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AN INTEGRATED FUZZY MULTI-CRITERIA DECISION-MAKING METHODS FOR SERVICE SELECTION: A SYSTEMATIC LITERATURE REVIEW AND META-ANALYSIS

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ABSTRACT

Background: Service selection refers to the process of picking services that best fulfill the user's functional and non-functional requirements. It is possible to pick a web service or a cloud service. Researchers examined a large number of service selection assessments that utilized different services based on Quality of Service (QoS) variables utilizing Multi-Criteria Decision Making Methods. Despite its positive outcomes, earlier research has shown that Multi-Criteria Decision Making Methods alone cannot handle the incompleteness, ambiguity, uncertainty, and, most importantly the fuzziness inherent in decision-making processes due to human involvement. To circumvent these constraints, the usage of Fuzzy Multi-Criteria Decision Making Methods is a growing study topic.

Objective: While the research community carefully examined the methodologies used by researchers when studying service selection, there is still a noticeable limited knowledge on how Fuzzy Multi-Criteria Decision Making Methods have been adopted for service selection and whether there are points of improvement to allow for a better service selection evaluation. The purpose of this paper is to offer an overview of and examine the use of Fuzzy Multi-Criteria Decision Making Methods in the subject of service selection with a focus on five research questions.

Method: A Systematic Literature Review (SLR) on Fuzzy Multi-Criteria Decision Making Methods for service selection is presented in this work. Our research looks at publications published between 2010 and 2021. Our initial database search resulted in 508 publications. Also, a search through another source (i.e. Reference Lists examination) resulted in 15 publications. After a thorough paper selection process using the PRISMA standard, only 60 publications met the final inclusion criteria. We looked at them from five distinct angles: (i) Quality of Service (QoS) factors used, (ii) Service Application Domains, (iii) Fuzzy Multi-Criteria Decision Making Methods employed, (iv) Dataset used, and (v) Sensitivity Analysis

Results: According to the results of the research, Response Time, Success Ability, Reliability, Throughput, and Performance have all been carefully studied in the literature. Other choices, the Cloud service option, and Web service selection received 68 percent, 20%, and 12%, respectively. Ten percent of the research employed heterogeneous datasets, whereas the other ninety percent used homogeneous datasets. The most popular integrated Fuzzy Multi-Criteria Decision Making Method used was the Fuzzy AHP+ Fuzzy TOPSIS. Thirty percent of the research performed a sensitivity analysis, whereas seventy percent did not. The findings indicate that more primary studies combining fuzzy MCDM methods are needed. Also, further reviews can consider the types of fuzzy numbers used as well as the membership functions used.

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Conclusion: Based on our findings, we believe that Fuzzy Multi-Criteria Decision Making Methods for Service Selection still have room for improvement. This study sets the pace for more primary studies utilizing Fuzzy MCDM methods in the subject of service selection.This, by extension will result in the development of intelligent applications to help service users moving forward. Researchers interested in developing more powerful approaches can look at the findings and conceptualize papers that will combine some powerful fuzzy MCDM techniques based on our overview findings. Also, the Type-3 Fuzzy Logic system can be explored with MCDM Method in service selection research moving forward as it has improved capabilities in terms of handling uncertainties than the others.

Keywords: *Fuzzy, Multi-Criteria Decision Making Methods, Service Selection, Fuzzy-TOPSIS.*

1. INTRODUCTION

During service selection and usage, a service client must request web and cloud services via the internet for (i) a service client to discover services published by a service provider in a service broker, (ii) a service broker to make services from the service provider available, and (iii) a service provider to hold together or bind a service client[1]. Due to the voluminous services available on the internet[2], service customers have difficulties selecting a service since numerous services in the service ecosystem have similar qualities[3]. As a result, efficient and precise service selection based on user-specific requirements has become a major issue for decision-makers and service customers[4], [5]. The process of selecting services that best meet the user's functional and non-functional properties(NFP) is known as service selection[6]. Quality of Service(QoS) factors[7] i.e. non-functional features or needs (NFP) of users include, among other things, availability, reaction time,cost, reputation, dependability, throughput, and security[8], [9]. Indeed, past research has discovered that not only do QoS aspects pertain to non-functional qualities of services[10] but also refer to the functional requirements as well [7], [11]–[13]. As a result, they have evolved into a suitable criterion for distinguishing functional and non-functional characteristics amongst identical services[14], [15]. In previous and recent years, the scientific community was quite active on the subject. For instance, various empirical investigations have been done to better understand (i) Quality of Service factors and their ranking[16]–[18] (ii) Quality of Service factors evaluation algorithms [18]–[27], and (iii) Quality of Service factors and Service composition [10], [28]–[34]

On the other hand, several service selection evaluation methods have been proposed as well[35]–[44] most of them if not all are Multi-Criteria Decision Making Methods. They are applied to decision-making problems involving many factors or criteria. The Multi-Criteria Decision Making Methods applied a series of steps or processes mostly of at least 4 steps or processes. They differ from each other for (i) the specific normalization algorithm used in each of them; for instance, TOPSIS, MOORA, MULTIMOORA, and ELECTRE used vector normalization algorithm. Also, COPRAS, ARAS AHP, and ANP used the Linear normalization algorithm. WASPAS and EDAS used the ratio-based normalization algorithm and Also, and VIKOR, MABAC, MACBETH, MAUT, and CoCoSo used the linear max-min normalization algorithms. (ii) the classification types such as; basic Graphical techniques, Simplex methods, Integer programming methods, Linear Programming and Goal Programming, Single methods such as DEMATEL, VIKOR, TOPSIS, DEA, AHP, and others, and ultimately hybrid methods such as VIKOR-AHP, TOPSIS-DEMATEL, and others. Although it has been demonstrated that Multi-Criteria Decision Making Methods have proven potential for solving multi-criteria decision problems, previous studies have highlighted some important limitations that may preclude the use of such Multi-Criteria Decision Making Methods in some situations[44], [45].In particular, service selection evaluation using Multi-Criteria Decision Making Methods can be subjective because the decision-maker in the process of making a decision can be biased [46], [47]. At the same time, most of them are susceptible to rank reversal problems by the normalization algorithm used[48].

For all of these reasons, a current trend in solving the problem is the use of integrated fuzzy multi-criteria decision-making techniques.[49], [50]. In this manner, fuzzy logic is used in conjunction with Multi-Criteria Decision Making Methods to analyze service selection challenges, hence addressing errors and uncertainties surrounding QoS parameters[51], [52]. These techniques vary from Multi-Criteria Decision Making Methods in that they rely on fuzzy theory, which depended on a membership function

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based on degree of membership rather than the conventional boolean.

While the academic community has extensively researched the fuzzy multi-criteria decision-making approach used by researchers and practitioners in various application fields, [53]–[55], there is limited information available on the use of integrated fuzzy multi-criteria decision making approaches on the web and cloud services application areas. This knowledge, we feel, is critical for academics interested in developing fresh effective approaches to cope with service selection challenges. To cope with this lack of knowledge, the purpose of this study is to provide an overview of and investigate the usage of Fuzzy Multi-Criteria Decision Making Methods in the field of service selection, with a focus on five research issues. Specifically, in this paper, we conducted a Systematic Literature Review (SLR) on the usage of fuzzy multi-criteria decision-making methods covering the papers published between 2010 and 2021. with the aim of (i) understanding and summarizing the current state of the art in this field and (ii) analyzing its limitations and open challenges to drive future research. More specifically, our SLR aims at providing a comprehensive investigation to elaborate on five research issues namely; (i) the Quality of factors taken into account by previous research, (ii) Service application domains (iii) the types of the dataset used in previous studies i.e. Homogeneous or Heterogeneous, (iv) Was sensitivity analysis performed (v) what Fuzzy Multi-Criteria Decision Making Methods were used in previous studies. Moreover, we report a meta-analysis of the performance of the relevant themes defined so far. To this aim, we set up the research questions reported in Table 2 and The Quality of Service factors in Table 1(Apendix).

