O P E R A T I O N S R E S E A R C H A N D D E C I S I O N S
No. 4 2021
DOI: 10.37190/ord210405

A LITERATURE REVIEW OF INTERVAL-VALUED INTUITIONISTIC FUZZY MULTI-CRITERIA DECISION-MAKING METHODOLOGIES

MELDA KOKOÇ[1*], SÜLEYMAN ERSÖZ[2]

[1]Gazi University, Rectorate, 06560 Yenimahalle/Ankara, Turkey

[2]Department of Industrial Engineering, Kirikkale University, 71450 Yahşihan, Kirikkale, Turkey

Multi-criteria decision-making (MCDM) is one of the most popular problems handled by researchers in the literature. Since the interval-valued intuitionistic fuzzy set (IVIFS) theory generates as realistic as possible evaluation of linguistic expressions, researchers have been expanding traditional MCDM methods to the IVIF environment, especially in the last decade. This study provides a literature review of the relevant articles from several academic databases on applications of IVIF-MCDM methods. The review of 131 publications addresses specific research questions. To understand the research publication trend, this review offers a visual analysis that examines the studies from different perspectives, such as application areas, IVIF-MCDM methods, citations, most relevant journals, and validation methods. One of the most remarkable results of the literature review is that most publications in this field are published in SCIE indexed journals. Another noteworthy issue is that China is the country that produces the most articles in this field. In addition, English journals are mostly selected for the publication of articles. While it is seen that the investment selection problem is chosen mostly as the application area, the TOPSIS method is preferred mostly in the applications. This study stands out as the most comprehensive one that compiles publications containing extended traditional MCDM methods for IVIF sets. This review will be an important reference for future researchers and decision-makers involved in advancing MCDM methods considering vagueness and ambiguity.

Keywords: *multi-criteria decision-making, review*, *interval-valued intuitionistic fuzzy set, MCDM, MADM*

1. Introduction

Multi-criteria decision-making (MCDM) is a branch of operations research that is concerned to evaluate the limited number of alternatives under various criteria. MCDM methods have been developed to select the best suitable alternative and to classify or

[*]Corresponding author, email address: meldakokoc@gazi.edu.tr
Received 16 January 2021, accepted 22 October 2021

rank alternatives in subjective preference order [1]. Since MCDM was introduced in the mid-1950s, it has been a hot topic in decision-making research. Also, it has proven as a useful approach owing to its widespread practical applications. In traditional MCDM methods, all evaluations about alternatives or criteria are handled with crisp values. Because evaluations are made within a limited time or lack information in many decision-making processes, the evaluations contain hesitation or uncertainty. Therefore, it is not effective to represent linguistic terms expressed by decision-makers with crisp values. So, the traditional MCDM methods are inadequate in handling ambiguity and vagueness in linguistic expressions [2, 3]. To overcome vagueness in a decision-making process, firstly, it has been suggested to apply MCDM approaches with the fuzzy sets. But then, Atanassov and Gargov [4] introduced IVIF sets theory to show and quantify the ambiguous nature of subjective judgments. In the IVIF sets theory, the belonging of an element to a set is represented by a membership degree, a non-membership degree, and a hesitancy degree whose values are intervals rather than crisp values. The decision--making methods extended for IVIFSs have been proven to be practical and realistic tools for managing MCDM problems [5–8]. So, traditional MCDM methods have been extended to the IVIF environment to enrich this area, especially since 2010. The compilation of these publications under various titles gives a roadmap to researchers about the up-to-date research trends of IVIF-MCDM methods. With this motivation, this study aims to compile papers on extended tradition MCDM methods for IVIF sets.

Table 1. The earlier review studies containing IVIF-MCDM applications

Authors	Journal	Scope	Year	NP
Behzadian et al. [1]	Expert Systems with Applications	TOPSIS applications	up to 2012	5
Mardani et al. [9]	Expert Systems with Applications	Fuzzy MCDM applications	up to 2014	5
Kahraman et al. [10]	International Journal of Computational Intelligence Systems	Fuzzy MCDM applications	up to 2014	2
Gul et al. [11]	Applied Soft Computing	VIKOR applications	up to 2015	4
Mardani et al. [12]	Economic Research – Ekonomska Istraživanja	MCDM utility determining techniques	up to 2016	4
Kaya et al. [13]	Energy Strategy Reviews	Fuzzy MCDM applications for energy policy making	up to 2017	3
Liu et al. [14]	Computers and Industrial Engineering	MCDM applications for FMEA	up to 2018	8

NP – number of papers relevant IVIF-MCDM.

Several researchers conducted review studies on MCDM methods or their fuzzy extension version. To find out a significant research gap related to the review of MCDM

applications, existing review studies including IVIF-MCDM methods are analysed under the four categories, such as scope, year, database, and the number of papers relevant to IVIF sets are presented in Table 1. Behzadian et al. [1] conduct a literature review to categorise the papers published up to 2012 on TOPSIS methodologies and applications. Mardani et al. [9] provide a systematic review of the fuzzy MCDM applications published between 1994 and 2014. Kahraman et al. [10] examine the fuzzy MCDM papers in the Scopus database by dividing them into two parts as fuzzy MADM and fuzzy MODM. Gul et al. [11] conduct a state-of-the-art review to categorise and interpret the papers that used VIKOR or its fuzzy extensions.

Mardani et al. [12] compile the MCDM utility determining techniques carried out until 2016. Kaya et al. [13] present a comprehensive review of the applications of fuzzy MCDM in the energy field. After reviewing the abovementioned studies, it has been observed that the existing literature reviews do not include most of the IVIF-MCDM applications. Hence, a need is felt to undertake a comprehensive review of publications that used IVIF-MCDM techniques to provide a detailed insight into the MCDM applications conducted under the IVIF environment. This study provides a comprehensive review of the extended version of the MCDM methods and their applications in several areas to cover this gap. To explain the recent developments of MCDM techniques for IVIF sets, tables and figures are presented related to year, document type, journal, country, method, application area, type of application, citations, validation method.

The remainder of this paper is organised as follows. Section 2 includes research questions that present the framework of the study. Section 3 describes the review methodology and present the summarising of the compiled publications. Section 4 provides the findings of the review analysis as based on the research questions. Section 5 discusses the results and gives suggestions for future studies.

List of abbreviations

AHP – analytic hierarchy process
ANP – analytic network process
ARAS – additive ratio assessment
BCI-C – book citation index – science
BWM – best worst method
CODAS – combinative distance-based assessment
COPRAS – complex proportional assessment
CPCI-S – conference proceedings citation index – science
CPCI-SSH – conference proceedings citation index – social science and humanities
DEMATEL – decision making trial and evaluation laboratory
EDAS – evaluation based on distance from average solution
ELECTRE – elimination and choice translating reality
FMEA – failure mode and effectect analysis
GRA – grey relational analysis

IF – intuitionistic fuzzy
IVIF – interval-valued intuitionistic fuzzy
IVIFSs – interval-valued intuitionistic fuzzy sets
IVIFWA – interval-valued intuitionistic fuzzy weighted arithmetic
IVIFWG – interval-valued intuitionistic fuzzy weighted geometric
LINMAP – linear programming technique for multidimensional analysis of preference
MABAC – multi-attributive border approximation area comparison
MADM – multi attribute decision making
MCDM – multi criteria decision making
MOORA – multi-objective optimisation method by ratio analysis
MULTIMOORA – multiobjective optimisation by ratio analysis plus full multiplicative form
PROMETHEE – preference ranking organisation method for enrichment evaluation
QUALIFLEX – qualitative flexible
SCIE – science citation index expanded
TODIM – iterative multi criteria decision making
TOPSIS – technique for order preference by similarity to an ideal solution
VIKOR – multicriteria optimization and compromise solution (Serb. *visekriterijumska optimizacija i kompromisno resenje*)
WASPAS – weighted aggregates sum product assessment

2. Purpose of the research

The purpose of this study is to conduct a literature review of relevant publications on the application of MCDM methods under the IVIF environment. This review would help to explain the trend in the application of IVIF-MCDM methods in several domains.

Table 2. Description of the research questions

Research question	Description
RQ#1	What is the year-wise publication trend?
RQ#4	What is the distribution of the publications according to countries?
RQ#5	Which journals publish the leading papers?
RQ#6	Which journals are the most relevant to IVIF-MCDM methods? What is the growth of the articles in journals over the years?
RQ#7	Which articles are the most cited?
RQ#8	Which are the applications area for IVIF-MCDM methods?
RQ#9	Which one of the IVIF-MCDM methods have been used and which one of these methods have been more preferred?
RQ#10	Which methods are used for validation of IVIF-MCDM methods?

Furthermore, the literature review would present the researchers with a detailed analysis of the IVIF-MCDM applications and provide them with the basic information

for developing further applications in the MCDM for the IVIF sets. This research is conducted within the framework of the following Research Questions (Table 2) which are not ranked according to their importance.

3. Literature review

Thanks to the analysis of various databases with different keywords, a comprehensive literature analysis is offered to the researchers. In addition, customising these publications under certain headings facilitates the analysis of the issue to be examined. The basic framework and components of the review methodology adopted in this study are presented in the phases of Fig. 1. This methodology consists of the main three stages: extraction, screening, and analysis.

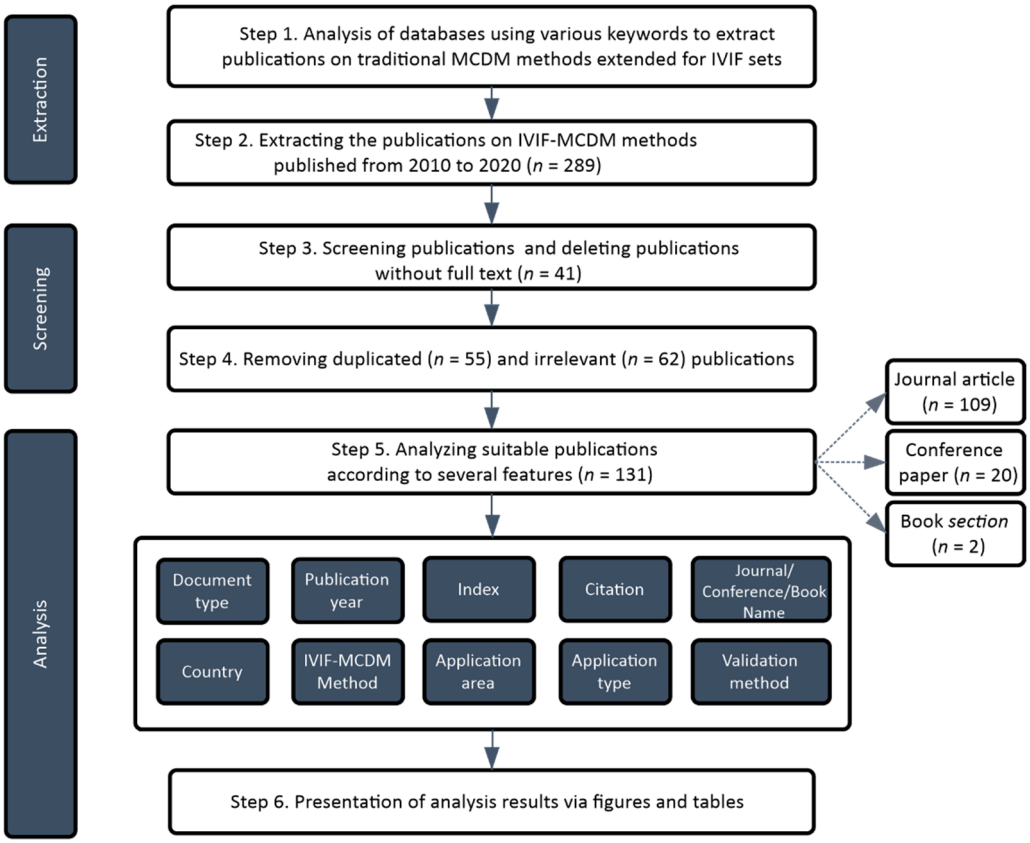

Fig. 1. The flowchart for the literature review

At the first stage, relevant publications were compiled from the database for the period between the years 2010 and 2020. Literature searches were conducted in the databases (Web of Science, Elsevier, Springer, Taylor and Francis, Scopus, Google Scholar, Hindawi, IEEExplore, Wiley) on various keywords as in Table 3. As a result of the literature review, 290 publications in English concerning the keywords were extracted. At the second stage, publications were screened and the papers that are not published in full-text were removed. The duplication between publications is checked to avoid incorrect statistics. Then, the irrelevant publications were deleted.

