,0.045)	(0.000,0.000,0.000)
Cost/Price	(0.020,0.032,0.044)	(0.000,0.000,0.000)
Reliability	(0.023,0.035,0.044)	(0.000,0.000,0.000)
Availability	(0.024,0.037,0.048)	(0.000,0.000,0.000)
Accessibility	(0.024,0.038,0.050)	(0.000,0.000,0.000)
Performance	(0.023,0.035,0.047)	(0.000,0.000,0.000)
Security	(0.026,0.040,0.048)	(0.000,0.000,0.000)
Reputation	(0.023,0.037,0.048)	(0.000,0.000,0.000)
Throughput	(0.024,0.037,0.046)	(0.000,0.000,0.000)
Compliance	(0.024,0.038,0.047)	(0.000,0.000,0.000)
Best Practices	(0.025,0.039,0.049)	(0.000,0.000,0.000)
Documentation	(0.025,0.039,0.051)	(0.000,0.000,0.000)
Accessibility	(0.027,0.040,0.050)	(0.000,0.000,0.000)
Latency	(0.019,0.032,0.043)	(0.000,0.000,0.000)
Encryption	(0.026,0.040,0.050)	(0.000,0.000,0.000)
Adaptability	(0.026,0.041,0.051)	(0.000,0.000,0.000)
Portability	(0.022,0.036,0.044)	(0.000,0.000,0.000)
Storage	(0.026,0.039,0.049)	(0.000,0.000,0.000)
Consistency	(0.025,0.040,0.052)	(0.000,0.000,0.000)

Table 12: The QoS factors, distance from positive ideal, and distance from negative ideal

	Distance from positive ideal	Distance from negative ideal
C1	0.206	0.592
C2	0.162	0.636
C3	0.261	0.542
C4	0.27	0.533
C5	0.29	0.514
C6	0.188	0.612
C7	0.176	0.622
C8	0.234	0.566
C9	0.206	0.595
C10	0.196	0.603
C11	0.222	0.579
C12	0.194	0.607
C13	0.192	0.607
C14	0.144	0.652
C15	0.18	0.618
C16	0.257	0.542
C17	0.177	0.62
C18	0.125	0.67
C19	0.271	0.531
C20	0.213	0.586
C21	0.158	0.646

- Step 5: Calculate the closeness coefficient and rank the alternatives: The closeness coefficient of each alternative can be calculated as follows:

$$\mathrm{CC_i} = \frac{\mathrm{S_i^-}}{\mathrm{S_i^+ + S_i^-}} \tag{25}$$

The output of Eq. 25 is presented in Table 13. The modified steps of the fuzzy VIKOR method:

- Step 1: Compute the values $\tilde{\mathrm{S}}_\mathrm{i}$and $\tilde{\mathrm{R}}_\mathrm{i}$: The normalized matrix is first converted into a weighted normalized decision matrix, and then the values are computed $\tilde{\mathrm{S}}_\mathrm{i}$and $\tilde{\mathrm{R}}_\mathrm{i}$ can be calculated as follows:

If $\quad \tilde{\mathrm{R}}_\mathrm{i} = (\mathrm{R_i^l, R_i^m, R_i^r})$ and $\tilde{\mathrm{s}}_\mathrm{i} = (\mathrm{s_i^l, s_i^m, s_i^r})$

$$\tilde{\mathrm{S}}_\mathrm{i} = \textstyle\sum_{\mathrm{j=1}}^{\mathrm{J}} \left(\tilde{\mathrm{w}}_\mathrm{j} \otimes \tilde{\mathrm{d}}_\mathrm{ij}\right) \tag{26}$$

$$\tilde{\mathrm{R}}_\mathrm{i} = \max_\mathrm{j}\left(\tilde{\mathrm{w}}_\mathrm{j} \otimes \tilde{\mathrm{d}}_\mathrm{ij}\right) \tag{27}$$

- Step 2: Determine the VIKOR index (Q): Q's value may be computed as follows (Table 14):