1.1 Related Works

To the best of our knowledge, no Systematic Literature Review and Meta-Analysis on Integrated Fuzzy Multi-Criteria Decision Making Methods has been undertaken. However, it is worth noting that some secondary research on Fuzzy Multi-Criteria Decision Making Methods has been offered[56]–[66]. Specifically, the SLR conducted by [62] explored cutting-edge Multi-Criteria Decision Techniques between 2010 and June 2020, with a focus on (i) How MCDM methods are coupled to get the desired results? (ii) What dataset is being used? (iii) What elements, datasets, simulators, and QoS requirements are being considered? (Iv) Does sensitivity analysis take place? [59] carried out another SLR their research intended to examine and analyze the literature on FMCDM in Construction Management (CM) from 2007 to 2017 using a network method to both summarize the development of FMCDM in CM and provide insights into the links between Fuzzy Systems, MCDM, and associated applications.[56] explored literature and critically analyzed existing methodologies and their applications to CSC in their study. The literature review is being utilized to draw attention to the importance of agent-based PN decision-making modeling for CSC. [66] conducted a systematic review study to answer the following research questions: RQ1. What evaluation criteria were employed for each problem domain of site selection? RQ2: Which MCDM approaches were often used in a certain site selection issue domain?. The following questions were answered by [63] systematic review:RQ1: What are the latest breakthroughs in MCDM in the realm of website quality assessment? RQ2: What is the goal of modern MCDM research in this field? RQ3: What are the advantages and disadvantages of MCDM methods? According to [67], a systematic review is required to: Identify gaps in existing research and propose areas for further study. Determine the scope of the research that is accessible to address a certain research issue.[65] survey's overarching purpose was: To give a rigorous examination of existing strategies for tackling the challenge of service composition, such as methodologies and algorithms for service selection, service composition, service orchestration, and optimization of composite services. To investigate the anatomy of key strategies for resolving the service composition challenge. To list the assessment methodologies, benchmarks, and datasets used by researchers to study the QoS characteristics of cloud service creation strategies. determining the scope of future research in cloud service composition.[61]The following research questions (RQs) have been raised: RQ 1. What are the primary objectives of the studies? RQ2: What is the planned methodology, and what approaches are employed? How did the researchers carry out their investigation? RQ 3: What datasets or benchmarks are employed, and what case studies are taken into account? RQ 4: What evaluation processes were employed to evaluate the outcomes of each paper? RQ5. What additional research was taken into account in each study to compare the results? RQ 6: What QoS factors are taken into account? RQ7: How can the applied objective function take into account user requirements and tendencies?

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Concerning the papers discussed above, it is important to point out that none of them explicitly targeted integrated fuzzy multi-criteria decision-making methods for service selection.[62] focused on service selection using Multi-Criteria Decision Making Methods. Their study did not consider integrated fuzzy Multi-Criteria Decision Making Methods. Also, they did not consider the nature of the dataset, i.e. Homogeneous or Heterogeneous. [59] took into account Fuzzy Multi-Criteria Decision Making Methods. However, their focus was on construction management. Also, their focus was not on service selection.[56] study focused on CSC, and therefore, they did not take into account integrated fuzzy Multi-Criteria Decision Making Methods or service selection. For instance, the papers by [66] [63] [65], and [61] focused instead on MCDMMs evaluation but with a different focus, for instance, the focus was; on site selection, Website evaluation, and Service composition, and cloud computing service composition respectively.[58] considered fuzzy multi-criteria decision-making methods with a focus on energy policymaking planning. None of the studies considered integrated fuzzy multi-criteria decision-making methods with a specific focus on service selection. Since the usage of integrated fuzzy multi-criteria for service selection is highly promising [49] and given the proven impact of integrated fuzzy multi-criteria decision-making methods in the decision-making arena, [13], [39], we believe that a specialized investigation is necessary to get a new understanding on the issue and identify the open difficulties that future research should address.

1.2 Contribution

The following are the contributions made by this SLR: 1. We identified 60 key papers that suggested a service selection model based on Integrated Fuzzy Multi-Criteria decision-making methodologies. They may be utilized as a starting point for the research community to learn more about the subject. 2. We give a complete summary of the identified main research. There are five major topics in this: (i) Quality of Service (QoS) criteria were evaluated, (ii) service application domains, (iii) the nature of the dataset employed, (iv) sensitivity analysis, and (v) Fuzzy Multi-Criteria Decision Making Methods that were applied. 3. Based on our findings, we propose suggestions and recommendations to help continue study in the field. 4. We give a thorough replication package that includes all of the data used to carry out this SLR.

2 METHODS

2.1 Introduction

This methods section considered the following sub-headings; PRISMA, literature search strategy and terms, exclusion, and inclusion criteria, selection of studies, data extraction, and appraisal of selected studies for risk. The section also included Fuzzy Multi-Criteria Decision Making Methods and Service selection sub-headings

2.2 PRISMA

This review was driven by the globally recognized Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PRISMA focuses on how writers may guarantee that systematic reviews and meta-analyses are reported transparently and completely. It does not, for example, cover systematic review methodology explicitly or in-depth[68]. [68] paved a way for researchers to adopt PRISMA in their studies, he focused on tourism research.

2.3 Literature Search Strategy And Terms

ScienceDirect, SpringerLink, IEEE Explore, Scopus, and a search engine (connected papers) associated articles were searched as top electronic databases for published research. It is worth noting that connected papers cited publications from other databases, including Inderscience, Wiley, Emerald, Hindawi, ACM Library, Oxford Academic, SpringerLink, ScienceDirect, and IEEE Xplore filter all research titles and abstracts, a modified strategy with search phrases identifying and targeting the defined population, intervention (defined correctly for non-experimental situations), the defined result of interest, and requisite setting for studies was utilized. [69], [70]. Terms specifying the intervention concept were "Multi-criteria Decision Making Methods", "Integrated Fuzzy", "Fuzzy Multi-Criteria Decision Making Methods", "Fuzzy AHP+Fuzzy TOPSIS", "fuzzy TOPSIS+ fuzzy PROMETHEE", "fuzzy DEMATEL+fuzzy ELECTRE", "Fuzzy SAW", "Fuzzy VIKOR + Fuzzy WASPAS", and "Fuzzy DEA+Fuzzy Bto". The outcome of interest was coded in the search strategy as "Service selection", "web service", "cloud service", "Selection" and "Service". Search terms were framed with the "OR" and "AND" operators [62]

2.4 Exclusion And Inclusion Criteria

Published primary papers from 2010 to 2021 that claim to use integrated Fuzzy Multi-Criteria Decision Making Methods as their intervention concept was included for screening. Primary studies that have service selection, web service, cloud service, and other service selection as their population were equally included for screening. Articles and papers that combine at least two or more Fuzzy Multi-Criteria Decision Making Methods and the focus is not on service selection, cloud service, or, web service were still included for screening. Studies written in English Language and met the above protocols were also included. Studies that failed to satisfy the conditions for inclusion were excluded in this review to prevent the impact of related confounding variables. These included case studies, reviews, expert commentary, and research that did not take into account fuzzy multi-criteria decision-making methodologies, as well as service selection and associated ideas. Papers that were not authored in the English Language were not considered for screening. Although reviews were not included in this work, a manual search of references identified in review articles was carried out. Studies that did not provide absolute or sub-population figures on service selection and associated concepts were also omitted from the quantitative synthesis or meta-analysis. Furthermore, studies that could not provide absolute intervention or sub-intervention values for Fuzzy Multi-Criteria Decision Making Methods were eliminated from the quantitative synthesis or meta-analysis.

2.5 Selection Of Studies

The database query results were imported into Mendeley Desktop 1.19.4, and duplicate reports from various sources were discovered and removed. The titles and abstracts of articles received via database searches using the afore-mentioned search techniques were individually evaluated and prescreened by the six co-authors, who marked non-suitable or extraneous reports for removal. Following that, the full-text reports of the pre-screened and promising studies were obtained and evaluated individually by two co-authors to check compliance with the stipulated inclusion criteria. This was achieved by using a checklist. Only materials published in the English Language were considered. The reviewer's consensus was used to resolve disagreements in the findings of independent screening. Relevant data was taken from the chosen study and entered into a consistent Microsoft Excel template. According to the PRISMA criteria, the rationale for discarding any item during the thorough screening stage was documented and reported.

2.6 Data Extraction

Using a standardized extraction form, relevant data were extracted from chosen full-text papers. [62], [69]. Details about the publication, such as the document title, author names, date of publication, digital object identifiers (DOIs), and other critical characteristics, were retrieved. Furthermore, informative variables such as service application domain, Quality of service factors used, the nature of the dataset used i.e. whether homogeneous or heterogeneous, the various combinations of fuzzy and Multi-Criteria Decision-Making Methods, sensitivity analysis information, and limitations from the papers were captured in excel for further analysis in a statistical package.

2.7 Appraisal of Selected Studies For Risk

All studies were evaluated for possible bias using an adequately established technique[71]. The approach is focused on determining the internal and external validity of reports from cross-sectional research. Based on the existence or absence of each construct being examined, two independent assessors classified the studies as high, low, or extremely low for bias. Concerns explored were whether the articles were suitably representative of the defined population, randomly sampled, and drawn from a suitable sampling frame with low non-response bias (external validity). Internal validity was established using views of instrument reliability and validity, test uniformity, QoS definition, major data collection, and exposure bias. Any disagreements were resolved via discussion and continuous touch with more experienced team members.

NB: Connected Papers is not an academic database. It is a search engine that sources papers from databases like; Inderscience, Wiley, Emerald, Hindawi, ACM Library, Oxford Academic, Springer Link, Science Direct, and IEEE Explore.