Table 3. Keywords of literature review

IVIF interval valued intuitionistic fuzzy	AHP AND DEMATEL ELECTRE MOORA PROMETHEE TOPSIS VIKOR MCDM	MADM MCDA MADA decision making multi criteria and decision-making multi attribute and decision-making multi criteria and decision analysis multi attribute and decision analysis

In the third step, 131 full-text papers consisting of 109 articles, 20 conference papers, and 2 book chapters were handled for review analysis. These 131 publications were analysed and recorded under the scheme which is shown in Table 4. As each publication was reviewed, it was classified by several categories: year, document type, journal (or book/conference) name, affiliation country, dex, publisher, method(s), application area, type of application, citations, sensitivity analysis, and comparative analysis.

Table 4. The classification scheme for the review on IVIF-MCDM

No.	1	2	3	...	131
Author(s)					
Year					
Document type					
Journal					
Country					
Index					
Publisher					
Method(s)					
Application area					
Type of application					
Citation					
Sensitivity analysis					
Comparative analysis					

4. Results of the review analysis

4.1. Document type

The number of publications based on the document type is presented in Table 5, and the percentage distribution of the publications according to document types is shown in Fig. 2.

Table 5. Number of the publications based on document type

Document type	Number of publications
Journal article	109
Conference paper	20
Book section	2

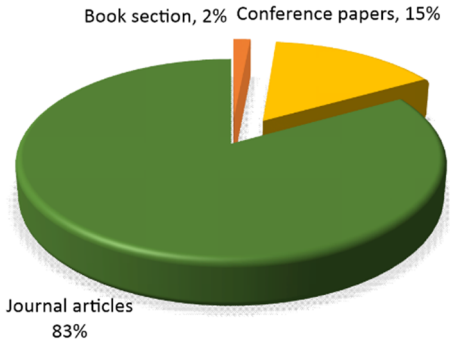

Fig. 2. The percentage distribution of the publications according to document types

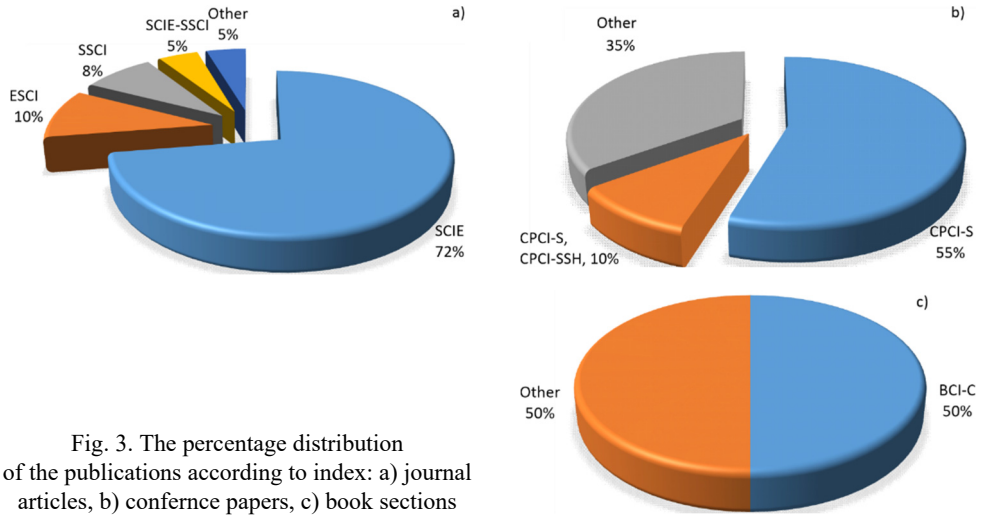

Fig. 3. The percentage distribution of the publications according to index: a) journal articles, b) confernce papers, c) book sections

There is a total of 131 publications contributing to the research area. The document type that has the highest percentage is article. It is seen that MCDM publications applied under the IVIF environment are generally in article form. In addition, the percentage distribution of the publications according to the index is shown Fig. 3.

The articles are published in journals of which 72% are indexed in SCIE, 10% in ESCI, 8% in SSCI, and 5% in both SCIE and SSCI. The conference papers are presented in conferences (55% indexed in CPCI-S, 10% indexed in both CPCI-S and CPCI-SSH). Finally, the book sections are published in the books of which 50% are indexed in BCI-C. As can be seen from the visual analysis, the expansion of MCDM methods under the IVIF environment attracts the attention of SCI-E indexed journals.

4.2. Year-wise publication trend

The number of papers published per year is given in Fig. 4. Out of 131 articles, the highest number of research papers is published in the year 2020 with 29 research papers, followed by the year 2019 with 19 articles. The lowest number of articles is published in the year 2010, and 2011 with 1 and 4. It is realised from Fig. 4 that the number of publications increases year by year. This increase explains the overall progress of research in the area. That is, it is clear that MCDM methods extended under the IVIF environment will get more and more attention from researchers.

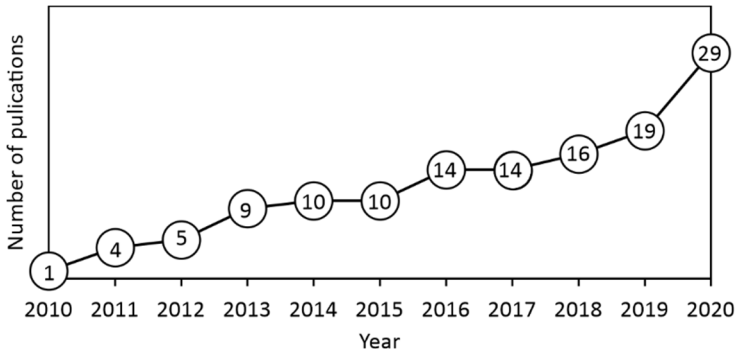

Fig. 4. Number of papers published per year

4.3. Countries' scientific production

The number of publications based on affiliation countries of corresponding authors is presented in Table 6. A total of 14 countries contributes to the research area. The majority of the publications are submitted from China. Turkey, India, and Iran follow China. In other words, the majority of the research in this area originates in Asian countries, and they contribute to 94% of the total research. Moreover, the number of papers

based on the publishers' country is analysed. The country of publishers with at least 4 papers published in their journal is shown in Table 7. It is noteworthy that journals of the United Kingdom, United States, and the Netherlands are more preferred.

Table 6. Number of the publications based on affiliation country

Country	Number of publications
China	46
Turkey	27
India	19
Iran	14
Taiwan	8
Malaysia	5
Tunisia	3
Korea	2
Lithuania	2
Brazil	1
Morocco	1
United Kingdom	1
United States	1
Vietnam	1

Table 7. Number of the publications based on the publisher's country

Country	Number of publications
United Kingdom	31
United States	26
Netherlands	24
Germany	7
Lithuania	5
Switzerland	5
China	4
France	4
Turkey	4

4.4. The most relevant journals

109 articles selected for this literature review have been published in 60 different journals, and 20 journals are presented in Table 8. The growth of the articles in journals that have published at least three articles over the years is shown in Fig. 5. The most relevant journal is Applied Soft Computing, followed by Soft Computing. The first article in the IVIF MCDM methods was published in the journal Expert Systems with Applications in 2010. The journal Soft Computing is the fastest-growing journal in the area of the IVIF MCDM methods with six articles published within the last three years,

while there is a drop in the articles in the Mathematical Problems in Engineering, Applied Mathematical Modelling, Journal of Applied Mathematics, and Knowledge-Based Systems during the same period.

Table 8. The most relevant journal

Journal	Articles	TC	PY start
Applied Soft Computing	9	769	2014
Soft Computing	9	223	2016
Journal of Intelligent and Fuzzy Systems	7	145	2013
Mathematical Problems in Engineering	6	143	2015
Information Sciences	4	183	2014
Applied Mathematical Modelling	3	483	2011
Computers and Industrial Engineering	3	170	2013
Journal of Applied Mathematics	3	42	2012
Knowledge-Based Systems	3	244	2012
Advances in Fuzzy Systems	2	75	2012
Arabian Journal for Science and Engineering	2	41	2018
Expert Systems with Applications	2	478	2010
Fuzzy Optimization and Decision Making	2	136	2011
Group Decision and Negotiation	2	64	2018
IEEE Access	2	28	2018
International Journal of Procurement Management	2	23	2017
Journal of Enterprise Information Management	2	11	2018
Journal of Intelligent Systems	2	14	2018
Sustainability	2	13	2019
Technological and Economic Development of Economy	2	90	2013
Forty other journals	40	923	–

TC – total citations, PY start – the starting year of the appearance of an article in the journal.