If $\quad \tilde{\mathrm{Q}}_\mathrm{i} = \left(\mathrm{Q_i^l, Q_i^m, Q_i^r}\right) \qquad (28)$

$$\tilde{\mathrm{Q}}_\mathrm{i} = \mathrm{v}\frac{(\tilde{\mathrm{s}}_\mathrm{i} \ominus \tilde{\mathrm{s}}^*)}{\mathrm{s}^{\circ\mathrm{r}} - \mathrm{s}^{*\mathrm{l}}} \oplus (1-\mathrm{v})\frac{(\tilde{\mathrm{R}}_\mathrm{i} \ominus \tilde{\mathrm{R}}^*)}{\mathrm{R}^{\circ\mathrm{r}} - \mathrm{R}^{*\mathrm{l}}}$$

where,

$$\tilde{\mathrm{s}}^* = \min_\mathrm{i} \tilde{\mathrm{s}}_\mathrm{i}$$
$$\mathrm{s}^{\circ\mathrm{r}} = \max_\mathrm{i}\ \mathrm{s_i^r}$$
$$\tilde{\mathrm{R}}^* = \min_\mathrm{i} \tilde{\mathrm{R}}_\mathrm{i}$$
$$\mathrm{R}^{\circ\mathrm{r}} = \max_\mathrm{i}\ \mathrm{R_i^r}$$

In this study, the variable v, which represents the highest group utility, is equal to 0.5. The following formula may be used to convert the fuzzy numbers S, R, and Q into crisp numbers.

If $\quad \tilde{\mathrm{A}} = (\mathrm{l, m, r})$ ($\tilde{\mathrm{A}}$ is expressed as a fuzzy number)

$$\mathrm{Crisp}(\tilde{\mathrm{A}}) = \frac{2\mathrm{m+l+r}}{4} \tag{30}$$

- Step 3: Propose a workable solution: In this stage, a choice is made based on the descending order of the values R, S, and Q for the possibilities. Two requirements must be met, and a variety of compromise solutions might be provided in response to these two conditions:

Table 13: The closeness coefficient of each QoS factor and the ranking order

QoS Factors	Ci	Rank
C1	0.742	13
C2	0.797	4
C3	0.675	18
C4	0.664	19
C5	0.64	21
C6	0.765	8
C7	0.78	5
C8	0.708	16
C9	0.743	12
C10	0.755	11
C11	0.723	15
C12	0.758	10
C13	0.759	9
C14	0.819	2
C15	0.774	7
C16	0.678	17
C17	0.778	6
C18	0.843	1
C19	0.663	20
C20	0.733	14
C21	0.803	3

Table 14: Fuzzy R, S, and Q values

	R	S	Q
C1	(0.019,0.031,0.042)	(0.306,0.208,0.684-)	(0.735,0.046,0.819-)
C2	(0.028,0.041,0.051)	(0.335,0.177,0.656-)	(0.613,0.193,0.936-)
C3	(0.022,0.034,0.045)	(0.255,0.277,0.739-)	(0.673,0.133,0.889-)
C4	(0.020,0.032,0.044)	(0.244,0.293,0.752-)	(0.699,0.100,0.875-)
C5	(0.023,0.035,0.044)	(0.238,0.298,0.761-)	(0.647,0.151,0.872-)
C6	(0.025,0.039,0.048)	(0.338,0.181,0.662-)	(0.660,0.156,0.892-)
C7	(0.025,0.038,0.050)	(0.346,0.167,0.648-)	(0.668,0.139,0.920-)
C8	(0.022,0.034,0.047)	(0.293,0.224,0.698-)	(0.681,0.108,0.897-)
C9	(0.026,0.039,0.048)	(0.314,0.211,0.688-)	(0.638,0.176,0.911-)
C10	(0.023,0.036,0.048)	(0.320,0.202,0.677-)	(0.685,0.131,0.906-)
C11	(0.025,0.038,0.046)	(0.298,0.232,0.709-)	(0.641,0.165,0.893-)
C12	(0.024,0.038,0.047)	(0.319,0.209,0.685-)	(0.662,0.159,0.896-)
C13	(0.026,0.040,0.049)	(0.325,0.197,0.675-)	(0.633,0.176,0.915-)
C14	(0.025,0.040,0.051)	(0.368,0.140,0.621-)	(0.666,0.160,0.931-)
C15	(0.027,0.040,0.050)	(0.343,0.175,0.655-)	(0.632,0.173,0.923-)
C16	(0.019,0.032,0.043)	(0.247,0.281,0.737-)	(0.705,0.099,0.853-)
C17	(0.025,0.039,0.050)	(0.344,0.171,0.647-)	(0.658,0.159,0.918-)
C18	(0.025,0.040,0.051)	(0.400,0.101,0.583-)	(0.681,0.142,0.912-)
C19	(0.020,0.034,0.044)	(0.256,0.277,0.735-)	(0.695,0.126,0.866-)
C20	(0.026,0.039,0.049)	(0.308,0.212,0.680-)	(0.630,0.175,0.918-)
C21	(0.025,0.040,0.052)	(0.378,0.159,0.646-)	(0.672,0.173,0.950-)

- Condition 1: Acceptable benefit: $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$ where $A^{(1)}$ is an alternative to first place and $A^{(2)}$ is the option ranked second in the ranking list by Q. m is the number of alternatives.
- Condition 2: Acceptable decision-making stability: The alternative $A^{(1)}$ S or/and R must also rank it as the highest.