2.8 Integrated Fuzzy Multi-Criteria Decision Making (FMCDM)

The fuzzy set theory was recommended by Prof.Zadeh in 1965. This theory tackles the issue of ambiguity and uncertainty in computer systems with linguistic and ambiguous variables. The purpose of intelligent decision support systems (expert knowledge stored in computers for decision making) is to replicate human thinking to make decisions like people in difficult situations.[73], [74]. Uncertainty is one of the most essential components in the simulation of human knowledge and linguistics[47], [59], therefore Fuzzy logic is one of the most compatible Artificial Intelligence tools with

Decision Support Systems(DSSs), as it aids in the importation of uncertainty and logic variables that are incorporated with human knowledge into DSSs. [73], [75], [76]. Fuzzy logic combined with Multi-Criteria Decision Making Methods(MCDMMs) is named Fuzzy Multi-Criteria Decision Making Methods (FMCDMMs). FMCDMM is a subset of Intelligent Multi-Criteria Decision Making Methods that are commonly used in assessment, ranking, and selection research[77]–[79]. For instance, integrated fuzzy multi-criteria decision-making methods were used for selection studies by [46], [49], [50], [52], [54], [55]. As the scope of the integrated Fuzzy Multi-Criteria Decision Making Method is vast, it is not advisable to mention their combinations by guess and so, the integrated fuzzy multi-criteria decision-making methods will be presented in the quantitative synthesis or meta-analysis output in the result section.

2.9 Service Selection

Service selection refers to the process of picking services that best fulfill the user's functional and non-functional requirements. [6]. For purposes of this study, three service application domains were considered; Web Service, Cloud service, and other selections studies. According to[7], a web service is a self-contained software application that can be promoted, found, and used via the internet. Cloud computing is a large-scale internet-based computing paradigm that offers computer services through the Internet. [8]. The meta-analysis will report on the number of studies per our criteria that used web services, cloud services, and others. (See Figure 3 in Apendix)

3. RESULTS

In this section, we provide a brief explanation of the demographics of the articles that passed the inclusion/exclusion criteria and the quality evaluation before presenting the SLR findings for the investigated research questions. (See Table 3 and Table 4 in Apendix)

Table 4 presents a cross-section of the final list of relevant primary studies examined in this SLR, with columns 'Authors' and 'Year' reflecting the number of publications published throughout time. As can be seen, all of the papers considered were published between 2010 and 2021; 65 percent of these primary studies were published between 2018 and 2021, possibly indicating a growing trend that is now in the process of becoming a more established discipline, while the remaining 35 percent were published between 2010 and 2017. Surprisingly, no study published in 2011 matched our inclusion requirements. Furthermore, we observed that around 2% of the primary publications were produced by Ghanaians. This suggests that just a few Ghanaian academics are working on the problem. The remaining 98% of the authors are not Ghanaians. It clearly shows a large geographical disparity. In conclusion, we estimated that integrated Fuzzy Multi-Criteria Decision Making Methods may still face challenges in the future based on the amount and types of publications published by the research community. Furthermore, we discovered that Ghanaians show a low level of interest in the issue.

RQ1: What Quality of Service (QoS) factors were used?

From figure 6**,** Response time was used in 19 studies across different years. In 2010, Response time was not analyzed. In 2011, Response time was used once. In 2012, response time was analyzed twice. In 2013, response time was studied once. In 2014, response time was analyzed four times. In 2016 and 2017, Response time was studied once. In,2018,2019, and 2020 it was studied twice and in 2021, Response time was studied thrice. Success ability and Reliability were also analyzed in 14 studies each across different years as indicated in Figure 6. Performance was also analyzed in 12 studies across different years. Availability was analyzed in 10 studies. Cost/Price was examined in 8 studies in that order as shown in the picture. (See Figure 3 and Table 5 in Apendix)

In our SLR, we discovered that prior research focused on 27 distinct quality of service characteristics, as shown in Figure 3 and Table 5, as well as the frequency of presence in main studies by year. As can be seen, response time is the most used, as 19 of the key studies examined it over time, such as;2010, 2012, 2013, 2014, 2016, 2017, 2018, 2019, 2020 and 2021. In terms of the percentage of appearance of Quality of service factors in years, response time again was analyzed 90.9% across years making it the highest QoS factor in that regard. While, Speed, Efficiency, Usability, Adaptability, Portability, and Service Name were the lowest as they were considered just once. This is partly because response time is measured from the client-side[80] and always needs to be less or minimum in values as it relates to the cost aspect of Quality of Service factors[7], [81]. It is also an uncertain factor in the QoS factors[82]. This result was somehow expected since response time is present in all openly available datasets for service research. These findings are in support of the findings of [62] Also, Succesability and Reliability Quality of Service were second to respond with 14 as the frequency of primary studies examining both across years. Next on the list are performance (12), availability (10), throughput and cost/price (8), latency, and the rest as shown in Figure 3 and Table 5

Also, 2017 witnessed the highest publications that analyzed much quality of service factors. Between the 11 years, i.e. 2010- 2021, 51.85% of all the Quality of Service factors used were analyzed in papers published in the year 2017, while, 2011 witnessed the lowest that is 0% of the Quality of Service factors used. 2011 recorded 0% because no paper published that year met our final inclusion criteria.

RQ2: What service application domains were considered?

The second research question of our SLR was related to service application domains. Specifically, we aimed at understanding (i) how many studies considered/addressed other service selection problems. (ii) cloud service selection problems, and (iii) web service selection problems.

Other service selections

Other service selection studies include; supplier selection[83], [84],stock selection[52], IT people selection[85], Vibration Technology selection[50], and flight selection[46].The above studies were all primary studies. To appropriately examine this, we first created a visual representation of the number of articles and the year they were published with the application domain, as shown in Figures 4 and 5 and Table 6. In particular, 2020 had the largest number of papers published with a focus on other service selections (15). The year 2021 came in second with eight papers, followed by 2019 with four papers. While no paper was recorded as the lowest in 2011, Following that, in 2010, 2012, and 2013, they registered one paper each, as seen in Figure 4 and Table 6. As shown in Figure 5, 41 articles were published with a focus on other service selections, accounting for 68 percent of the main research examined for the quantitative synthesis (Meta-Analysis).

Cloud Service Selection

On the cloud service application domain,2018 and 2021 recorded the highest number of papers published with each having 3 papers. Next is 2016 with 2 papers. 2010,2011,2012,2013, and 2015 recorded the lowest with no papers each. Finally, 2014,2017,2019, and 2020 recorded one paper each as shown in Figures 4, 5, and Table 6. Largely, 12 papers were published with a focus on cloud service selection representing 20% of primary studies that focused on cloud service as portrayed in figure 8. Cloud service selection was studied by[37], [86], [87]. More studies are needed using integrated fuzzy multi-criteria decision-making methods with a focus on cloud service selection.

Web service selection

On the web service selection domain, 2020 recorded the highest papers with 2 publications focusing on it. Next were 2012, 2014, 2016, 2018, 2019 and 2020 they recorded 1 paper each. 2010, 2011, 2013, 2015, 2017 and 2021 recorded the lowest with zero publications focusing on the Web service selection domain. Finally, 7 papers representing 12% of the 60 primary studies considered focused on web service selection as shown in Figures 4, 5, and Table 6. Web service selection was studied by [23], [81], [88].All these were primary studies. This demonstrated there is a huge gap requesting more studies in that regard. (See Figure 4, 5 and Table 6)

RQ3: Was the dataset used heterogeneous or homogeneous?

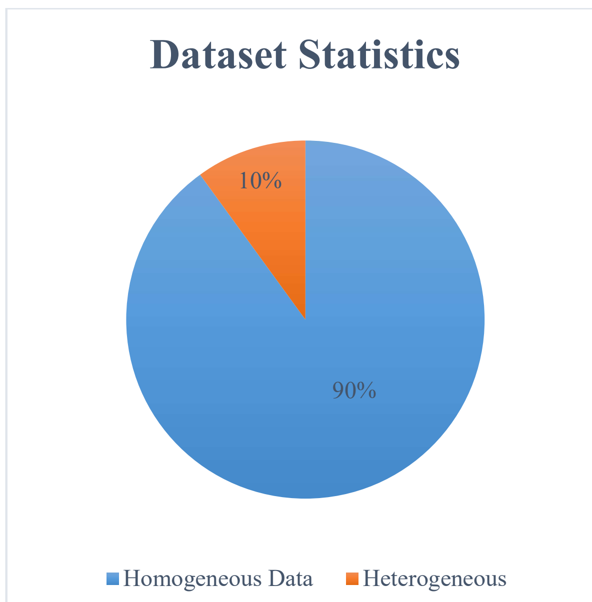

Fig.7 Dataset statistics

From Figure 6, the QWS dataset was used most by studies in 2021. For instance, the QWS dataset was used by [33], [42], [44], [89] Still in 2021, a heterogeneous dataset of cloud Harmony and QWS dataset was also used. In 2012 and 2018, author generated dataset was also used by some studies. 90% of the studies used homogeneous datasets [14],

[33], [42], [90], [91] while 10% used Heterogeneous Datasets as indicated in Figure 7. Heterogeneous data was used by[38]. More studies are needed particularly studies that will combine cloud datasets with web service datasets. Also, further studies are needed particularly studies that combine different cloud datasets and different web dataset. (See Figure 6 in Apendix)

RQ4: What Integrated Fuzzy Multi-Criteria Decision Making Methods(MCDMMs) were used?