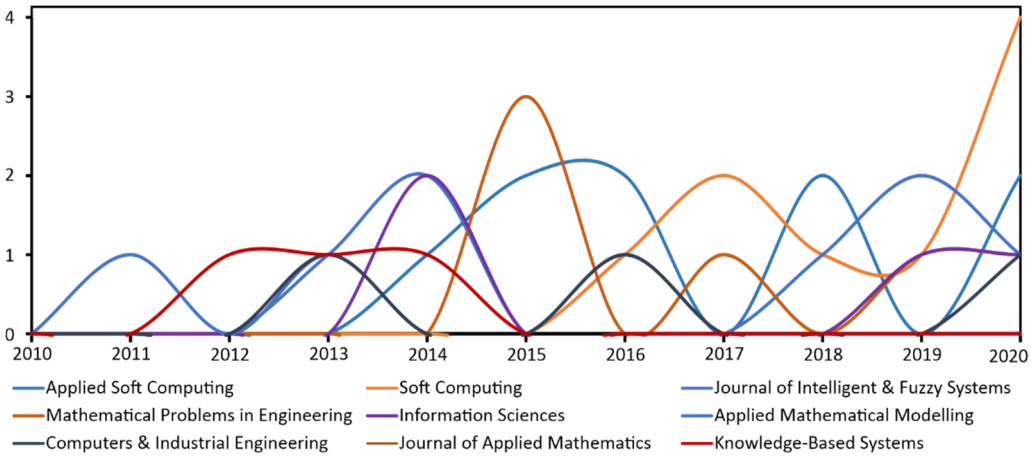

Fig. 5. Growth of articles journal-wise over the years

4.5. The most cited articles

The total citation defines the citation values until December 2020. The publications that are cited at least 100 times globally are presented in Table 9. The four of the most cited articles are in Applied Soft Computing, two are in Expert Systems with Applications, and the others are published in the journals Applied Mathematical Modeling, Computational and Applied Mathematics, Knowledge-Based Systems, Soft Computing, Applied Mathematical Modeling, Information Sciences, Energy, Mathematical Problems in Engineering. The article by Park et al. [15] entitled *Extension of the TOPSIS method for decision making problems under interval-valued intuitionistic fuzzy environment* is the most cited one. This paper studies the air-conditioning selection problem. The second most cited article is by Tan [6] entitled *A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS* which focuses on the investment selection problem. The third most cited article is by Ye [16] entitled *An extended TOPSIS method with interval-valued intuitionistic fuzzy numbers for virtual enterprise partner selection*. The IVIF-TOPSIS method is used in the top five articles with the most citations. Four articles in the top 10 most cited articles are analysed the investment selection problem.

Table 9. The most cited articles

Author (s)	Journal	Application area	TC
Park et al. [15]	Applied Mathematical Modelling	air-conditioning selection problem	284
Tan [6]	Expert Systems with Applications	investment selection problem	262
Ye [16]		partner selection problem	216
Chen [17]	Applied Soft Computing	basilar artery occlusion diagnosis problem	172
Kumar and Garg [18]	Computational and Applied Mathematics	investment selection problem	168
Zavadskas et al. [19]	Applied Soft Computing	derelict building's redevelopment problem, investment selection problem	158
Zhang and Xu [20]	Applied Soft Computing	supplier selection problem	158
Zhang and Yu [21]	Knowledge-Based Systems	investment selection problem	127
Xue et al. [22]	Applied Soft Computing	material selection problem	123
Zhao et al. [23]	Soft Computing	failure mode and effect analysis	112
Hashemi et al. [24]	Applied Mathematical Modelling	investment project selection problem	111
Chen [25]	Information Sciences	bridge construction selection problem	109
Onar et al. [26]	Energy	wind energy technology selection problem	109
Zavadskas et al. [27]	Mathematical Problems in Engineering	derelict building's redevelopment problem, investment selection problem	108

TC – total citations.

4.6. Application area

The 131 publications selected for IVIF-MCDM methods for review vary in their subject and domain. Therefore, these 131 publications are manually classified based on the application area into 16 categories. The publications that cannot be classified due to their application areas are collected in the other category (see Table 10). The evolution of the application area over the years is shown in Fig. 6.

Table 10. Application category, number of publications, and IVIF-MCDM methods

No.	Application area	NP	IVIF-MCDM methods-count [source]
1	Investment selection problem (ISP)	21	IVIF-AHP-1 [28], IVIF-BWM-1 [29], IVIF-COPRAS-1 [30], IVIF-ELECTRE-3 [24, 31, 32], IVIF-TODIM-1 [33], IVIF-TOPSIS-10 [6, 18, 21, 34–40], IVIF-VIKOR-2 [41, 42], IVIF-WASPAS-1 [19], IVIF-MULTIMOORA-1 [27]
2	Supplier selection problem (SSP)	19	IVIF-AHP-1 [43], IVIF-MOORA-1 [44], IVIF-AHP + IVIF-ARAS-2 [45, 46], IVIF-ELECTRE-3 [47-49], IVIF-TOPSIS-7 [20, 50–55], IVIF-VIKOR-1 [56], IVIF-MULTIMOORA-1 [57], IVIF-COPRAS + IVIF-WASPAS-1 [58], IVIF-TODIM-1 [59], IVIF-TODIM + IVIF-WASPAS + IVIF-TOPSIS-1 [60]
3	Location selection problem (LSP)	9	IVIF-ELECTRE-1 [61], IVIF-VIKOR-1 [62], IVIF-TODIM-1 [63], IVIF-CODAS-1 [64], IVIF-TOPSIS-1 [65], IVIF-TODIM-1 [66], IVIF-WASPAS + IVIF-MULTIMOORA-1 [67], IF-DEMATEL + IVIF-AHP+IVIF-TOPSIS-1 [68], IVIF-AHP+IVIF-TOPSIS-1 [69]
4	Technological device selection problem (TDSP)	9	IVIF-TOPSIS-4 [15, 70–72], IVIF-VIKOR-1 [73], IVIF-ARAS + IVIF-TOPSIS-1 [74], IVIF-COPRAS-1 [75], IVIF-AHP +IVIF-TOPSIS-2 [76, 77]
5	Service quality evaluation problem (SQEP)	11	IVIF-AHP-2 [78, 79], IVIF-CODAS-1 [80], IVIF-COPRAS-1 [81], IVIF-PROMETHEE-2 [82, 83], IVIF-TODIM-1 [84], IVIF-TOPSIS-1 [85], IVIF-GRA-1 [86], IVIF-ANP + IVIF-TODIM-1 [87], IVIF-EDAS-1 [88]
6	Technological system evaluation problem (TSEP)	10	IVIF-DEMATEL + IVIF-TOPSIS-1 [89], IVIF-TOPSIS-4 [90–93], IVIF-AHP-1 [26], IVIF-DEMATEL-1 [94], IVIF-MABAC-1 [95], IVIF-AHP + IVIF-CODAS-1 [96], IVIF-CODAS-1 [97]
7	Failure mode and effect analysis problem (FMEAP)	7	IVIF-ANP + IVIF-COPRAS-1 [98], IVIF-COPRAS-1 [99], IVIF-MULTIMOORA-3 [23, 100, 101], IVIF-TOPSIS-1 [102], IVIF-MABAC-1 [103]
8	Construction evaluation problem (CEP)	4	IVIF-AHP-1 [104] , IVIF-QUALIFLEX-1 [25], IVIF-PROMETHEE + IVIF-ELECTRE-1 [8], IVIF-PROMETHEE-1 [105]
9	Cloud computing technology selection problem (CCTSP)	5	IVIF-GRA-1 [106], IVIF-TOPSIS-1 [107], IVIF-AHP + IVIF-COPRAS + IVIF-MULTIMOORA + IVIF-VIKOR-1 [108], IVIF-CODAS-1 [109], IVIF-WASPAS-1 [110]
10	Personnel selection problem (PSP)	4	IVIF-TOPSIS-1 [111], IVIF-AHP-2 [5, 112], IVIF-CODAS-1 [113]
11	Strategy selection problem (StSP)	4	IVIF-AHP + IVIF-TOPSIS-2 [13, 114], IVIF-TODIM + IVIF-BWM-1 [115], IVIF-DEMATEL + IVIF-VIKOR-1 [116]

Table 10. Application category, number of publications, and IVIF-MCDM methods

No.	Application area	NP	IVIF-MCDM methods-count [source]
12	Material selection problem (MSP)	3	IVIF-MABAC-1 [22], IVIF-CODAS-1 [117], IVIF-TODIM-1 [118]
13	Risk assessment problem (RAP)	2	IVIF-TOPSIS-1 [119], IVIF-VIKOR-1 [120]
14	Outsource provider selection problem (OPSP)	3	IVIF-AHP + IVIF-TOPSIS-2 [121, 122], IVIF-ELECTRE-1 [123]
15	Flood management problem (FMP)	3	IVIF-LINMAP-1 [124], IVIF-WASPAS-1 [125], IVIF-TOPSIS-1 [126]
16	Partner selection problem (PrSP)	2	IVIF-TOPSIS-1 [16], IVIF-VIKOR-1 [127]
17	Other	15	IVIF-LINMAP-2 [7, 128], IVIF-VIKOR-2 [129, 130], IVIF-CODAS-1 [131], IVIF-TOPSIS-6 [17, 132–136], IVIF-GRA-1 [137], FAHP + IVIF--TOPSIS-1 [138], IVIF-TOPSIS + IVIF-GRA-1 [139], IVIF-ANP-1 [140]

NP – number of publications.

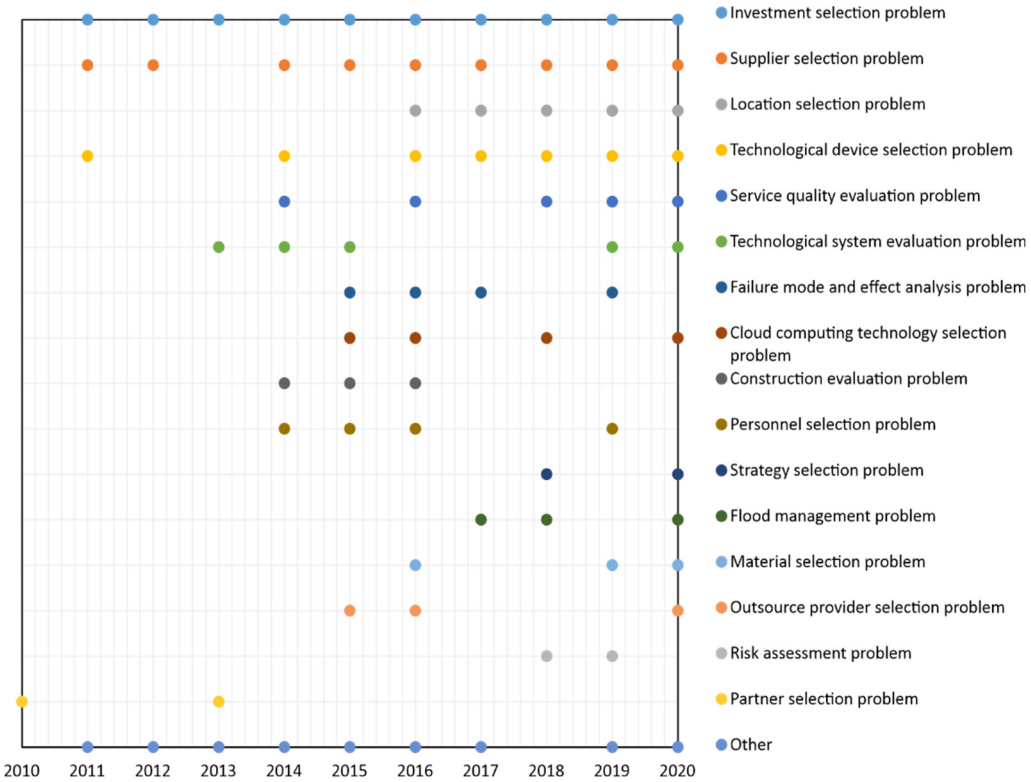

Fig. 6. The evolution of the application area over the years

From this chart, it is seen that the application areas where MCDM methods developed for IVIF sets are applied are diversified. The majority of the publications belong to the category investment selection problem followed by supplier selection problem. The top three most cited publications belong to the category technological device selection problem [15], investment selection problem [6], and partner selection problem [16].

