mathematics

Type of the Paper (Review)

Industrial and management applications of type-2 multi-attribute decision-making techniques extended with type-2 fuzzy sets from 2013 to 2022

Aleksandar Aleksić [1,*], Danijela Tadić [2]

[1] Faculty of Engineering, University of Kragujevac, 34000 Kragujevac, Serbia; galovic@kg.ac.rs
* Correspondence: aaleksic@kg.ac.rs;

Abstract: The ongoing research in the field of decision-making can be analyzed from different perspectives. Research trends indicate that multi-attribute decision-making (MADM) methods have a significant impact on engineering and management scientific areas. Since many of the problems existing in the mentioned areas are associated with a certain level of uncertainty, type 2 fuzzy sets represent a common solution for the enhancement of conventional MADM methods. In this way, the decision-makers are encouraged to use linguistic expressions for the assessment of attributes' relative importance and their values. The purpose of this paper is to review a determination of attributes' relative importance, and their values, as well as the extension of ranking methods with type 2 fuzzy sets. The papers are systematically adjoined to groups consisting of hybrid models with the following characteristics: (1) indicating the procedure for modeling attribute relative importance and their values, (2) determining the extension of MADM methods with type 2 fuzzy sets to determine attributes' vector weights, (3) extension of MADM for attributes ranking with type 2 fuzzy sets. This study reviewed a total of 42 papers in the domain of engineering and management published from 2013 to 2023 in different journals indexed by the Springer, Science Direct, Emerald, Wiley, ProQuest, Taylor, and Francis research platforms.

Keywords: Fuzzy multi-attributive decision making; The type 2 fuzzy sets; Literature review

MSC:

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

This paper provides insight into how certain MADM methods have been employed to bring solutions in the scientific areas of engineering and management with their enhancements and modifications. Decision-making represents one of the most important activities executed by the decision-makers (DMs) at the strategic, tactical, and operational levels in any company. The essential motivation of the DMs is to determine the best solution among the alternatives that lead to successful business results. Respecting their experience and results of the best practice, DMs should consider many attributes that may conflict with each other. According to the stated, it may be considered that the management problems can be presented as multi-attribute decision-making problems (MADMs). Also, it may be assumed that MADM techniques strive to make the decision-making process more formalized [1] so the obtained solution seems to be less burdened by the bias of DMs. MADM is the discipline of operations research that has been widely studied by researchers and practitioners [1,2].

In recent decades, a large number of MADM techniques have been proposed and used for solving different area problems [1]. It should be underlined that the proposed

MADM techniques are developed on different mathematical foundations so they have different characteristics in finding the optimal solution.

In this paper, the classification of the analyzed MADM methods is performed according to [1,3–5] which is presented in Table 1.

Table 1. The classification of MADM techniques

	Classification is given by [5]	**Classification is given by** [1]	**Classification is given by** [3,4]
Weighted Aggregated Sum Product Assessment - WASPAS [6]	Utility-based		Other MADMs
Technique for Order Preference by Similarity to Ideal Solution - TOPSIS [7]	Distance-based	Normalizing models-additive types	Compromise
VIekriterijumsko KOmpromisno Rangiranje - VIKOR [8]	Distance-based	Normalizing models-additive types	Compromise
Complex Proportional Assessment - COPRAS [9]	Utility-based		Compromise
Multi-Objective Optimization on the basis of Ratio Analysis - MOORA [10]	Other		
Additive Ratio ASsessment - ARAS [11]	Other		Utility-based
Elimination et Choix Traduisant la Realité - ELECTRE [12]	Outranking	Normalizing models-additive types	Outranking
Analytical Network Process - ANP [13]	Pairwise comparison	Weighting models	Utility-based
Analytic Hierarchy Process - AHP [14]	Pairwise comparison	Weighting models	Utility-based
(An acronym in Portuguese for interactive and multi-criteria decision-making) – TODIM [15]	Outranking		Utility-based
Best Worst Method - BWM [16]	Pairwise comparison		Compromise
Multi-attributive border approximation area comparison method - MABAC [17]	Other		Compromise
Decision Making Trial and Evaluation Laboratory – DEMATEL [18]	Interaction based	Evaluating or choosing models	Other

As analysis covers different MADM methods, it may be noticed that there are more MADM methods than those considered by this research. The MADM methods enhanced with IT2FNs have different mathematical foundations. That is why scholars can adjoin them in different groups. A good example of this is BWM which can be interpreted as a pairwise comparison and/or compromise method. It can be concluded that there is no unique classification although scholars are trying to propose different frameworks.