If one of the prerequisites is not met, a list of compromise options is provided, which includes:

- Solution 1: Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if Condition 1 is not satisfied; Alternative $A^{(M)}$ is determined by $Q(A^{(M)}) - Q(A^{(1)}) < 1/(m-1)$ for maximum M (the positions of these alternatives are "in closeness").
- Solution 2: Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition 2 is not satisfied.
- Solution 3: If both requirements are met, the alternative with the lowest Q value will be chosen as the best alternative. The results of the conditions survey are presented in Table 16.

5. Data analysis and results

The data were analyzed in the following folds. Thus, first, the 21 experts' rating of the 21 QoS factors was captured in an excel file format for each expert. To meet the contributions of this study as claimed in the introduction, further analysis was performed on each expert's data using a commercial software called OnlineOutput from https://onlineoutput.com/. The software produced the results. The authors adopted the OnlineOutput software for the analysis owing to its simplicity, user-friendly, data and model editing, no need to install, and above all low cost to use as compared to other software tools such as; MATLAB, R, and excel. Additionally, this analysis used the OnelineOutput software due to its ability to handle many criteria and alternatives without placing a threshold on the number of criteria and alternatives to be used. Showed in sections 5.1, 5.2, 5.3, and 5.4 are the results of the QoS factors Model, QoS factors ranking, and the compromise solution and Sensitivity analysis of QoS factors respectively.

5.1. QoS factors model

Table 8 shows the results of the QoS factors model statistics that classify the QoS factors into Cause-and-Effect groups based on the D+R statistic values. The study used D+R and D-R statistics from which calculated the weights of each QoS factor using equation 8 and the result presented in Table 8. As far as D+R and D-R statistics are concerned, all the QoS factors scored values between 5-7 and -0.217–0.704 boundaries inclusive for D+R and D-R accordingly. Following the (Lin et al., 2013) criterion for assessing QoS factors, the higher the D+R value, the greater the importance of the criteria. As shown in Table 8, The D+R values presented the degree of importance of the QoS factors in the model. In terms of the degree of importance, consistency was ranked first followed by documentation, adaptability, success ability, encryption, storage, best practices, security reputation, availability, compliance, performance, throughput, response time, cost, price, portability, reliability, and finally integrity in descending order (Table 8 and Fig. 1). The D-R denoted the degree to which QoS factors influenced the model. In general, a positive D-R value reflects a causative variable, whereas, a negative D-R value represents an effect variable(Pandey et al., 2019). According to the results in Fig. 1, and Table 8, Integrity, Availability, Access Ability, Compliance, Documentation, Latency, and Adaptability were classified as causality variables. Whereas Transaction, Response Time, Cost/Price, Reliability, Performance, Security, Reputation, Best Practices, Success Ability, Encryption, Portability, Storage, and Consistency were grouped effect variables.

5.2. QoS factors ranking

Table 13 and Fig. 4 show the results of the Fuzzy TOPSIS ranking. The fuzzy TOPSIS technique is used to rank and efficiently analyze the QoS factors. According to Sangaiah et al. (2015), the Fuzzy TOPSIS technique is based on the premise that the chosen option should be the “farthest distance” from the ideal solution and the “shortest distance” from the ideal solution. As shown in Table 13 and Fig. 4, the QoS factors; C18, C14, C21, C2, C7, C17, C15, and C6 were extreme QoS factors since their values are closer to the positive ideal solution and farthest from the negative ideal solution. As a result, from Table 13 and Fig. 4, The QoS factors were ranked in the descending order as followed; C18> C14 > C21 > C2 > C7 > C17 > C15 > C6 > C13 > C12 > C10 > C9 > C1 > C20 > C11 > C8 > C16 > C3 > C4 > C19 > C5. That is Adaptability, Documentation, Consistency, Transaction, Accessibility, Encryption, Success ability, Availability, Best Practices, Compliance, Reputation, Security, Integrity, Storage, Throughput, Performance, Latency, Response Time, Cost, Portability, and, Reliability.