4.7. IVIF-MCDM methods

IVIF-MCDM methods are used to calculate criteria weights or to select alternatives. IVIF-AHP and IVIF-ANP methods are generally preferred to assess criteria weights as well as the ranking of alternatives. IVIF-MCDM methods can be used alone or in combination with two or more different IVIF-MCDM methods. The percentage distribution of the methods included in the publications evaluated within the scope of the literature study is shown in Fig. 7. The most common method used during the last decade is IVIF--TOPSIS, having a percentage of 29.8%. The IVIF-AHP and IVIF-ELECTRE methods follow it with a percentage of 6.1%.

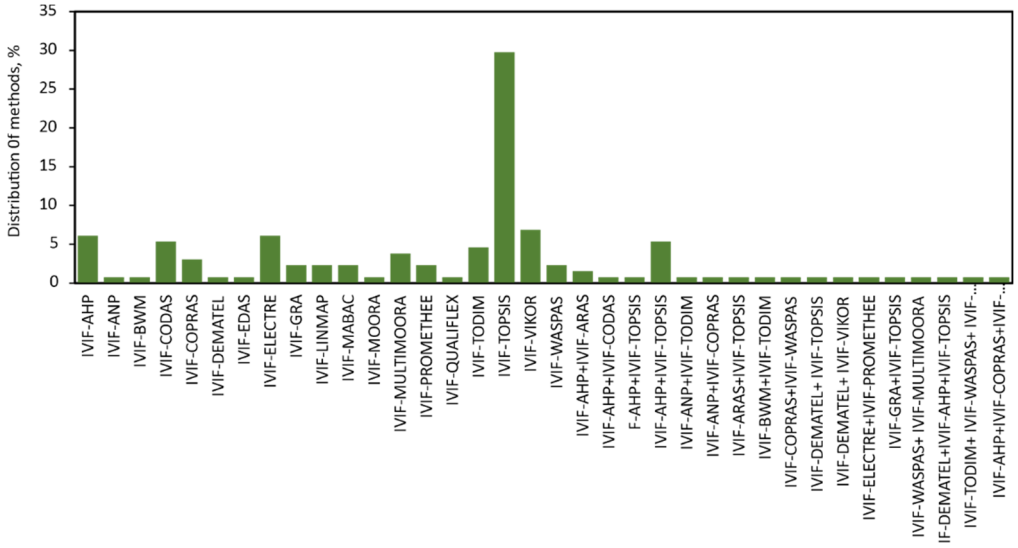

Fig. 7. The percentage distribution of the IVIF-MCDM methods

The rate of individual use of IVIF-MCDM methods is higher than the rate of combined use. When the evolution of the IVIF-MCDM methods over the years presented in Fig. 8 is examined, it is seen that the use of IVIF-MCDM methods together is handled mostly in recent years. As far as is known, IVIF-MCDM methods used together for the first time are IVIF-ELECTRE and IVIF-PROMETHEE. This combination was used in the Construction evaluation problem application field in 2014.

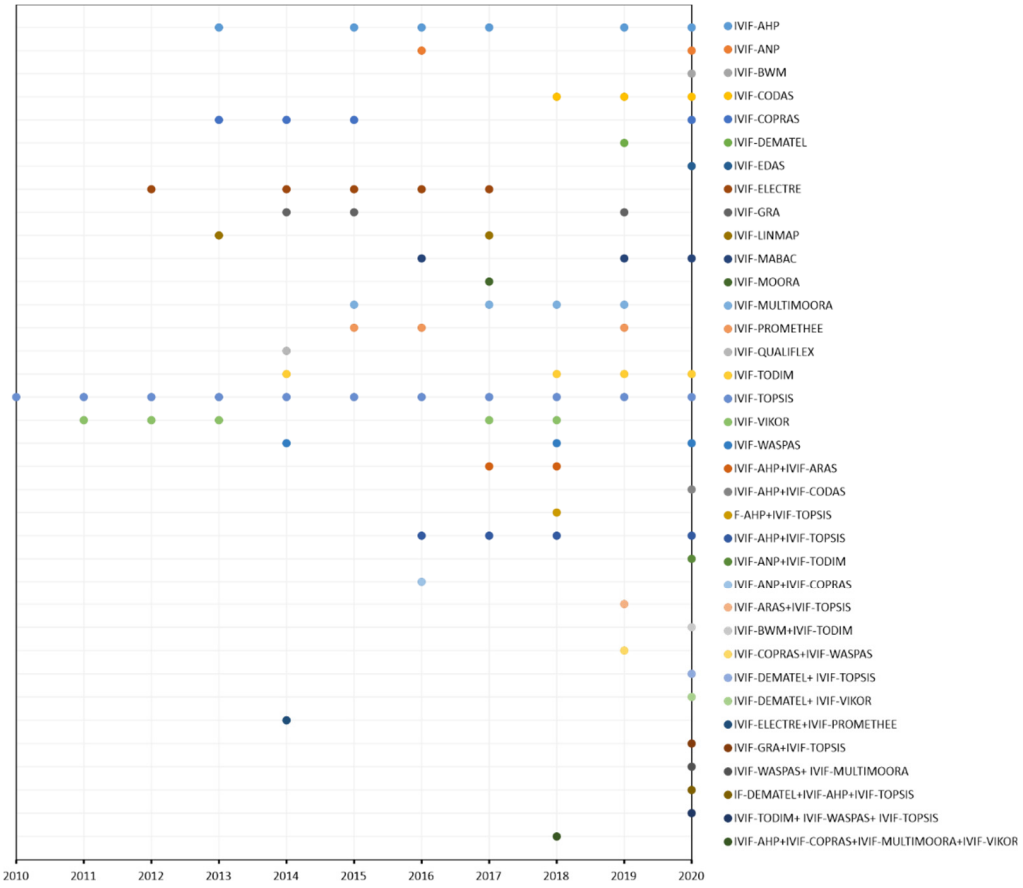

Fig. 8. The evolution of the IVIF-MCDM methods over the years

Table 11. IVIF-MCDM methods, number of publications, and application category

IVIF-MCDM method	NP	Application area-count [source]
IVIF-AHP	8	ISP-1 [28], SSP-1 [43], SQEP-2 [78, 79], TSEP-1 [26], CEP-1 [104], PSP-2 [5, 112]
IVIF-ANP	1	Other-1 [140]
IVIF-BWM	1	ISP-1 [29]
IVIF-CODAS	7	LSP-1 [64], TSEP-1 [97], CCTSP-1 [109], PSP-1 [113], MSP-1 [117], SQEP-1 [80], Other-1 [131]
IVIF-COPRAS	4	ISP-1 [30], TDSP-1 [75], FMEAP-1 [99], SQEP-1 [81]
IVIF-DEMATEL	1	TSEP-1 [94]
IVIF-EDAS	1	SQEP-1 [88]
IVIF-ELECTRE	8	ISP-3 [24, 31, 32], SSP-3 [47–49], LSP-1[61], OPSP-1 [123]
IVIF-GRA	3	SQEP-1 [86], CCTSP-1 [106], Other-1 [137]
IVIF-LINMAP	3	FMP-1 [124], Other-2 [7, 128]

Table 11. IVIF-MCDM methods, number of publications, and application category

IVIF-MCDM method	NP	Application area-count [source]
IVIF-MABAC	3	TSEP-1 [95], FMEAP-1 [103], MSP-1 [22]
IVIF-MOORA	1	SSP-1 [44]
IVIF-MULTIMOORA	5	ISP-1 [27], SSP-1 [57], FMEAP-3 [23, 100, 101]
IVIF-PROMETHEE	3	SQEP-2 [82, 83], CEP-1 [105]
IVIF-QUALIFLEX	1	CEP-1 [25]
IVIF-TODIM	6	ISP-1 [33], SSP-1 [59], LSP-2 [63, 66], MSP-1 [118], SQEP-1[84]
IVIF-TOPSIS	39	ISP-10 [6, 18, 21, 34–40], SSP-7 [50–55, 141], LSP-1 [65], TDSP-4 [15, 70–72], SQEP-1 [85], TSEP-4 [90–93], FMEAP-1 [102], CCTSP-1 [107], PSP-1 [111], RAP-1 [119], FMP-1 [126], PrSP-1 [16], Other-6 [17, 132–136]
IVIF-VIKOR	9	ISP-2 [41, 42], SSP-1 [56], LSP-1 [62], TDSP-1 [73], RAP-1 [120], PrSP-1 [127], Other-2 [129, 130]
IVIF-WASPAS	3	ISP-1 [19], CCTSP-1 [110], FMP-1 [125]
IVIF-AHP + IVIF-ARAS	2	SSP-2 [45, 142]
IVIF-AHP + IVIF-CODAS	1	TSEP-1 [96]
F-AHP + IVIF-TOPSIS	1	Other-1 [138]
IVIF-AHP + IVIF-TOPSIS	7	LSP-1 [69], TDSP-2 [76, 77], StSP-2 [13, 114], OPSP-2 [121, 122]
IVIF-ANP + IVIF-TODIM	1	SQEP-1 [87]
IVIF-ANP + IVIF-COPRAS	1	FMEAP-1 [98]
IVIF-ARAS + IVIF-TOPSIS	1	TDSP-1 [74]
IVIF-BWM + IVIF-TODIM	1	StSP-1 [115]
IVIF-COPRAS + IVIF-WASPAS	1	SSP-1 [58]
IVIF-DEMATEL + IVIF-TOPSIS	1	TSEP-1 [89]
IVIF-DEMATEL + IVIF-VIKOR	1	StSP-1 [116]
IVIF-ELECTRE +IVIF-PROMETHEE	1	CEP-1 [8]
IVIF-GRA + IVIF-TOPSIS	1	Other-1 [139]
IVIF-WASPAS + IVIF-MULTIMOORA	1	LSP-1 [67]
IF-DEMATEL + IVIF-AHP+IVIF-TOPSIS	1	LSP-1 [68]
IVIF-TODIM + IVIF-WASPAS + IVIF-TOPSIS	1	SSP-1 [60]
IVIF-AHP + IVIF-COPRAS + IVIF-MULTIMOORA + IVIF-VIKOR	1	CCTPS-1 [108]