The increase in social and economic environment's complexity (the change of customer expectation, political change, business in a time of crisis, etc.), as well as the vagueness of the inherently subjective nature of human thinking, brings the inability to describe input data of the decision-making process with the crisp values. A lot of scholars believe that a more accurate assessment of uncertainties into the relative importance of attributes and their values may be obtained if the DMs use linguistic variables [19–21]. These variables are defined as words and/or sentences in a natural or artificial language [22]. It may be suggested that the concept of linguistic variables is useful in dealing with complex situations. The shortcoming of this assessment approach is that the words might not have a clear and well-defined meaning since the DMs may have different subjective perceptions or personalities. In this research, the authors' attention is focused on the application of type 2 fuzzy sets (T2FSs) which were introduced by Zadeh [23], for the modeling of uncertainties. These T2FSs represent the extension of the concept of type 1 fuzzy sets (TFSs) [24] that are characterized by a primary and a secondary membership function with an additional dimension of membership function. T2FSs can deal with the fuzziness and uncertainty characteristics of decision-making problems more accurately and effectively compared to T1FSs. It should be emphasized that in real-world applications, interval type 2 fuzzy numbers (IT2FNs) [25] are widely applied. The IT2FNs represent the special version of generalized T2FSs. It may be assumed that the handling of uncertainties by using T2FNs means making fewer assumptions and making fewer assumptions provides more realistic solutions to real-life decision-making problems. IT2FNs are the most frequently used T2FSs [25] because of their easiness and reduced computational effort in comparison with T2FSs. Just a few authors [26] have used other fuzzy numbers, such as Gaussian interval type 2 fuzzy numbers (GIT2FN). Therefore, many real-life situations can be described by employing IT2FNs so the calculation effort is decreased but the preciseness of the obtained data is satisfied.

The literature contains a variety of research MADM methods that have been extended with IT2FNs (Interval Type 2 Fuzzy Multi-Attribute Decision Making - IT2FMADMs). This research attempts to document the exponentially grown interest in IT2FMADM techniques and provide a state-of-the-art review of relevant literature where the treated problems have been solved within the last ten years. In literature, solving many complex management and engineering problems is based on using IT2FMADMs (see Table 2). To present the data in Table 2 in a concise manner, the titles of MADM methods and techniques are extended with the prefix IT2F denoting that the mentioned methods and techniques are enhanced with IT2F numbers. As the research domain of industrial and management applications is considered, the literature sources containing IT2FMADM explanations and applications are comprehensively reviewed employing academic databases of Springer, Science Direct, Emerald, Wiley, ProQuest, Taylor and Francis. It is worth mentioning that some papers containing adequate MADM techniques are not considered due to different application domains. The other criteria for filtering research were the enhancement of MADM techniques with IT2FNs. Table 2 denotes the papers with the research focus on industrial and management applications with IT2FMADMs.