From Figure 8 and Table 7 (see in appendix), It is observed that apart from the integrated Fuzzy Multi-Criteria Decision Making Methods namely; Fuzzy AHP + Fuzzy TOPSIS and Fuzzy AHP + PROMETHEE which have a frequency of 6 (i.e., 2013,2014,2017,2018,2020 and 2021 and 2(i.e.2015 and 2019) respectively[92], the rest of the methods have 1 frequency each showing a colossal research gap in that regards. Fuzzy-AHP and Fuzzy-TOPSIS methods are not prone to rank reversal problems[93] and are also found to be proven in service selection evaluation studies[94]. This could be the reason why many researchers are using it for ranking, selection, and evaluation studies. Also, it was found that only a few studies integrate more than 2 fuzzy Multi-Criteria Decision Making Methods

Q5: Was sensitivity analysis conducted to verify the achieved results

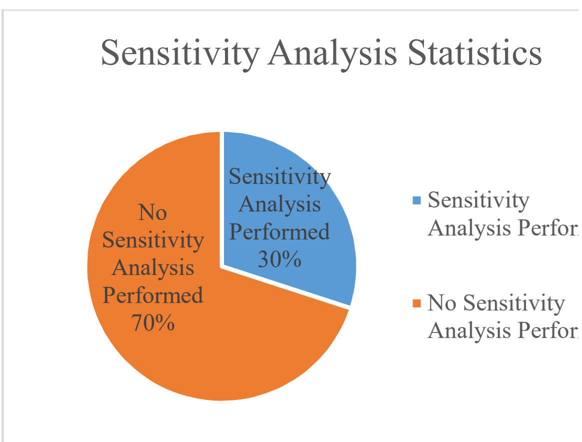

Fig. 9: Sensitivity Analysis Statistic

Figure 9 showed studies that have undertaken sensitivity analysis to better validate their acquired findings. Sensitivity analysis is a well-known tool for evaluating the impact of fluctuating input parameters on system output and studying model correctness in uncertain settings[62]. To carry out this analysis, each input parameter should be altered by a particular percentage while remaining constant for the other values. The model should then be run to determine the extent of change in the relevant performance metric. As depicted in Figure 9, only 18 studies representing 30% of the primary studies selected for the quantitative synthesis(Meta-analysis) performed sensitivity analysis[37], [40], [44] while, 42 studies representing 70% of the studies did not perform sensitivity analysis. This also demonstrated a huge gap necessitating more studies in that direction.

4. DISCUSSION

At the end of our studies, we highlight the key findings of our work in this area, as well as outline guidelines and future trends that the research community may be interested in. In the interest of clarity, we have also included the precise research question relevant to the mentioned topic below. RQ1 - What Quality of Service (QoS) factor was used? Considering the quality of service aspects that have previously been investigated by researchers (RQ **1**), we can delineate a lack of cloud service QoS combined with Web Service QoS factors studies. Indeed, we showed that only a few Quality of Service factors, Response Time, Success ability, Reliability, Availability, performance, and throughput, have received some attention, this is confirmed by [29], [57], [80] while the remaining 21 Quality of Service(QoS) have not been paid attention to. This, to the researchers, is because most of the studies focused on single service Quality of service factors i.e. either Web service QoS or Cloud service QoS which may not contain a quarter of the available Quality of Service factors. The researchers' first recommendation is that more studies can look further at combining Web Service Quality of Service factors with Cloud service quality of service factors to come up with a complete QoS factors list for better evaluation, ranking, and selection of services based on QoS using Integrated Fuzzy Multi-Criteria Decision Making Methods that combine at least three fuzzy multi-criteria decision-making techniques**.** To ease the work of researchers in the field, a complete list of Quality of service factors is reported in Table 5. RQ2: What service application domains were considered*?* Only a small amount of works 7 (12%) focused on the domain of Web Service Selection: For instance, Web service selection was studied by [13], [14], [42]. We presented the number of studies that focus on web service selection in Table 6. Thus, we say that more studies are needed with a focus on web service selection. RQ2: What service application domains were considered*?* Only a small number of studies 12

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(20%) focused on the domain of Cloud Service Selection. For instance, cloud service selection was studied by [39], [43], [95] we argue that more studies with a focus on cloud service ranking, selection, and evaluation are needed. Particularly, studies that deploy a more robust integration of Fuzzy Multi-Criteria Decision Making methods or Just FUZZY INFERENCE SYSTEM(FIS). RQ2: What service application domains were considered? In the majority of the studies, *41(68%) focused on* other service selections**.** This is quite good**.** However, there is still a lack of understanding of the other service selection specificity**.** Therefore, further studies are needed to further break down and understand the other service selection well. For instance, [96] focused on supplier selection, [97] focused on outsourcing provider selection, and stock selection focused by [52] but all these among others are classified under other selections. RQ3: Was the dataset used heterogeneous or homogeneous? Only 10% of the studies used a Heterogeneous dataset. While 90% of the studies used homogeneous single service-specific datasets. We recommend that more studies with heterogeneous datasets are needed. Also, two different single clouds or web service datasets can be combined.RQ4: What Integrated Fuzzy Multi-Criteria Decision Making Methods(MCDMMs) was used?. It is observed that, apart from integrated Fuzzy AHP + Fuzzy TOPSIS, all other Fuzzy Multi-Criteria Decision Making Methods presented in Table 7 require further studies. This finding is similar to [58] finding that Fuzzy AHP and Fuzzy TOPSIS are the most widely used integrated Fuzzy Multi-Criteria Decision Making Methods. Thus, we recommend that further studies can be done using the Fuzzy Multi-Criteria Decision Making Methods presented in Table 7. Also, more studies can be done by combining more than two Fuzzy Multi-Criteria Decision Making Methods up to like say five. RQ5: Was sensitivity analysis conducted to verify the achieved results? Only 18 studies representing 30% of the primary studies selected for the quantitative synthesis(Meta-analysis) performed sensitivity analysis while 42 studies representing 70% of the studies did not perform sensitivity analysis**.** We recommend that more studies with sensitivity analysis are needed most

5. LIMITATIONS AND DEMERIT OF THE STUDY

This study is without limitations. First, the number of primary studies (Sample Size) considered for the Meta-Analysis was small. Because the search terms developed from the research questions were well-focused. Also, on both the subject area and the approach, there was limited information on them. This is probably because the authors sourced papers from only recognized academic databases and also because the topic is relatively new with this approach. This study used papers from only highly respected and reliable academic databases hence, a plus. The demerits of this study stemmed from the fact that the study did not consider Type-3 fuzzy logic systems. Also, the normalization techniques used in the various fuzzy Multi-Criteria Decision Making Methods were not examined in this study. The interesting aspect of these findings is that just a few studies performed sensitivity analysis.

6. CONCLUSION

This study presented an overview of the use of integrated fuzzy multi-criteria decision-making techniques in the subject of service selection from five perspectives**.** From the QoS factors viewpoint, many QoS factors were used in the extant literature gathered for which response time was the most utilized. Also, Other service selection studies recorded the highest studies against cloud and web services selection. Additionally, many studies had utilized homogeneous datasets than studies that used heterogeneous datasets. From the Integrated Fuzzy Multi-Criteria Decision Making Methods used perspective, Fuzzy AHP + Fuzzy TOPSIS was the most deployed hybrid technique. Finally, the majority of the studies did not perform sensitivity analysis. Sensitivity analysis is performed to test the robustness of a model in scenarios where some alternatives and criteria are removed or added to the model and how will that affect the ranking positions. This study indisputably will set the pace for an increase in the number of primary studies using integrated fuzzy multi-criteria decision-making techniques in the context of service selection. By extension, many intelligent applications will be developed by Information Technology professionals to assist service users to select the right service when faced with voluminous candidate services on the internet with a click. However, this study did not take into consideration type-3 fuzzy logic systems, hence the current study limitation. Also, this study did not consider the types of fuzzy numbers used as well as the membership functions used.