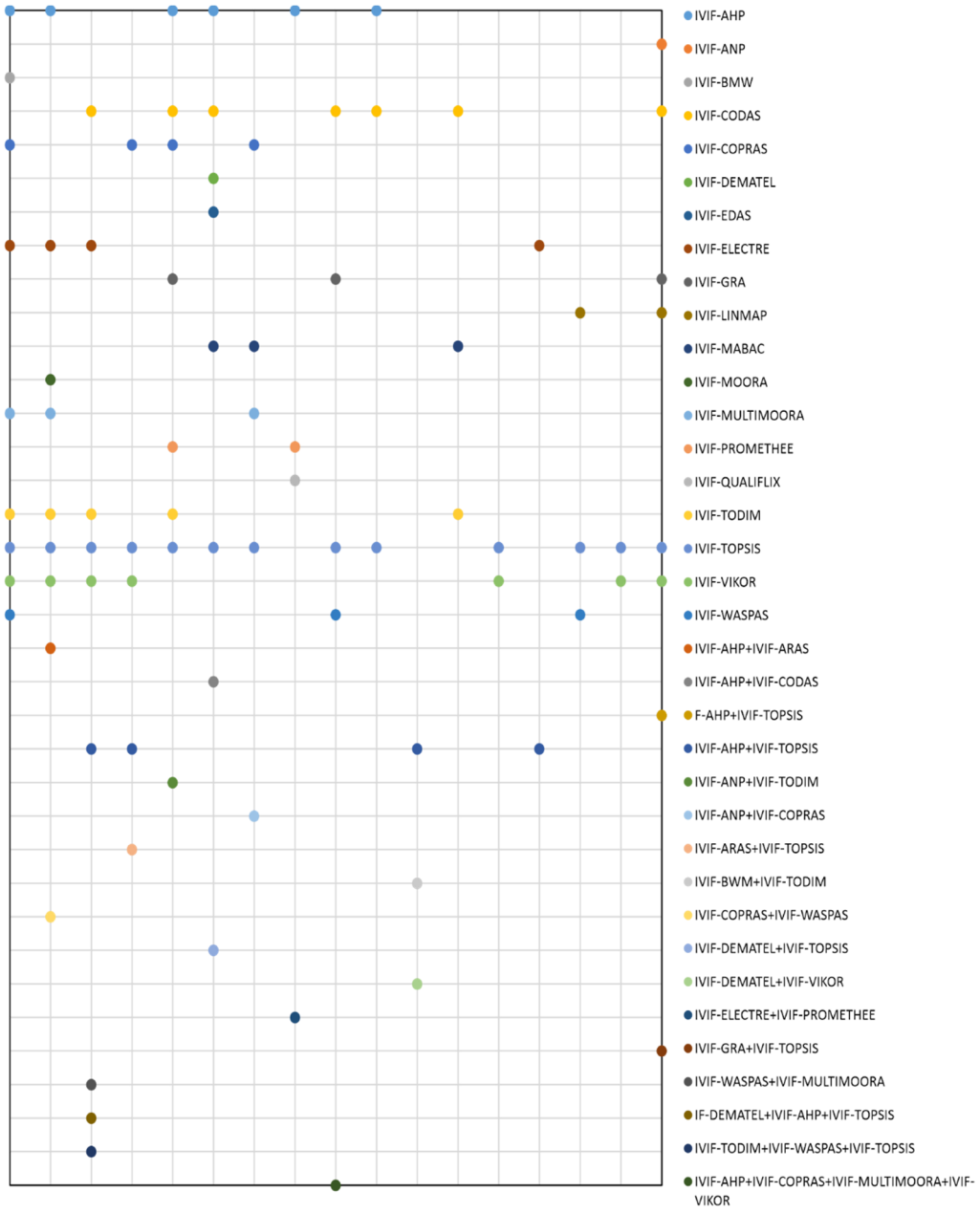

Fig. 9. IVIF-MCDM methods used across the application categories

The details of the IVIF-MCDM methods used as per the application area are presented in Table 11. Furthermore, IVIF-MCDM methods used per application categories

are illustrated in Fig. 9. It is seen from these figures that one of the earliest extended methods is the TOPSIS having applications in thirteen of the seventeen categories. The second extended method, as far as the authors know, is the VIKOR, having five applications in seventeen application categories.

4.8. Validation analysis

Validation of the proposed MCDM model is a requirement for the acceptability of any model. The 131 publications reviewed conduct several validation methods for their study. Sensitivity analysis is the most common approach. The other common approach is comparing the application results with other MCDM methods. The methods used for validation in the publications are indicated in Appendix. Moreover, the distribution of validation methods is summarised in Fig. 10. Forty-three research publications have not presented any details concerning validation. Forty-nine articles utilised only comparative analysis, six articles used only sensitivity analysis, and twenty-seven articles applied both analyses for validation. Five conference papers and one book section applied only comparative analysis to show the applicability of the proposed methods.

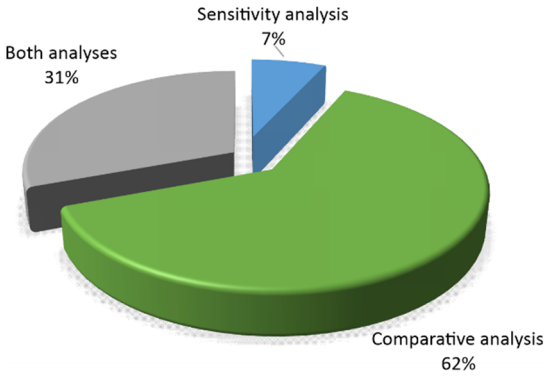

Fig. 10. Distribution of validation methods based on document type

5. Discussion and conclusion

The foundation of the MCDM methods was laid in the mid-1950s, and from then on, many researchers have studied for developing new models or improving the existing approaches. After Atanassov and Gargov [4] introduced the IVIF sets theory in 1986, traditional MCDM methods have begun to be extended to the IVIF environment. In this study, the literature review is conducted to examine extended traditional MCDM methods for IVIF sets. It is aimed to ensure a roadmap to researchers by providing them with a comprehensive summary on this topic. Moreover, it is aimed to fill the gaps in the

literature about the review of IVIF-MCDM studies. In the light of these aims, this study, 131 studies, consisting of 109 articles, 20 conference papers, and 2 book chapters, are analysed. These studies are examined by grouping them according to years, document types, journals, countries, dex, method, application area, application type, and validation method.

The earliest application of extending traditional MCDM methods as per the several databases was discovered in 2010. In 2010, Ye published an article in the journal Expert Systems with Applications on extending the TOPSIS [16]. Park et al. [15] published another article in the domain under the application category technological device selection problem in 2011.

The most prominent IVIF-MCDM method is IVIF-TOPSIS used to rank alternatives. IVIF-TOPSIS method has been employed in all application categories except for the material selection problem. The second most prominent IVIF-MCDM methods used in studies on IVIF-MCDM methods are the IVIF-AHP and IVIF-ELECTRE methods. IVIF-AHP method that can compute the criteria weights as well as rank the alternatives. Moreover, the IVIF-AHP is used in combination with methods like IVIF-ARAS, IVIF-CODAS, IVIF-COPRAS, IVIF-MULTIMOORA, IVIF-VIKOR, IVIF-TOPSIS [13, 45, 68, 69, 76, 77, 96, 108, 121, 122].

The first application category applied on extension traditional MCDM into IVIF--environment is a partner selection problem. In 2010, the first article in this category was conducted by Ye [16] by using the IVIF-TOPSIS method. The majority of the articles on the IVIF-MCDM methods are published in the investment selection problem category and IVIF-TOPSIS is the earliest IVIF-MCDM method employed by Tan in 2011 [6] in this category. The next article in the category was published in 2012 and the IVIF-ELECTRE method was used in this article [31]. The last article that introduced the IVIF-BWM method was published in 2020 in the investment selection problem category [29]. The second most prominent application category is the supplier selection problem. In the category, the first conference paper applied the IVIF-VIKOR method in 2011 [56], and the first article used the IVIF-ELECTRE method in 2014 [47]. The most cited article in this category was published in 2015 by Zhang and Xu [20], and the IVIF-TOPSIS method was preferred. In 2017, the IVIF-AHP method was recommended, and it was again used for weight criteria, while the IVIF-ARAS method was employed for ranking suppliers [45]. The combination of the AHP and ARAS method was used also in 2018 [46].

The most relevant journal on extended IVIF-MCDM methods is Applied Soft Computing. Applied Soft Computing has published 9 articles across eight application categories with a total of 769 citations. The earliest article on extended IVIF-MCDM methods published in this journal was by Zavadskas et al. [19] in 2014. The second most relevant journal Soft Computing has published 9 articles on extended IVIF-MCDM across eight application categories with 223 citations in the last five years. The Applied Mathematical Modelling has published only three articles [15, 28, 143] on extended IVIF-MCDM

methods and has the second-highest citations owing to the presence of the article by Park et al. [15]. Moreover, the Expert Systems with Applications has published only two articles [6, 16] on extended IVIF-MCDM methods and has the third-highest citations because both articles have the highest citations following Park et al. [15]. It is seen from the analysis of journals that gradually more journals have accepted articles on extended IVIF-MCDM methods.

The publications on the IVIF-MCDM methods have used sensitivity analysis and comparative analysis methods for validation. All journal articles have provided validation analysis; on the other hand, 15 conference paper and 1 book section that have not provided any details about validation belong to the following methods; IVIF-AHP [104, 112], IVIF-AHP + IVIF-ARAS [45], IVIF-ARAS + IVIF-TOPSIS [74], IVIF-CODAS [131], IVIF-COPRAS [99], IVIF-DEMATEL + IVIF-TOPSIS [89], IVIF-LINMAP [128], IVIF-MOORA [73], IVIF-PROMETHEE [82], IVIF-TODIM [33], IVIF-TOPSIS [70, 134], IVIF-VIKOR [56, 73, 129].

As a result of this review analysis, it is determined that a large number of traditional MCDM methods are extended for IVIF sets and many of these methods are applicable for the various decision-making problems. Also, it is seen that extended MCDM methods to the IVIF environment can be used jointly as traditional methods are. In the last five years, it has been seen an increasing trend in the research publications on the IVIF-MCDM applications, and also, it is expected that it will increase in the coming years, as well.

This review is limited to traditional methods extended for IVIF sets. The authors have tried their best to contain all the relevant publications to get a correct review result, but there is a minor possibility of some publications being left out. The publications whose full-text were not accessible were also excluded from this study. In future work, it is suggested that the extended version of fuzzy sets such as hesitant, spherical, Pythagorean in addition to intuitionistic can be reviewed in the specific domain.

References

[1] BEHZADIAN M., OTAGHSARA S.K., YAZDANI M., IGNATIUS J., *A state-of the-art survey of TOPSIS applications*, Exp. Syst. Appl., 2012, 39 (17), 13051–13069.

[2] KAYA İ., ÇOLAK M., TERZI F., *A comprehensive review of fuzzy multi criteria decision making methodologies for energy policy making*, En. Strat. Rev., 2019, 24, 207–228.

[3] KOKOC M., ERSOZ S., *New ranking functions for interval-valued intuitionistic fuzzy sets and their application to multi-criteria decision-making problem*, Cyber. Inf. Techn., 2021, 21 (1), 3–18.

[4] ATANASSOV K.T., GARGOV G., *Interval-valued intuitionistic fuzzy sets*, Fuzzy Sets Syst., 1989, 3 (1989), 343–349.