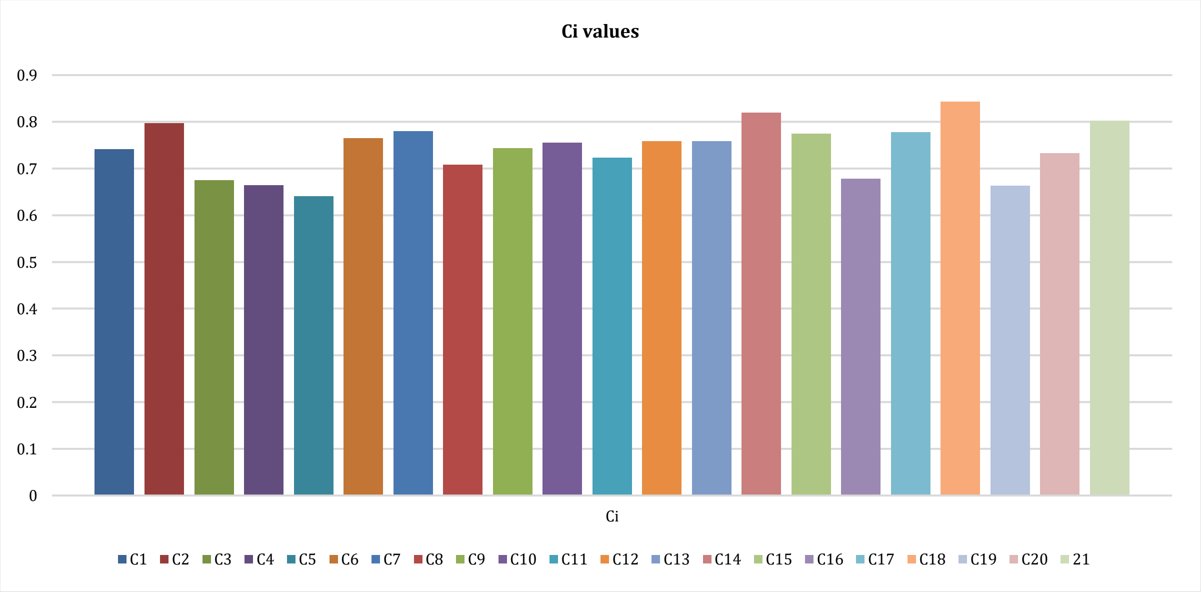

Fig. 4: Closeness coefficient of each QoS factor

5.3. Compromise solution

The ranking based on the compromise solution was done using the Fuzzy VIKOR. The Fuzzy VIKOR is a rating technique that was developed by Afful-Dadzie et al. (2014b), and Opricovic et al. (2004). The VIKOR approach begins by establishing three things; a compromise ranking list, a compromise solution, and a weight stability interval for the compromise solution (Opricovic et al., 2004). The Fuzzy VIKOR MCDM method's core idea is to cope with ranking and selection of alternatives that have many conflicting or incommensurable criteria (Afful-Dadzie et al., 2014a). To propose a workable compromise solution, two conditions namely;

condition 1 and condition 2 are followed (Ayouni et al., 2021; Opricovic et al., 2004).

Condition 1: Acceptable benefit: $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$ where $A^{(1)}$ is an alternative to first place and $A^{(2)}$ is the option ranked second in the ranking list by Q. m is the number of alternatives. Condition 2: Acceptable decision-making stability: The alternative $A^{(1)}$ S or/and R must also rank it as the highest.

If one of the prerequisites is not met, a list of compromise options is provided, which includes:

Solution 1: Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if Condition 1 is not satisfied; Alternative $A^{(M)}$ is determined by $Q(A^{(M)}) - Q(A^{(1)}) < 1/(m-1)$ for maximum M (the positions of these alternatives are "in closeness"). As shown in Tables 15 and 3, QoS factors C1, C16, and C4 are selected as the alternative QoS factors. These are; Integrity, Latency, and Cost.