A type-3 fuzzy logic system is well-defined as an interval type-2 fuzzy set. Whereas, in Type-1 Fuzzy System and Type-2 Fuzzy Systems the membership is a crispy number and Type-1 fuzzy set correspondingly[98]. The type-3 fuzzy logic system is an improved version of both type 1 and type-2 fuzzy systems and is believed to have better capabilities in terms of handling uncertainties based on membership functions than the type-1 and Type-2 fuzzy systems. Moving forward, future studies both primary and review can explore the type-3 fuzzy logic system with MCDM Methods in the context of service selection. An integrated fuzzy DEMATEL, Fuzzy TOPSIS, and Fuzzy VIKOR can be used to investigate service selection-based QoS factors. Other possible hybridization of Fuzzy Multi-Criteria Decision Making Techniques can be explored.

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APENDIX

Table 1: Quality Of Service(Qos) Factors Used

C1	Response Time
C2	Availability
C3	Throughput
C4	Successability
C5	Reliability
C6	Compliance
C7	Best Practices
C8	Latency
C9	Documentation
C10	Service Name
C11	cost/Price
C12	Reputation
C13	Security
C14	Encryption
C15	Performance
C16	Scalability
C17	Adaptability
C18	Portability
C19	Storage
C20	Suitability
C21	Transparency
C22	Usability
C23	Accuracy
C24	Interoperability
C25	efficiency
C26	Speed
C27	Consistency

Table 2: Research Questions Posed For Our Systematic Literature Review

Research Question	Motivation
RQ1: What QoS factors were used in previous studies?	To explore the QoS factors used
RQ2: What Service Application domains were considered?	To explore the service application area
RQ3: Was the dataset used homogeneous or heterogeneous?	To examine the dataset Used
RQ4: What Fuzzy Multi-Criteria Decision Methods are used?	To examine FMCDMMs Used
RQ5: Was sensitivity analysis performed?	To ascertain whether or not sensitivity analysis was performed

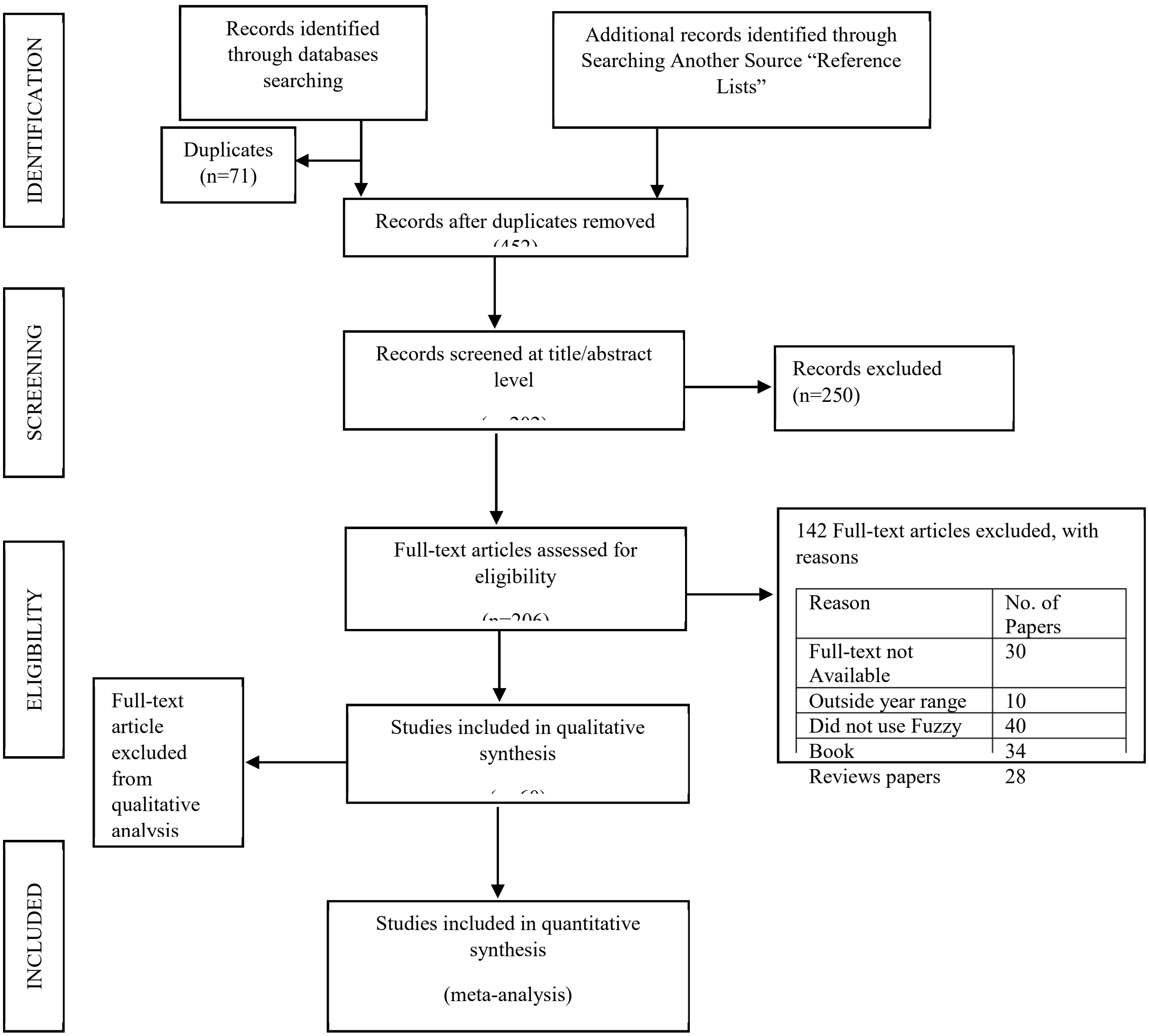

Figure 1: The Study Selection Method Is Depicted Using A PRISMA Flow Diagram.

Table 3: Data Sources And Search Results

Resource name	Total results	Not Relevant	Final Selection
Connected Papers	305	288	17
ScienceDirect	35	28	7
Springer link	57	38	19
IEEE Explore	92	88	4
Scopus	19	14	5
Reference List	15	7	8
Total	**523**	**463**	**60**

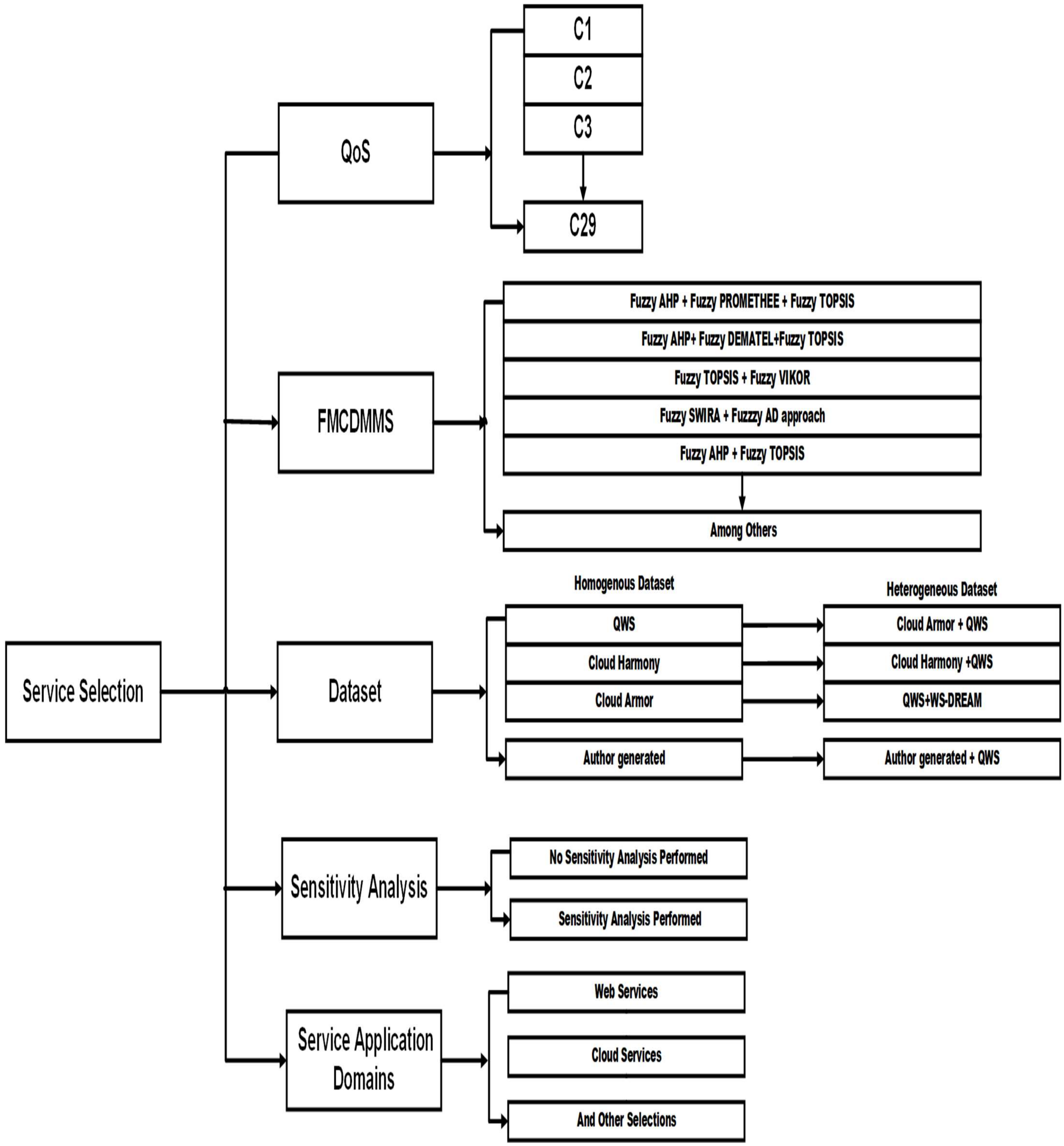

Figure 2: Service Selection Properties And Other Relevant Themes Based On The Research Questions.(Author Construct)