[5] ABDULLAH L., NAJIB L., *A new preference scale mcdm method based on interval-valued intuitionistic fuzzy sets and the analytic hierarchy process*, Soft Comp., 2016, 20 (2), 511–523.

[6] TAN C.Q., *A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS*, Exp. Syst. Appl., 2011, 38 (4), 3023–3033.

[7] CHEN T.Y., *An interval-valued intuitionistic fuzzy LINMAP method with inclusion comparison possibilities and hybrid averaging operations for multiple criteria group decision making*, Knowl. Bas. Syst., 2013, 45, 134–146.
[8] CHEN T.-Y., *Multiple criteria decision analysis using a likelihood-based outranking method based on interval-valued intuitionistic fuzzy sets*, Inf. Sci., 2014, 286, 188–208.
[9] MARDANI A., JUSOH A., ZAVADSKAS E.K., *Fuzzy multiple criteria decision-making techniques and applications. Two decades review from 1994 to 2014*, Exp. Syst. Appl., 2015, 42 (8), 4126–4148.
[10] KAHRAMAN C., ONAR S.C., OZTAYSI B., *Fuzzy multicriteria decision-making: a literature review*, Int. J. Comp. Int. Syst., 2015, 8 (4), 637–666.
[11] GUL M., CELIK E., AYDIN N., GUMUS A., T.GUNERI A.F., *A state of the art literature review of VIKOR and its fuzzy extensions on applications*, Appl. Soft Comp., 2016, 46, 60–89.
[12] MARDANI A., JUSOH A., HALICKA K., EJDYS J., MAGRUK A., AHMAD U.N.U., *Determining the utility in management by using multi-criteria decision support tools: a review*, Econ. Res., 2018, 31 (1), 1666–1716.
[13] KAYA I., ERDOGAN M., KARASAN A., OZKAN B., *Creating a road map for industry 4.0 by using an integrated fuzzy multicriteria decision-making methodology*, Soft Comp., 2020, 24 (23), 17931–17956.
[14] LIU H.C., CHEN X.Q., DUAN C.Y., WANG Y.M., *Failure mode and effect analysis using multi-criteria decision making methods. A systematic literature review*, Comp. Ind. Eng., 2019, 135, 881–897.
[15] PARK J.H., PARK I.Y., KWUN Y.C., TAN X.G., *Extension of the TOPSIS method for decision making problems under interval-valued intuitionistic fuzzy environment*, Appl. Math. Model., 2011, 35 (5), 2544–2556.
[16] YE F., *An extended TOPSIS method with interval-valued intuitionistic fuzzy numbers for virtual enterprise partner selection*, Exp. Syst. Appl., 2010, 37 (10), 7050–7055.
[17] CHEN T.Y., *The inclusion-based TOPSIS method with interval-valued intuitionistic fuzzy sets for multiple criteria group decision making*, Appl. Soft Comp., 2015, 26, 57–73.
[18] KUMAR K., GARG H., *TOPSIS method based on the connection number of set pair analysis under interval-valued intuitionistic fuzzy set environment*, Comp. Appl. Math., 2018, 37 (2), 1319–1329.
[19] ZAVADSKAS E.K., ANTUCHEVICIENE J., HAJIAGHA S.H.R., HASHEMI S.S., *Extension of weighted aggregated sum product assessment with interval-valued intuitionistic fuzzy numbers (WASPAS-IVIF)*, Appl. Soft Comp., 2014, 24, 1013–1021.
[20] ZHANG X., XU Z., *Soft computing based on maximizing consensus and fuzzy TOPSIS approach to interval-valued intuitionistic fuzzy group decision making*, Appl. Soft Comp., 2015, 26, 42–56.
[21] ZHANG H.M., YU L.Y., *MADM method based on cross-entropy and extended TOPSIS with interval-valued intuitionistic fuzzy sets*, Knowl. Bas. Syst., 2012, 30, 115–120.
[22] XUE Y.X., YOU J.X., LAI X.D., LIU H.C., *An interval-valued intuitionistic fuzzy MABAC approach for material selection with incomplete weight information*, Appl. Soft Comp., 2016, 38, 703–713.
[23] ZHAO H., YOU J.X., LIU H.C., *Failure mode and effect analysis using MULTIMOORA method with continuous weighted entropy under interval-valued intuitionistic fuzzy environment*, Soft Comp., 2017, 21 (18), 5355–5367.
[24] HASHEMI S.S., HAJIAGHA S.H.R., ZAVADSKAS E.K., MANDIRAJI H.A., *Multicriteria group decision making with ELECTRE III method based on interval-valued intuitionistic fuzzy information*, Appl. Math. Model., 2016, 40 (2), 1554–1564.
[25] CHEN T.Y., *Interval-valued intuitionistic fuzzy QUALIFLEX method with a likelihood-based comparison approach for multiple criteria decision analysis*, Inf. Sci., 2014, 261, 149–169.
[26] ONAR S.C., OZTAYSI B., OTAY I., KAHRAMAN C., *Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets*, Energy, 2015, 90, 274–285.
[27] ZAVADSKAS E.K., ANTUCHEVICIENE J., HAJIAGHA S.H.R., HASHEMI S.S., *The interval-valued intuitionistic fuzzy MULTIMOORA method for group decision making in engineering*, Math. Probl. Eng., 2015, 1–13.

[28] WU J., HUANG H.B., CAO Q.W., *Research on AHP with interval-valued intuitionistic fuzzy sets and its application in multi-criteria decision making problems*, Appl. Math. Model., 2013, 37 (24), 9898–9906.
[29] MOHAMMADI S.E., MOHAMMADI E., *A novel approach to fuzzy multi-attribute group decision making based on interval-valued intuitionistic fuzzy best-worst method*, Int. J. Ind. Eng., 2020, 31 (3), 435–454.
[30] RAZAVI HAJIAGHA S.H., HASHEMI S.S., ZAVADSKAS E.K., *A complex proportional assessment method for group decision making in an interval-valued intuitionistic fuzzy environment*, Techn. Econ. Dev. Econ., 2013, 19 (1), 22–37.
[31] WU M., CHEN T., *Interval-valued intuitionistic fuzzy ELECTRE method*, Appl. Sci. Eng. Prog., 2012, 5 (3), 33–40.
[32] DAMMAK F., BACCOUR L., AYED A.B., ALIMI A.M., *Electre method using interval-valued intuitionistic fuzzy sets and possibility theory for multi-criteria decision making problem resolution*, 2017 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Naples, Italy, 2017.
[33] KROHLING R.A., PACHECO A.G., *Interval-valued intuitionistic fuzzy TODIM*, *information technology and quantitative management (ITQM2014)*, Agadir, Morocco, 2016.
[34] ZHANG J.L., QI X.W., *Induced interval-valued intuitionistic fuzzy hybrid aggregation operators with TOPSIS order-inducing variables*, J. Appl. Math., 2012, 1–24.
[35] LIU S.H., YU F.S., XU W.H., ZHANG W.X., *New approach to MCDM under interval-valued intuitionistic fuzzy environment*, In. J. Mach. Learn. Cyber., 2013, 4 (6), 671–678.
[36] XIAN S., DONG Y., LIU Y., JING N., *A novel approach for linguistic group decision making based on generalized interval-valued intuitionistic fuzzy linguistic induced hybrid operator and TOPSIS*, Int. J. Int. Syst., 2018, 33 (2), 288–314.
[37] GARG H., KUMAR K., *A novel exponential distance and its based TOPSIS method for interval-valued intuitionistic fuzzy sets using connection number of SPA theory*, Art. Int. Rev., 2020, 53 (1), 595–624.
[38] DAMMAK F., BACCOUR L., ALIMI A.M., *Interval valued intuitionistic fuzzy weight techniques for topsis method*, 13th International Conference of Computer Systems and Applications (AICCSA), Agadir, Morocco, 2016.
[39] KUMAR S., BISWAS A., *A unified TOPSIS approach to MADM problems in interval-valued intuitionistic fuzzy environment*, *Computational Intelligence: Theories, Applications and Future Directions*, Vol. 2, Springer, 2019, 435–447.
[40] KUMAR S., BISWAS A., *TOPSIS based on linear programming for solving MADM problems in interval-valued intuitionistic fuzzy settings*, 4th International Conference on Recent Advances in Information Technology (RAIT), Dhanbad, India, 2018.
[41] TAN C.Q., CHEN X.H., *Interval-valued intuitionistic fuzzy multicriteria group decision making based on VIKOR and choquet integral*, J. Appl. Math., 2013, 28, 1172–1195.
[42] RANI P., JAIN D., HOODA D.S., *Shapley function based interval-valued intuitionistic fuzzy VIKOR technique for correlative multi-criteria decision making problem*s, Iranian J. Fuzzy Syst., 2018, 15 (1), 25–54.
[43] TOORANLOO H.S., IRANPOUR A., *Supplier selection and evaluation using interval-valued intuitionistic fuzzy AHP method*, Int. J. Proc. Manage., 2017, 10 (5), 539–554.
[44] BÜYÜKÖZKAN G., GÖÇER F., *An extension of MOORA approach for group decision making based on interval valued intuitionistic fuzzy numbers in digital supply chain*, Joint 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems (IFSA-SCIS), Otsu, Japan, 2017.
[45] BÜYÜKÖZKAN G., GÖÇER F., *An extention of ARAS methodology based on interval valued intuitionistic fuzzy group decision making for digital supply chain*, 2017 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Naples, Italy, 2017.
[46] BÜYÜKÖZKAN G., GÖÇER F., *An extension of ARAS methodology under interval valued intuitionistic fuzzy environment for digital supply chain*, Appl. Soft Comp., 2018, 69, 634–654.