Table 15: The crisp values and rankings of R, S, and Q

	Crisp value of R	Rank in R	Crisp value of S	Rank in S	Crisp value of Q	Rank in Q
C1	0.031	1	0.199	12	0.044	1
C2	0.04	21	0.169	7	0.177	21
C3	0.034	5	0.259	18	0.12	6
C4	0.032	3	0.273	20	0.094	3
C5	0.034	6	0.28	21	0.132	9
C6	0.038	11	0.171	8	0.136	11
C7	0.038	12	0.159	4	0.132	10
C8	0.034	7	0.213	15	0.108	5
C9	0.038	13	0.199	14	0.156	16
C10	0.036	8	0.19	10	0.121	7
C11	0.037	9	0.219	16	0.145	14
C12	0.037	10	0.196	11	0.138	12
C13	0.039	16	0.186	9	0.158	18
C14	0.039	19	0.133	2	0.146	15
C15	0.039	18	0.166	6	0.159	19
C16	0.032	2	0.263	19	0.086	2
C17	0.038	15	0.161	5	0.145	13
C18	0.039	17	0.097	1	0.129	8
C19	0.033	4	0.258	17	0.106	4
C20	0.038	14	0.199	13	0.159	20
C21	0.04	20	0.146	3	0.156	17

From Table 16, the conditions followed in the Fuzzy VIKOR approach are presented. As indicated, condition 1 was non-acceptance meaning it did not meet the acceptance condition given in condition 1. Condition 2–means acceptance, which implied condition 2 was accepted which gave solution 1 as the selected solution then. As indicated in Table 3, C1, C4 and C16 were found to be conflicting or incommensurable QoS factors.

Table 16: The result of the conditions survey

Condition 1	Non-acceptance
Condition 2	
Selected solution	Solution 1

5.4. Sensitivity analysis

According to Evans (1984) Sensitivity analysis is mathematical research that determines how possible modifications or mistakes in parameter values affect model results. Sensitivity analysis, in an applied organizational environment, may be roughly described as a study to test the responsiveness of an analysis's results to modifications or mistakes in parameter values employed in the analysis. 'The use of sensitivity analysis improves the compatibility of outcomes (Chen et al., 2010; Ustaoglu and Aydınoglu, 2020). This study employed the Fuzzy TOPSIS Technique to perform the sensitivity analysis. The resilience ability of this model was tested to verify the scientific validity of the QoS factors evaluation model utilizing the Fuzzy DEMATEL-Fuzzy TOPSIS and Fuzzy VIKOR techniques. The testing was done using the coefficient values of the Fuzzy TOPSIS techniques under three different weights scenarios. If a change in the input weights of the model results in a vast difference in the ranking order, then the model is susceptible to sensitivity analysis. But, when an alteration in the weights of the input variables or criteria results in a negligible change in the final ranking, then the model is robust to sensitivity analysis. Assessment of a change in weight of key QO factors of a model (i.e., Response Time, Availability, Storage, Security among others) would produce a significant variance in a decision making can verify the decision-making model as scientific (Wang et al., 2021). Given this, the sensitivity analysis was conducted in three ways; Scenario One, Scenario Two, and Scenario Three as shown in Fig. 2, Scenario One (S1) coefficient values were based on the proposed methodology's initial weights. Scenario Two (S2) saw the original weights changed to see how it affected the ranking position. In Scenario Three (S3), the weights of some QoS factors were removed to see how they affected the ranking. According to Ustaoglu and Aydınoglu (2020), resilience is achieved if there is no significant change in values in S1, S2, and S3. Given that, the coefficient values of the scenario presented in Fig. 3 demonstrate no significant changes, it could be concluded that the model was robust to sensitivity analysis.

6. Discussion

The purpose of this study was to examine combined web and cloud QoS factors using integrated fuzzy MCDM methods. The findings propose a QoS model of web and cloud services that classified QoS factors into cause-and-effect groups. integrity, availability, accessibility, compliance, documentation, latency, and adaptability are the causal factors. This implies that the QoS factors (i.e., Service Integrity, Service Availability, Service Access Ability, and Service Compliance among others) are independent in the model and believed to cause service positively or negatively. As a result, depending on the nature of the factor (i.e., either cost factors like response time, Throughput, and Latency that aim to minimize or benefit factors like the rest that seek to maximize), the greater the value of a benefit causative factor of online service, the more satisfied service customers are using that service and vice versa. Likewise, the smaller the values of a cost causative factor of online service, the more satisfied service customers are using that service and vice versa. Also, the findings discover transaction, response time, cost/price, reliability, performance, security, reputation, best practices, Success Ability, encryption, portability, storage, and consistency as influential QoS factors. This points out that service customers and providers like services that have better QoS factors such as transaction, response time, cost/price, reliability, performance, security, reputation, best practices, success Ability, encryption, portability, storage, and consistency. Therefore, this study suggests that improving the causative and influential QoS factors of Online services will improve the satisfaction level of service customers and maximize profit for service providers. This QoS model is different from Park and Jeong, (2013) QoS model which contains only 6 criteria: Functionality, Reliability, Usability, Efficiency, Maintainability, and Business. Also, the model of Park and Jeong (2013) was only for cloud services.