Table 5: The Reviewed Primary Studies

Authors	Title	Year
Tarik		
Liu, Fang; Wu, Ju; Mou, Lianming; Liu, Yi	Decision Support Methodology Based on Covering-Based Interval-Valued Pythagorean Fuzzy Rough Set Model and Its Application to Hospital Open-Source EHRs System Selection	2020
Ali, Sikandar; Ullah, Niamat; Abrar, Muhammad Faisal; Yang, Zhongguo; ...	Fuzzy Multicriteria Decision-Making Approach for Measuring the Possibility of Cloud Adoption for Software Testing	2020
Carnero, María Carmen	Fuzzy Multicriteria Model for Selection of Vibration Technology	2016
Iampan, Aiyared; García, Gustavo Santos; Riaz, Muhammad; Athar Fari...	Linear Diophantine Fuzzy Einstein Aggregation Operators for Multi-Criteria Decision-Making Problems	2021
Bakioglu, Gozde; Atahan, Ali Osman	AHP integrated TOPSIS and VIKOR methods with Pythagorean fuzzy sets to prioritize risks in self-driving vehicles	2021
Kannan, Devika; Khodaverdi, Roohollah; Olfat, Laya; Jafarian, Ah...	Integrated fuzzy multi criteria decision making method and multiobjective programming approach for supplier selection and order allocation in a green supply chain	2013
Rostamzadeh, Reza; Ghorabaee, Mehdi Keshavarz; Govindan, Kannan...	Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS- CRITIC approach	2018
Büyüközkan, Gülçin; Göçer, Fethullah; Feyzioğlu, Orhan	Cloud computing technology selection based on interval-valued intuitionistic fuzzy MCDM methods	2018
Jokar, Ebrahim; Aminnejad, Babak; Lork, Alireza	Assessing and Prioritizing Risks in Public-Private Partnership (PPP) Projects Using the Integration of Fuzzy Multi-Criteria Decision-Making Methods	2021
Chen, L.; Pan, W.	A BIM-integrated Fuzzy Multi-criteria Decision Making Model for Selecting Low-Carbon Building Measures	2015
Dragović, Ivana; Turajlić, Nina; Radojević, Dragan; Petrović, Bratislav	Combining boolean consistent fuzzy logic and ahp illustrated on the web service selection problem	2014
Zhang, Ruichen; Xu, Zeshui; Gou, Xunjie	An integrated method for multi-criteria decision-making based on the best-worst method and Dempster-Shafer evidence theory under double hierarchy hesitant fuzzy linguistic environment	2021
Kumar, Rakesh Ranjan; Kumari, Binita; Kumar, Chiranjeev	CCS-OSSR: A framework based on Hybrid MCDM for Optimal Service Selection and Ranking of Cloud Computing Services	2021
Tiwari, Rohit Kumar; Kumar, Rakesh	G-TOPSIS: a cloud service selection framework using Gaussian TOPSIS for rank reversal problem	2021

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Table 4: Continuous

Authors	Title	Year
Yeni, Fatma Betül; Özçelik, Gökhan	Interval-Valued Atanassov Intuitionistic Fuzzy CODAS Method for Multi Criteria Group Decision Making Problems	2019
Goswami, Shankha Shubhra; Behera, Dhiren Kumar	Evaluation of the best smartphone model in the market by integrating fuzzy-AHP and PROMETHEE decision-making approach	2021
Gireesha, Obulaporam; Somu, Nivethitha; Krithivasan, Kannan; Sha...	IIVIFS-WASPAS: An integrated Multi-Criteria Decision-Making perspective for cloud service provider selection	2020
Hussain, Abid; Chun, Jin; Khan, Maria	A novel multicriteria decision making (MCDM) approach for precise decision making under a fuzzy environment	2021
Ighravwe, Desmond Eseoghene; Oke, Sunday Ayoola	A two-stage fuzzy multi-criteria approach for proactive maintenance strategy selection for manufacturing systems	2020
Pallavi Bagga, Aarchit Joshi, Rahul Hans	QoS based Web Service Selection and Multi-Criteria Decision Making Methods	2020
Khalilzadeh, Mohammad; Karami, Arya; Hajikhani, Alborz	The multi-objective supplier selection problem with fuzzy parameters and solving the order allocation problem with coverage	2020
Kafa, Nadine; Hani, Yasmina; El Mhamedi, Abederrahman	Evaluating and selecting partners in sustainable supply chain network: a comparative analysis of combined fuzzy multi-criteria approaches	2018
Boutkhoum, Omar; Hanine, Mohamed; Agouti, Tarik; Tikniouine, Abdessadek	Selection problem of Cloud solution for big data accessing: Fuzzy AHP-PROMETHEE as a proposed methodology	2016
Afful-Dadzie, Eric; Nabareseh, Stephen; Klimek, Petr; Oplatkova, Z...	Ranking fragile states for support facility: A fuzzy topsis approach	2014
Chen, Yanping; Jiang, Lu; Zhang, Jianke; Dong, Xiaoxiao	A Robust Service Selection Method Based on Uncertain QoS	2016
Akshya Kaveri, B.; Gireesha, O.; Somu, Nivethitha; Gauthama Raman...	E-FPROMETHEE: An entropy based fuzzy multi criteria decision making service ranking approach for cloud service selection	2018
Alam, Khubaib Amjad; Ahmed, Rodina; Butt, Faisal Shafique; Kim, Soon Goh...	An Uncertainty-aware Integrated Fuzzy AHP-WASPAS Model to Evaluate Public Cloud Computing Services	2018
Chauhan, Sameer Singh; Pilli, Emmanuel S.; Joshi, R. C.	BSS: a brokering model for service selection using integrated weighting approach in cloud environment	2021