[47] XU J., SHEN F., *A new outranking choice method for group decision making under Atanassov's interval-valued intuitionistic fuzzy environment*, Knowl. Bas. Syst., 2014, 70, 177–188.
[48] VEERAMACHANENI S., KANDIKONDA H., *An ELECTRE approach for multicriteria interval-valued intuitionistic trapezoidal fuzzy group decision making problems*, Adv. Fuzzy Syst., 2016, 1–17.
[49] KRISHANKUMAR R., RAVICHANDRAN K.S., RAMPRAKASH R., *A scientific decision framework for supplier selection under interval valued intuitionistic fuzzy environment*, Math. Probl. Eng., 2017, 1–18.
[50] TIWARI A., LOHANI Q.D., MUHURI P.K., *Interval-valued intuitionistic fuzzy TOPSIS method for supplier selection problem*, IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Glasgow, UK, 2020.
[51] GAUTAM S.S., SINGH S.R., *An improved-based TOPSIS method in interval-valued intuitionistic fuzzy environment*, Life Cycle Rel. Saf. Eng., 2018, 7 (2), 81–88.
[52] TOORANLOO H.S., AYATOLLAH A.S., KARAMI M., *IT outsourcing through group decision-making based on the principles of interval-valued intuitionistic fuzzy theory*, Int. J. Proc. Manage., 2018, 11 (1), 96–112.
[53] HAJEK P., FROELICH W., *Integrating TOPSIS with interval-valued intuitionistic fuzzy cognitive maps for effective group decision making*, Inf. Sci., 2019, 485, 394–412.
[54] JIA Z.S., ZHANG Y.J., *Interval-valued intuitionistic fuzzy multiple attribute group decision making with uncertain weights*, Math. Probl. Eng., 2019, 1–9.
[55] IZADIKHAH M., *Group decision making process for supplier selection with TOPSIS method under interval-valued intuitionistic fuzzy numbers*, Adv. in Fuzzy Syst., 2012, 1–14.
[56] LI C., JIANG H., *Extension of VIKOR method with interval-valued intuitionistic fuzzy sets*, International Conference on Management and Service Science, Wuhan, China, 2011.
[57] QUAN M.Y., WANG Z.L., LIU H.C., SHI H., *A hybrid MCDM approach* for *large group green supplier selection with uncertain linguistic information*, IEEE Access, 2018, 6, 50372–50383.
[58] DAVOUDABADI R., MOUSAVI S.M., MOHAGHEGHI V., VAHDANI B., *Resilient supplier selection through introducing a new interval-valued intuitionistic fuzzy evaluation and decision-making framework*, Ar. J. Sci. Eng., 2019, 44 (8), 7351–7360.
[59] MAO R.J., YOU J.X., DUAN C.Y., SHAO L.N., *A heterogeneous MCDM framework for sustainable supplier evaluation and selection based on the IVIF-TODIM method*, Sust., 2019, 11 (18), 5057.
[60] DAVOUDABADI R., MOUSAVI S.M., MOHAGHEGHI V., *A new last aggregation method of multi-attributes group decision making based on concepts of TODIM, WASPAS and TOPSIS under interval-valued intuitionistic fuzzy uncertainty*, Knowl. Inf. Syst., 2020, 62, 1371–1391.
[61] CHEN T.Y., *An IVIF – electre outranking method for multiple criteria decision-making with interval--valued intuitionistic fuzzy sets*, Techn. Econ. Dev. Econ., 2016, 22 (3), 416–452.
[62] LIU P.D., QIN X.Y., *An extended VIKOR method for decision making problem with interval-valued linguistic intuitionistic fuzzy numbers based on entropy*, Inform., 2017, 28 (4), 665–685.
[63] MISHRA A.R., RANI P., *Biparametric information measures-based TODIM technique for interval-valued intuitionistic fuzzy environment*, Arabian J. Sci. Eng., 2018, 43 (6), 3291–3309.
[64] BOLTURK E., KAHRAMAN C., *Interval-valued intuitionistic fuzzy CODAS method and its application to wave energy facility location selection problem*, J. Int. Fuzzy Syst., 2018, 35 (4), 4865–4877.
[65] MOUSAVI S.M., ANTUCHEVICIENE J., ZAVADSKAS E.K., VAHDANI B., HASHEMI H., *A new decision model for cross-docking center location in logistics networks under interval-valued intuitionistic fuzzy uncertainty*, Transp., 2019, 34 (1), 30–40.
[66] LU J.P., WEI C., *TODIM method for performance appraisal on social-integration-based rural reconstruction with interval-valued intuitionistic fuzzy information*, J. Int. Fuzzy Syst., 2019, 37 (2), 1731–1740.
[67] AYDIN N., SEKER S., *WASPAS based MULTIMOORA method under IVIF environment for the selection of hub location*, J. Ent. Inf. Manage., 2020, 33 (5), 1233–1256.

[68] KARAŞAN A., KAYA İ., ERDOĞAN M., *Location selection of electric vehicles charging stations by using a fuzzy MCDM method. A case study in Turkey*, Neural Comp. Appl., 2020, 32, 4553–4574.
[69] DOGAN O., DEVECI M., CANITEZ F., KAHRAMAN C., *A corridor selection for locating autonomous vehicles using an interval-valued intuitionistic fuzzy AHP and TOPSIS method*, Soft Comp., 2020, 24 (12), 8937–8953.
[70] ZHANG L., *The application of TOPSIS method to group decision making based on similarity measures under interval-valued intuitionistic fuzzy settings*, 7th International Conference on Education, Management, Computer and Medicine (EMCM 2016), Shenyang, China, 2016.
[71] LIU Y., BI J.W., FAN Z.P., *A method for ranking products through online reviews based on sentiment classification and interval-valued intuitionistic fuzzy TOPSIS*, Int. J. Inf. Techn. Dec. Mak., 2017, 16 (6), 1497–1522.
[72] GUPTA P., MEHLAWAT M.K., GROVER N., PEDRYCZ W., *Multi-attribute group decision making based on extended TOPSIS method under interval-valued intuitionistic fuzzy environment*, Appl. Soft Comp., 2018 69, 554–567.
[73] BÜYÜKÖZKAN G., GÖÇER F., *Smart medical device selection based on interval valued intuitionistic fuzzy VIKOR*, The 10th Conference of the European Society for Fuzzy Logic and Technology, Warsaw, Poland, 2017.
[74] RANI P., MISHRA A.R., ANSARI M.D., *Analysis of smartphone selection problem under interval-valued intuitionistic fuzzy ARAS and TOPSIS methods*, 5th International Conference on Image Information Processing (ICIIP), Shimla, India, 2020.
[75] VAHDANI B., MOUSAVI S.M., TAVAKKOLI-MOGHADDAM R., GHODRATNAMA A., MOHAMMADI M., *Robot selection by a multiple criteria complex proportional assessment method under an interval-valued fuzzy environment*, Int. J. Adv. Manuf. Techn., 2014, 73 (5–8), 687–697.
[76] OZTAYSI B., ONAR S.C., KAHRAMAN C., YAVUZ M., *Multi-criteria alternative-fuel technology selection using interval-valued intuitionistic fuzzy sets*, Transp. Res. Part D, Transp. Environ., 2017, 53, 128–148.
[77] NUR F., ALRAHAHLEH A., BURCH R., BABSKI-REEVES K., MARUFUZZAMAN M., *Last mile delivery drone selection and evaluation using the interval-valued inferential fuzzy TOPSIS*, J. Comp. Des. Eng., 2020, 7 (4), 397–411.
[78] BUYUKOZKAN G., HAVLE C.A., FEYZIOGLU O., *A new digital service quality model and its strategic analysis in aviation industry using interval-valued intuitionistic fuzzy AHP*, J. Air Transp. Manage., 2020, 86, 101817.
[79] LI Z.M., LI H.M., AN X.W., *Assessment of the sustainable of water-based tourism on the basis of interval-valued intuitionistic fuzzy sets*, Ekol., 2019, 28 (107), 259–265.
[80] DAHOOEI J.H., ZAVADSKAS E.K., VANAKI A.S., FIROOZFAR H.R., KESHAVARZ-GHORABAEE M., *An evaluation model of business intelligence for enterprise systems with new extension of CODAS (CODAS-IVIF)*, Ekon. Manage., 2018, 21 (3), 171–187.
[81] MISHRA A.R., RANI P., MARDANI A., PARDASANI K.R., GOVINDAN K., ALRASHEEDI M., *Healthcare evaluation in hazardous waste recycling using novel interval-valued intuitionistic fuzzy information based on complex proportional assessment method*, Comp. Ind. Eng., 2020, 139, 106140.
[82] SENNAROGLU B., TUZKAYA M.M.G., *An interval valued intuitionistic fuzzy PROMETHEE approach for hospital service quality evaluation*, 12th International FLINS Conference, Roubaix, France, 2016.
[83] TUZKAYA G., SENNAROGLU B., KALENDER Z.T., MUTLU M., *Hospital service quality evaluation with IVIF-PROMETHEE and a case study*, Soc.-Econ. Plan. Sci., 2019, 68, 100705.
[84] MISHRA A.R., RANI P., PARDASANI K.R., MARDANI A., STEVIC Z., PAMUCAR D., *A novel entropy and divergence measures with multi-criteria service quality assessment using interval-valued intuitionistic fuzzy TODIM method*, Soft Comp., 2020, 24 (15), 11641–11661.

[85] ZHAO X.F., *TOPSIS method for interval-valued intuitionistic fuzzy multiple attribute decision making and its application to teaching quality evaluation*, J. Int. Fuzzy Syst., 2014, 26 (6), 3049–3055.
[86] LIU A., GUO X., LIU T., ZHANG Y., TSAI S.-B., ZHU Q., HSU C.-F., *A GRA-based method for evaluating medical service quality*, IEEE Access, 2019, 7, 34252–34264.
[87] LI M., LI Y., PENG Q., WANG J., YU C., *Evaluating community question-answering websites using interval-valued intuitionistic fuzzy DANP and TODIM methods*, Appl. Soft Comp., 2020, 99, 106918.
[88] LI S.H., WANG B., *Research on Evaluating algorithms for the service quality of wireless sensor networks based on interval-valued intuitionistic fuzzy EDAS and CRITIC methods*, Math. Probl. Eng., 2020, 1–12.
[89] ERKAL G., KILIC H.S., KALENDER Z.T., YALCIN A.S., TUZKAYA G., *An integrated IVIF-DEMATEL and IVIF-TOPSIS methodology for hotel information system selection*, International Conference on Intelligent and Fuzzy Systems. Istanbul, Turkey, 2020.
[90] TONG X., YU L.Y., *A novel MADM approach based on fuzzy cross entropy with interval-valued intuitionistic fuzzy sets*, Math. Probl. Eng., 2015, 1–9.
[91] HU K.J., TAN Q., ZHANG T.Y., WANG S.P., *Assessing technology portfolios of clean energy-driven desalination-irrigation systems with interval-valued intuitionistic fuzzy sets*, Ren. Sust. En. Rev., 2020, 132, 109950.
[92] INTEPE G., BOZDAG E., KOC T., *The selection of technology forecasting method using a multi-criteria interval-valued intuitionistic fuzzy group decision making approach*, Comp. Ind. Eng., 2013, 65 (2), 277–285.
[93] LI Y.P., CHU X.N., CHU D.X., GENG X.L., WU X.S., *An integrated approach to evaluate module partition schemes of complex products and systems based on interval-valued intuitionistic fuzzy sets*, Int. J. Comp. Int. Manuf., 2014, 27 (7), 675–689.
[94] ABDULLAH L., ZULKIFLI N., LIAO H., HERRERA-VIEDMA E., AL-BARAKATI A., *An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management*, Eng. Appl. Art. Int., 2019, 82, 207–215.
[95] MISHRA A.R., CHANDEL A., MOTWANI D., *Extended MABAC method based on divergence measures for multi-criteria assessment of programming language with interval-valued intuitionistic fuzzy sets*, Gran. Comp., 2020, 5 (1), 97–117.
[96] SEKER S., AYDIN N., *Sustainable public transportation system evaluation. A novel two-stage hybrid method based on IVIF-AHP and CODAS*, Int. J. Fuzzy Syst., 2020, 22 (1), 257–272.
[97] DEVECI K., CIN R., KAGIZMAN A., *A modified interval valued intuitionistic fuzzy CODAS method and its application to multi-criteria selection among renewable energy alternatives in Turkey*, Appl. Soft Comp., 2020, 96, 106660.
[98] WANG L.E., LIU H.C., QUAN M.Y., *Evaluating the risk of failure modes with a hybrid MCDM model under interval-valued intuitionistic fuzzy environments*, Comp. Ind. Eng., 2016, 102, 175–185.
[99] HAJIGHASEMI Z., MOUSAVI S., SIADAT A., *An improved method with interval-valued intuitionistic fuzzy setting to failure mode and effects analysis based on complex proportional assessment*, 45th International ence on Computers and Industrial Engineering, Metz, France, 2015.
[100] LI Y.L., WANG R., CHIN K.S., *New failure mode and effect analysis approach considering consensus under interval-valued intuitionistic fuzzy environment*, Soft Comp., 2019, 23 (22), 11611–11626.
[101] LV L.L., LI H.M., WANG L.Y., XIA Q., JI L., *Failure mode and effect analysis (FMEA) with extended MULTIMOORA method based on interval-valued intuitionistic fuzzy set. Application in operational risk evaluation for infrastructure*, Inf., 2019, 10 (10), 313.
[102] AIKHUELE D.O., TURAN F.M., ODOFIN S.M., ANSAH R.H., *Interval-valued intuitionistic fuzzy TOPSIS--based model for troubleshooting marine diesel engine auxiliary system*, Int. J. Marit. Eng., 2017, 159, 107–114.