Table 2. A brief explanation of IT2FMADM ranking techniques

Authors	Year	Research focus	Rank of alternatives
Celik et al. [27]	2013	The satisfaction of customers with public transportation	IT2FTOPSIS
Baležentis and Zeng [28]	2013	Selection of manager for research and development	IT2FMULTIMOORA
Ghorabaee et al. [29]	2014	Supplier selection	IT2FCOPRAS
Chen and Hong [30]	2014	The selection of a system analysis engineer	IT2FTOPSIS
Qin et al. [31]	2015	Metro station dynamic risk assessment	IT2FTOPSIS
Kilic and Kaya [32]	2015	Evaluation and selection of investment projects	IT2FTOPSIS
Abdullah and Zulkifli [33]	2015	Human resource management problem	IT2FDEMATEL
Cebi and Otay [34]	2015	Cement factory selection	IT2FTOPSIS
Qin et al. [35]	2015	Evaluation of the high-tech risk investment project	IT2FVIKOR
Ghorabaee et al. [36]	2015	Selecting a suitable hydroelectric power station project	IT2FVIKOR
Özkan et al. [37]	2015	Determining the best electrical energy storage technology	IT2FTOPSIS
Liao [38]	2015	Evaluation of materials	IT2FTOPSIS
Sang and Liu [39]	2015	Green supplier selection in the automotive industry	IT2FTODIM
Ghorabaee [19]	2016	Selecting the suitable robot for its production process	IT2FVIKOR
Celik et al. [40]	2016	Green Logistic Service Providers Evaluation	IT2FELECTRE

Authors	Year	Research focus	Rank of alternatives
Ghorabaee et al. [41]	2016	Green supplier selection	IT2FWASPAS
Buyoukozkan et al. [42]	2016	Evaluation of Knowledge Management Tools	IT2FTOPSIS
Qin et al. [43]	2017	Green supplier selection	IT2FTODIM
Gorener et al. [44]	2017	Supplier selection in a high-stake aviation company	IT2FTOPSIS
Deveci et al. [45]	2017	Airline new route selection	IT2FTOPSIS
Mousakhani et al. [46]	2017	Green supplier evaluation	IT2FTOPSIS
Soner et al. [47]	2017	Selecting the right hatch cover design in maritime transportation industry	IT2FVIKOR
Zhong and Yao [48]	2017	Supplier selection	IT2FELECTRE
Deveci et al. [49]	2018	Selection for car-sharing station	IT2FWASPAS
Celik and Akyuz [20]	2018	Selecting the appropriate ship loader type	IT2FTOPSIS
Debnath and Biswas [50]	2018	The supplier selection problem	IT2FAHP
Meng et al. [51]	2019	Risk assessment of supply chain in social commerce	IT2FTODIM
Đurić et al. [52]	2019	The software failure analysis	IT2FCOPRAS
Dinçer et al. [53]	2019	Evaluate the financial service performance in E7 economies	IT2FMOORA
Xu et al. [54]	2019	Green supplier selection	IT2FAHP Sort II
Wu et al. [55]	2019	Green supplier selection	IT2FVIKOR
Aleksić et al. [56]	2019	Ranking failures in a recycling center	IT2FTOPSIS
Yucesan et al. [57]	2019	Green supplier selection	IT2FTOPSIS
Dorfeshan and Mousavi [58]	2020	Aircraft maintenance planning	IT2FMABAC
Bera et al. [59]	2020	Supplier selection	IT2FTOPSIS
Mohamadghasemi et al. [26]	2020	Selection of conveyors	IT2FELECTRE
Ayyildiz et al. [60]	2020	Credit application	IT2FELECTRE
Yang et al. [61]	2020	Choosing the best investment option	IT2FTOPSIS
Kiraci and Akan [21]	2020	Aircraft selection	IT2FTOPSIS
Pourmand et al. [62]	2020	Water Resources Management	IT2FTOPSIS
Özdemir and Üsküdar [63]	2020	Strategy selection	IT2FTOPSIS
Deveci et al. [64]	2020	Offshore wind farm development	IT2FTOPSIS
Mirnezami et al. [65]	2021	Project cash flow evaluation	IT2FTODIM
Sharaf [66]	2021	Solar power systems	IT2FTOPSIS
Komatina et al. [67]	2021	Evaluation of different risk factors	IT2FTOPSIS
Karagöz et al. [68]	2021	Facility location	IT2FARAS
Celik et al. [69]	2021	Green supplier selection	IT2FTODIM
Zhang et al. [70]	2022	The subway station's risk s	IT2FTOPSIS
Komatina et al. [71]	2022	Supplier selection	IT2FMABAC
Aleksić et al. [72]	2022	Evaluation and ranking of failures in the automotive industry	IT2FVIKOR
Ecer [73]	2022	Green supplier selection in-home appliance manufacturer	IT2FAHP