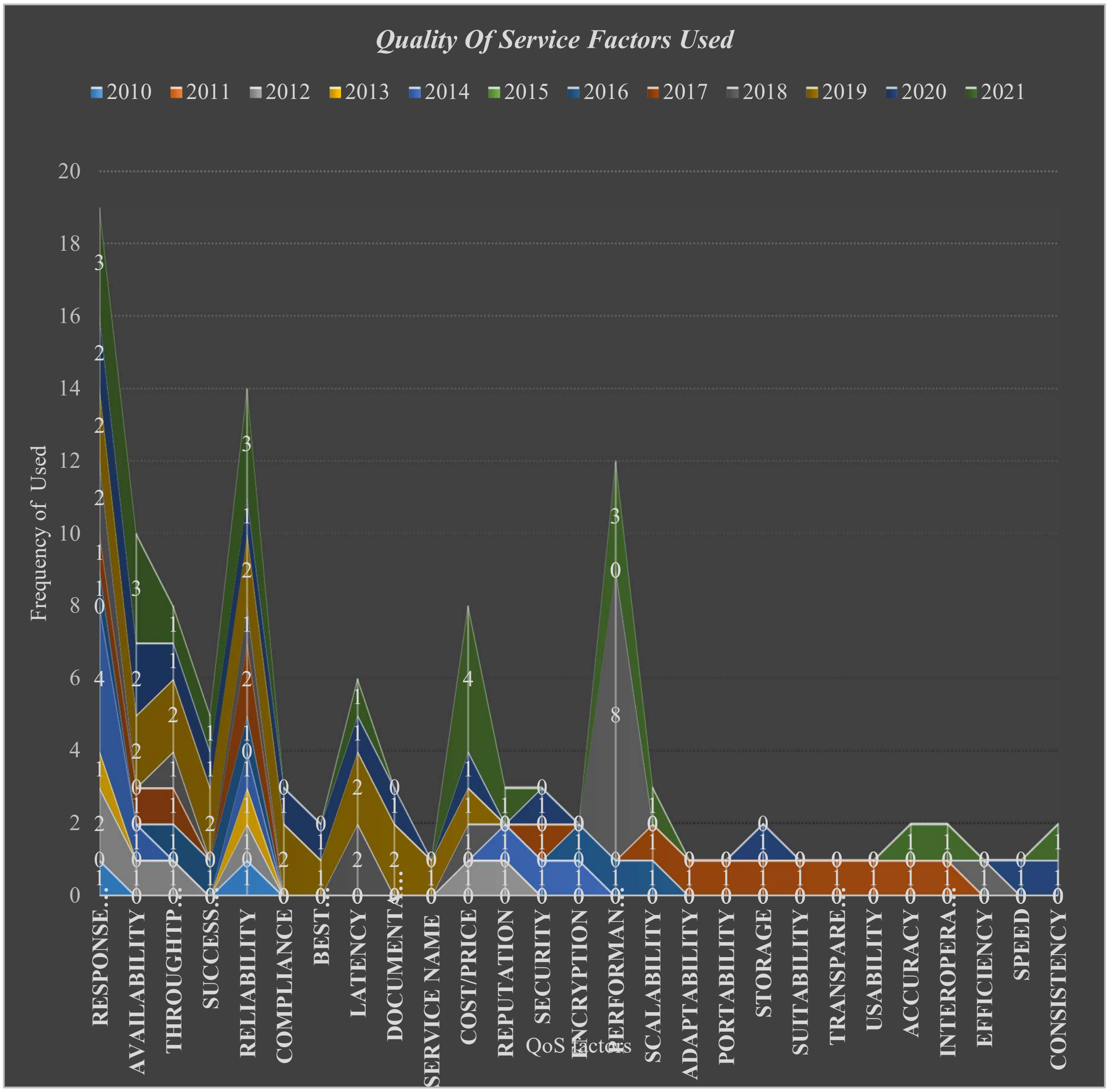

Figure.3: Quality Of Service Factors Used

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Table 5: Year, Frequency, and Quality of Service Factors Used.

Year	Frequency	Quality of Service factors Used
2010, 2012(2),2013,2014(4),2016,2017,2018(2),2019(2),2020(2),2021(3)	19	Response Time
2012,2014,2017,2019(2),2020(2),2021(3)	10	Availability
2012,2016.2017,2018,2019(2),2020, 2021	8	Throughput
2016,2019(2),2020.2021	14	Success ability
2010,2012,2013,2014,2016,2017(2),2018,2019(2),2020,2021(3)	14	Reliability
2019(2),2020	3	Compliance
2019 and 2020	2	Best Practices
2018(2),2019(2),2020,2021	6	Latency
2019(2),2020	3	Documentation
2019	1	Service Name
2012,2018,2019,2020,2021(4)	8	cost/Price
2012,2014, and 2021	3	Reputation
2014,2017 and 2020	3	Security
2014 and 2016	2	Encryption
2016,2018(8),2021(3)	12	Performance
2016,2017 and 2021	3	Scalability
2017	1	Adaptability
2017	1	Portability
2017 and 2020	2	Storage
2017	1	Suitability
2017	1	Transparency
2017	1	Usability
2017 and 2021	2	Accuracy
2017 and 2021	2	Interoperability
2018	1	efficiency
2020	1	Speed
2020 and 2021	2	Consistency

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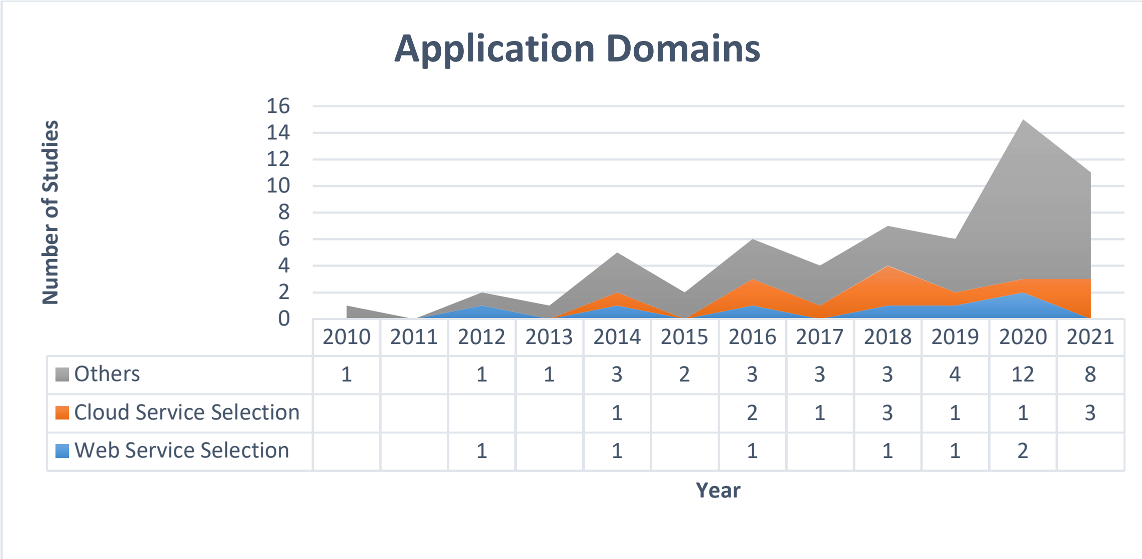

Figure 4: Service Application Domains

Table 6: The Number Of Papers Published Each Year And The Distribution Of Service Application Areas.

Year	Number of Papers Published	Other Selections	Cloud Service Selection	Web Service Selection
2010	1	1		
2011	0			
2012	2	1		1
2013	1	1		
2014	5	3	1	1
2015	2	2		
2016	6	3	2	1
2017	4	3	1	
2018	7	3	3	1
2019	6	4	1	1
2020	15	12	1	2
2021	11	8	3	
Total	60	41	12	7