[103] LIU H.C., YOU J.X., DUAN C.Y., *An integrated approach for failure mode and effect analysis under interval-valued intuitionistic fuzzy environment*, Int. J. Prod. Econ., 2019, 207, 163–172.
[104] YANIK S., KAHRAMAN C., *Multicriteria decision making for construction projects using interval-valued intuitionistic AHP*, 12th International FLINS Conference, Roubaix, France, 2016.
[105] CHEN T.Y., *IVIF-PROMETHEE outranking methods for multiple criteria decision analysis based on interval-valued intuitionistic fuzzy sets*, Fuzzy Opt. Dec. Mak., 2015, 14 (2), 173–198.
[106] XU G.L., WAN S.P., XIE X.L., *A selection method based on MAGDM with interval-valued intuitionistic fuzzy sets*, Math. Probl. Eng., 2015, 1–13.
[107] DUGENCI M., *A new distance measure for interval valued intuitionistic fuzzy sets and its application to group decision making problems with incomplete weights information*, Appl. Soft Comp., 2016, 41, 120–134.
[108] BÜYÜKÖZKAN G., GÖÇER F., FEYZIOĞLU O., *Cloud computing technology selection based on interval--valued intuitionistic fuzzy MCDM methods*, Soft Comp., 2018, 22 (15), 5091–5114.
[109] DAHOOIE J.H., VANAKI A.S., MOHAMMADI N., *Choosing the appropriate system for cloud computing implementation by using the interval-valued intuitionistic fuzzy CODAS multiattribute decision-making method (case study: Faculty of New Sciences and Technologies of Tehran University)*, IEEE Trans. Eng. Manage., 2020, 67 (3), 855–868.
[110] GIREESHA O., SOMU N., KRITHIVASAN K., SRIRAM V.S.S., *IIVIFS-WASPAS. An integrated multi-criteria decision-making perspective for cloud service provider selection*, Fut. Gen. Comp. Syst. Int. J. Esci., 2020, 103, 91–110.
[111] LIU S., MOUGHAL T.A., *A novel method for dynamic multicriteria decision making with hybrid evaluation information*, J. Appl. Math., 2014, 2014, 1–11.
[112] FAHMI A., DERAKHSHAN A., KAHRAMAN C., *Human resources management using interval valued intuitionistic fuzzy analytic hierarchy process*, 2015 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Istanbul, Turkey, 2015.
[113] YENI F.B., OZCELIK G., *Interval-valued Atanassov intuitionistic fuzzy CODAS method for multi criteria group decision making problems*, Group Dec. Negot., 2019, 28 (2), 433–452.
[114] KARASAN A., ERDOGAN M., ILBAHAR E., *Prioritization of production strategies of a manufacturing plant by using an integrated intuitionistic fuzzy AHP and TOPSIS approach*, J. Ent. Inf. Manage., 2018, 31 (4), 510–528.
[115] MAHDIRAJI H.A., ZAVADSKAS E.K., SKARE M., KAFSHGAR F.Z.R., ARAB A., *Evaluating strategies for implementing industry 4.0: a hybrid expert oriented approach of BWM and interval valued intuitionistic fuzzy TODIM*, Econ. Res., 2020, 33 (1), 1600–1620.
[116] QI W.H., HUANG Z.X., DINCER H., KORSAKIENE R., YUKSEL S., *Corporate governance-based strategic approach to sustainability in energy industry of emerging economies with a novel interval-valued intuitionistic fuzzy hybrid decision making model*, Sust., 2020, 12 (8), 3307.
[117] ROY J., DAS S., KAR S., PAMUCAR D., *An extension of the CODAS approach using interval-valued intuitionistic fuzzy set for sustainable material selection in construction projects with incomplete weight information*, Symm., 2019, 11 (3), 393.
[118] ZINDANI D., MAITY S.R., BHOWMIK S., *Interval-valued intuitionistic fuzzy TODIM method based on Schweizer–Sklar power aggregation operators and their applications to group decision making*, Soft Comp., 2020, 24 (18), 14091–14133.
[119] LAMRANI ALAOUI Y., TKIOUAT M., *Risks assessment in Moroccan microfinance sector. An interval--valued intuitionistic fuzzy set approach*, Int. J. Eng. Bus. Manage., 2018, 10, 1847979018805359.
[120] WU L.P., GAO H., WEI C., *VIKOR method for financing risk assessment of rural tourism projects under interval-valued intuitionistic fuzzy environment*, J. Int. Fuzzy Syst., 2019, 37 (2), 2001–2008.

[121] KAHRAMAN C., OZTAYSI B., ONAR S.Ç., *Intuitionistic fuzzy multicriteria evaluation of outsource manufacturers*, 8th IFAC Conference on Manufacturing Modelling, Management and Control MIM, Troyes, France, 2016.

[122] KAHRAMAN C., ÖZTAYŞI B., ONAR S.Ç., *An integrated intuitionistic fuzzy AHP and TOPSIS approach to evaluation of outsource manufacturers*, J. Int. Syst., 2020, 29 (1), 283–297.

[123] EBRAHIMNEJAD S., HASHEMI H., MOUSAVI S., VAHDANI B., *A new interval-valued intuitionistic fuzzy model to group decision making for the selection of outsourcing providers*, Econ. Comp. Econ. Cyber. Stud., 2015, 49 (2), 269–290.

[124] ZHANG W.K., JU Y.B., LIU X.Y., *Interval-valued intuitionistic fuzzy programming technique for multicriteria group decision making based on Shapley values and incomplete preference information*, Soft Comp., 2017, 21 (19), 5787–5804.

[125] MISHRA A.R., RANI P., *Interval-valued intuitionistic fuzzy WASPAS method. Application in reservoir flood control management policy*, Group Dec. Negot., 2018, 27 (6), 1047–1078.

[126] ABDULLAH L., GOH C., ZAMRI N., OTHMAN M., *Application of interval valued intuitionistic fuzzy TOPSIS for flood management*, J. Int. Fuzzy Syst., 2020, 38 (1), 873–881.

[127] ZHAO X.Y., TANG S., YANG S.L., HUANG K.D., *Extended VIKOR method based on cross-entropy for interval-valued intuitionistic fuzzy multiple criteria group decision making*, J. Int. Fuzzy Syst., 2013, 25 (4), 1053–1066.

[128] WANG W.Z., LIU X.W., *An extended LINMAP method for multi-attribute group decision making under interval-valued intuitionistic fuzzy environment*, 1st International Conference on Information Technology and Quantitative Management, Asan, Korea, 2016.

[129] ZHAO X., YANG S., YANG M., *Extended VIKOR method with fuzzy cross-entropy of interval-valued intuitionistic fuzzy sets*, 2nd International Conference on Computer and Information Application, Taiyuan, China, 2012.

[130] PARK J.H., CHO H.J., KWUN Y.C., *Extension of the VIKOR method for group decision making with interval-valued intuitionistic fuzzy information*, Fuzzy Opt. Dec. Mak., 2011, 10 (3), 233–253.

[131] OUHIBI A., FRIKHA H., *Interval-valued intuitionistic fuzzy CODAS-SORT method. Evaluation of natural resources in Tunisia*, International Multi-Conference Organization of Knowledge and Advanced Technologies (OCTA), Tunis, Tunisia, 2020.

[132] AIKHUELE D.O., TURAN F.B.M., *An integrated fuzzy dephi and interval-valued intuitionistic fuzzy M-TOPSIS model for design concept selection*, Pak. J. Stat. Oper. Res., 2017, 13 (2), 425–438.

[133] BAI Z.Y., *An interval-valued intuitionistic fuzzy TOPSIS method based on an improved score function*, Sci. World J., 2013, 879089.

[134] ERVURAL B.Ç., ERVURAL B., KAHRAMAN C., *Fuzzy sets in the evaluation of socio-ecological systems: an interval-valued intuitionistic fuzzy multi-criteria approach*, *fuzzy logic in its 50th*, Springer, 2016, 309–326.

[135] GARG H., KUMAR K., *An extended technique for order preference by similarity to ideal solution group decision-making method with linguistic interval-valued intuitionistic fuzzy information*, J. Multi-Crit. Dec. Anal., 2019, 26 (1–2), 16–26.

[136] LI W.W., WU C., *A multicriteria interval-valued intuitionistic fuzzy set TOPSIS decision-making approach based on the improved score function*, J. Int. Syst., 2016, 25 (2), 239–250.

[137] HE L., TENG H., *GRA model for dynamic hybrid multiple attribute decision making*, J. Int. Fuzzy Syst., 2014, 27 (2), 1067–1075.

[138] AIKHUELE D., *Interval-valued intuitionistic fuzzy multi-criteria model for design concept selection*, Manage. Sci. Lett., 2017, 7 (9), 457–466.

[139] BU F.K., HE J., LI H.R., FU Q., *Interval-valued intuitionistic fuzzy MADM method based on TOPSIS and grey correlation analysis*, Math. Biosci. Eng., 2020, 17 (5), 5584–5603.

[140] YANG Y., LI H.X., ZHANG Z.M., LIU X.W., *Interval-valued intuitionistic fuzzy analytic network process*, Inf. Sci., 2020, 526, 102–118.
[141] ZHANG X.L., XU Z.H., *Soft Comp. based on maximizing consensus and fuzzy TOPSIS approach to interval-valued intuitionistic fuzzy group decision making*, Appl. Soft Comp., 2015, 26, 42–56.
[142] BUYUKOZKAN G., GOCER F., *An extension of ARAS methodology under interval valued intuitionistic fuzzy environment for digital supply chain*, Appl. Soft Comp., 2018, 69, 634–654.
[143] YE J., *Multicriteria fuzzy decision-making method using entropy weights-based correlation coefficients of interval-valued intuitionistic fuzzy sets*, Appl. Math. Model., 2010, 34 (12), 3864–3870.