In addition, the study finds that adaptability, documentation, consistency, transaction, and accessibility are the most ranked QoS factors of online services. This implies that though all the QoS factors are important, paramount importance should be given to the QoS in the order of importance as presented in the result section of this study. Even though service response time and service security are usually regarded as very important in practice, they are not among the top five factors. Following, the findings of this study as far as ranking of QoS factors are concerned, the five most ranked QoS factors and by extension following the order of importance provided by this study will result in better service to customers. This result confirms the findings of Maheswari and Karpagam (2018) that, Fuzzy TOPSIS offered respectable results for any expert preference. Moreover, the study found that integrity, cost, and latency are conflicting or incommensurable factors meaning, they are having no common standard of measurements. OR they are unable to be judged by the same standards. Finally, the sensitivity analysis result demonstrates no clear changes in the ranking order, hence, this study's model has a greater resistance to sensitivity analysis. This finding conforms with the results of Kaviani et al. (2019), Kumar et al. (2018), and Tiwari and Kumar (2021) where the authors found their fuzzy MCDM models were robust to sensitivity analysis. Hence, this study confirms the position of existing knowledge on sensitivity analysis in the QoS literature.

6.1. Implication for research, policy, and practice

This research focused on combining web and cloud QoS factors using integrated fuzzy MCDM methods. The findings obtained offer some insightful contributions to research, policymakers, and service providers. For research, to the best of the knowledge of the authors, so far, no study has investigated hybridized QoS factors of web and cloud services under an integrated fuzzy MCDM environment. Hence, this study contributes to knowledge by way of the research approach. The lack of knowledge on composite QoS factors of web and cloud services cum factors that are considered causative and influential factors not only contribute to the QoS literature but opens the gate for further discourse. The findings imply that, given that practically everything is now done over the internet, it is salient to analyze both the functional and non-functional needs (i.e., integrity, response time, availability, security, latency, and throughput, among others) of online services. Also, witnessing the voluminous nature of candidate services available via the internet providing similar services, it is necessary to assess the QoS factors of services to assist service users and service providers improve on the optimal use and efficient service provision respectively particularly from experts' perspectives while the expected subjectiveness likely to emanate from experts handled using fuzzy set theory. This research combined the fuzzy logic theory with three MCDM methods; DEMATEL, TOPSIS, and VIKOR to examine both web and cloud QoS factors based on experts' opinions. Considering that, the QoS factors are classified into causal and influential factors and also ranked, policymakers can consider making the factors a standard. For practice, the findings can serve as a blueprint for service platform developers to improve on the non-functional requirements of the systems.

6.2. Limitations and future research directions

The limitation of this study stemmed from the dependency on data from QoS experts from only one developing country (i.e. Ghana). As such, the findings are restricted to a small educational institution in resources constrained environment. To address this limitation, we suggest further studies to examine QoS factors using secondary data or from the perspective of multiple developing and developed countries. Further studies can also improve on this study by considering the Fuzzy-Type-3 system with other MCDM Methods. Future studies can also download the QWS-dataset from the internet and treat all causal variables found in this study as independent variables and effect variables as the dependent variable for a performance evaluation study using Machine Learning on online services.

7. Conclusion

The study intended to assess online QoS factors under a fuzzy MCDM environment. From the findings, the higher the values of a benefit causative component of online service, the happier service users are, and vice versa. Similarly, the lower the values of a cost-causative component of online service, the happier service clients are, and vice versa. Also, the findings of this study are critical for policymakers since they contribute to a better understanding of QoS variables in online and cloud services for which policymakers can make standards. Furthermore, IT specialists should be aware that, while all QoS elements are significant, the order of importance of QoS factors provided by this study is necessary for a better service experience.

This study contributes to the approach and research on online QoS factors in Fuzzy MCDM Methods. First, this study successfully combined three MCDM approaches in the subject of online service selection. Also, it incorporates expert insights to present a cause and effect model of QoS elements that consolidates the QoS components of both web and cloud services. As a result, we contend that the combined web and cloud QoS factors provide a more complete QoS factors model for service selection and optimization research in Computer Science. We also use sensitivity analysis to expand on the current concept of model resilience. Where changes in the input weight have no substantial effect on the ranking order.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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