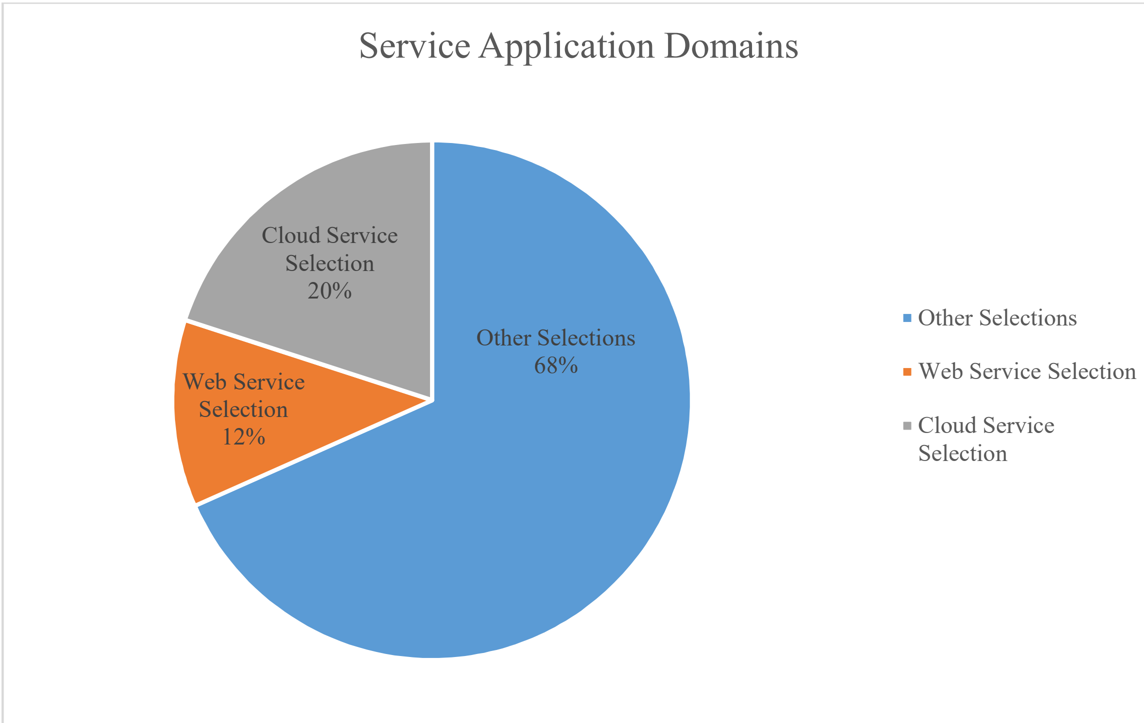

Figure 5: Service Application Domains

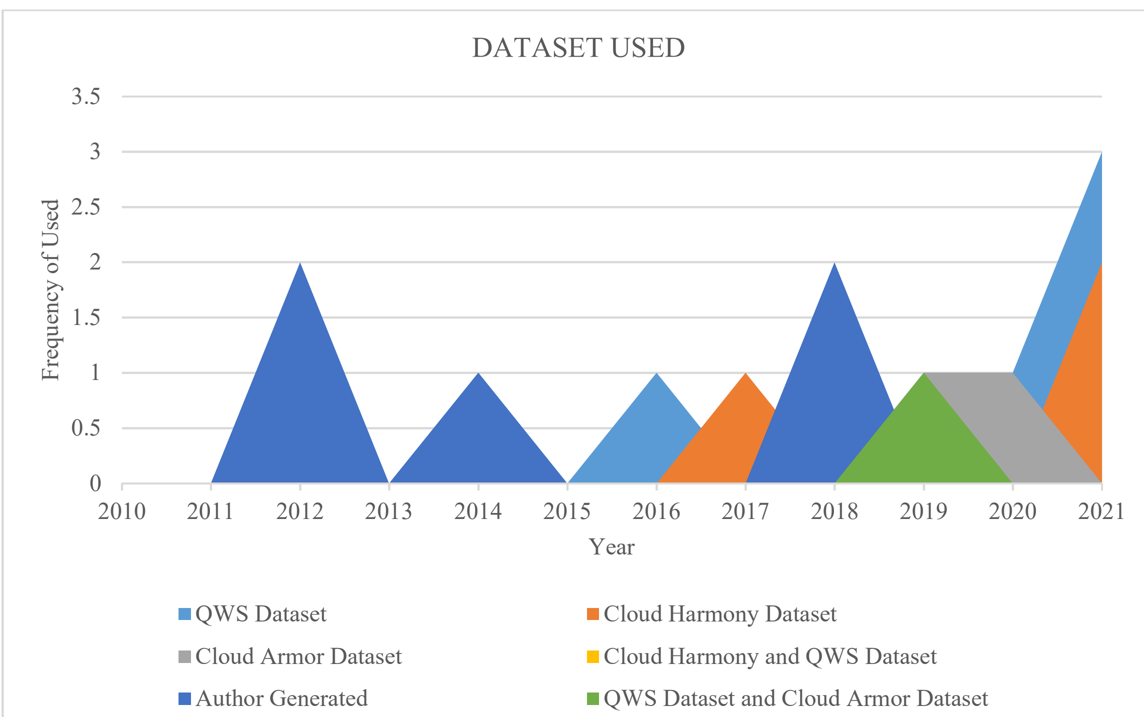

Fig. 6 Various Datasets Used

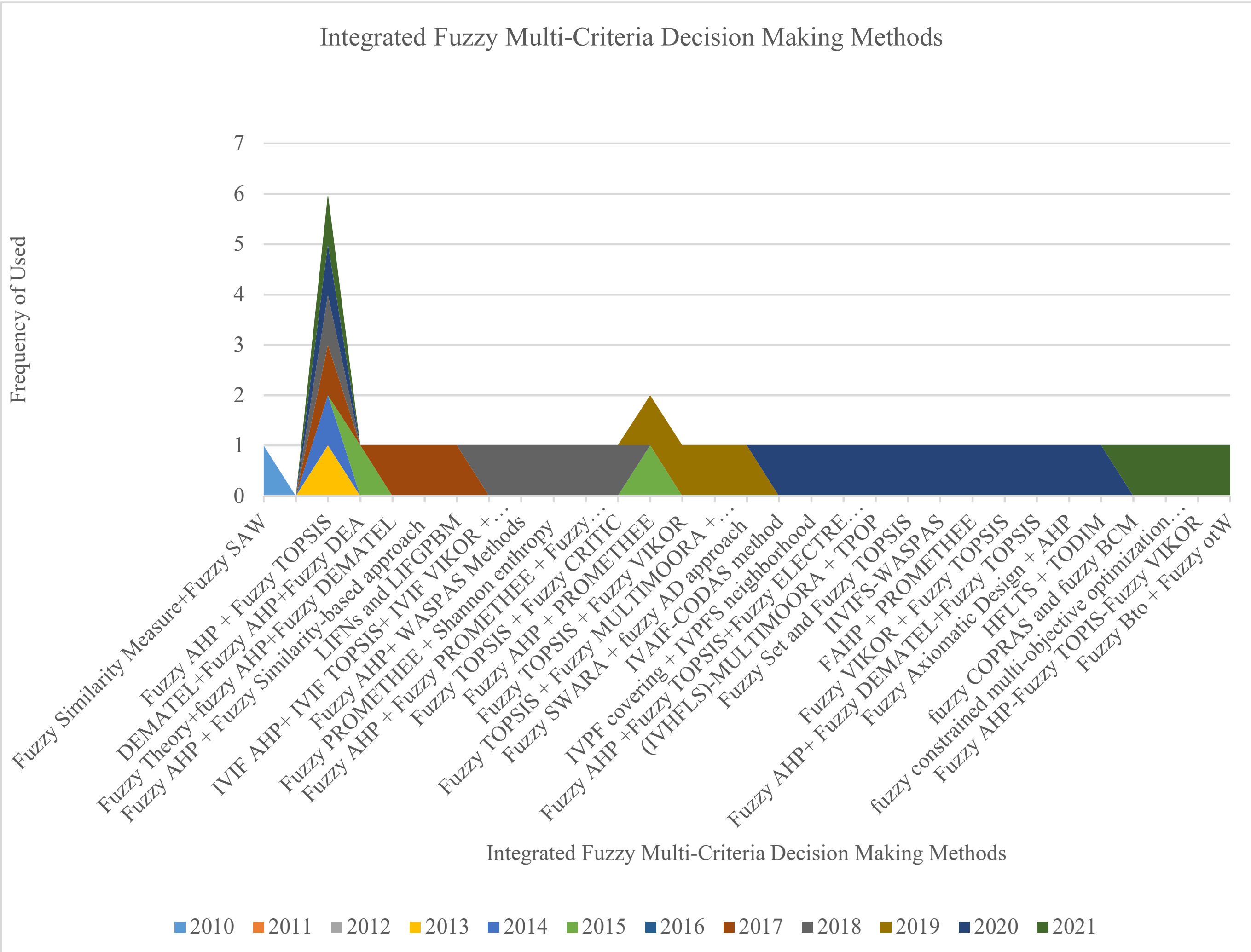

Fig.8: Integrated Fuzzy Multi-Criteria Decision Making Methods Used Publication Over Years.

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Table 7: Integrated Fuzzy Multi-Criteria Decision Making Methods and year of publication

Year	Integrated FMCDMM
2010	Fuzzy Similarity Measure+Fuzzy SAW
2011	
2013, 2014, 2017, 2018, 2020 and 2021	Fuzzy AHP + Fuzzy TOPSIS
2015	DEMATEL+Fuzzy AHP+Fuzzy DEA
2017	Fuzzy Theory+fuzzy AHP+Fuzzy DEMATEL
2017	Fuzzy AHP + Fuzzy Similarity-based approach
2017	LIFNs and LIFGPBM
2018	IVIF AHP+ IVIF TOPSIS+ IVIF VIKOR + IVIF COPRAS+ IVIF MULTIMOORA
2018	Fuzzy AHP+ WASPAS Methods
2018	Fuzzy PROMETHEE + Shannon entropy
2018	Fuzzy AHP + Fuzzy PROMETHEE + Fuzzy TOPSIS.
2018	Fuzzy TOPSIS + Fuzzy CRITIC
2015 and 2019	Fuzzy AHP + PROMETHEE
2019	Fuzzy TOPSIS + Fuzzy VIKOR
2019	Fuzzy TOPSIS + Fuzzy MULTIMOORA + Fuzzy ARDAS
2019	Fuzzy SWARA + fuzzy AD approach
2020	IVAIF-CODAS method
2020	IVPF covering + IVPFS neighborhood
2020	Fuzzy AHP +Fuzzy TOPSIS+Fuzzy ELECTRE +ANN
2020	(IVHFLS)-MULTIMOORA + TPOP
2020	Fuzzy Set and Fuzzy TOPSIS
2020	IIVIFS-WASPAS
2020	FAHP + PROMETHEE
2020	Fuzzy VIKOR + Fuzzy TOPSIS
2020	Fuzzy AHP+ Fuzzy DEMATEL+Fuzzy TOPSIS
2020	Fuzzy Axiomatic Design + AHP
2021	HFLTS + TODIM
2021	fuzzy COPRAS and fuzzy BCM
2021	fuzzy constrained multi-objective optimization model and a fuzzy teaching learning based optimization
2021	Fuzzy AHP+Fuzzy TOPIS+Fuzzy VIKOR
2021	Fuzzy Bto + Fuzzy otW