The scientific objective of the research is to provide insight into the used MADM techniques enhanced with interval type 2 fuzzy numbers (IT2FNs) and applied in solving management and engineering problems. At the same time, the utilitarian objective of the research is to provide answers on conducting MADM techniques steps regarding different approaches and their execution considering the process of decision-making and mathematical operations. In this way, scholars can think about different approaches to the MADM steps execution in their future work. It is worth mentioning that this research is scoped to papers containing hybrid MADM for modeling attributes' weights and values, determining weights and values, and their ranking. As denoted methods are used for ranking, it should be noticed that other MADM mainly used for determining the attributes' relative importance are analyzed in section 2.3

The motivation for this research comes from the fact the literature does not suggest the answers to the following questions:

1) Which IT2FMADM techniques are being used frequently in (i) industrial engineering, and (ii) computer science;
2) Which characteristics of IT2FNs are mostly employed?;
3) Which method is mostly used for the aggregation of DMs' assessment into unique opinion?;
4) Which type of study is executed on these IT2FMADM techniques (distance between two IT2FNs; method of defuzzification, a method for comparison of IT2FNs, etc.)?

This paper provides a systematic survey that brings answers to the identified gap in the literature.

2. Materials and Methods

It is known that fuzziness and vagueness in the relative importance of attributes and their values exist in many MADM problems. Dealing with uncertainties by employing T2FNs means making fewer assumptions during the decision-making process, so it should lead to more realistic solutions to real-life decision-making problems. This can be seen as a main advantage of T2FNs over T1FSs. On the other hand, employment of the T2FSs brings the need of solving very complex mathematical calculations which is their main shortcoming.

The majority of scholars employ interval type 2 triangular fuzzy numbers (IT2FNs) and interval type 2 trapezoidal fuzzy numbers (IT2FTrFNs) [36,45]. Handling uncertainties by using these IT2FNs demands less complex computational calculations compared to IT2FNs of higher order. Generally, it may be said that there are no official guidelines on how to choose the appropriate shape of membership functions and this problem may be analyzed as a task itself. The same approach is valid for the rest of the two IT2FNs' characteristics – granularity and domain. The number of linguistic expressions, that are used for describing the uncertainty, depends on the scale and the complexity of the problem. In real decision-making problems, it is necessary to set the fine gradation, in other words, it is necessary to use a larger number of linguistic expressions that are used for defining the relative importance and values of alternatives. Many scholars propose IT2FMADM techniques based on 3 or 5 linguistic expressions for describing the attributes' relative importance and more than 5 linguistic expressions for describing alternatives' value [21,56]. Almost all the research found in the referent literature supports the definition of the IT2FNs' domain on the set of real numbers with different domains, as it is further explained.

Many scholars believe that when it comes to real decision-making problems [1] a group of DMs should assess the attributes' relative importance according to which the assessment is brought, as well as their values. In this case, the assessment of attributes' relative importance and their value is stated as a fuzzy group decision-making problem. In situations where more DMs participate in the decision-making process, it is necessary to aggregate their opinion in the unique assessment. The aggregation of DMs' assessments into the unique assessment can be given by using various aggregation operators. The selection of the aggregation operator is based on an assumption of the DMs' importance.

In the course of an easier understanding of the analyzed papers, firstly, the basic considerations on type 2 fuzzy sets and arithmetic operations on IT2FNs are presented in the next section.

2.1 Basic consideration of type 2 fuzzy sets

In this section, a brief review of some definitions of type-2 fuzzy sets and IT2FSs [74,75] is presented.

Definition 1. A type 2 fuzzy set, $\tilde{\tilde{A}}$ in the universe of discourse X can be represented by a type-2 membership function $\mu_{\tilde{\tilde{A}}}$ shown as follows:

$$\tilde{\tilde{A}} = \left\{(x, u), \mu_{\tilde{\tilde{A}}}(x, u) \mid \forall x \in X, \forall u \in J_x \subseteq (0,1), 0 \leq \mu_{\tilde{\tilde{A}}}(x, u) \leq 1\right\}, \quad (2.1)$$

Definition 2. If X is a set of real numbers, then a type-2 fuzzy set and an interval type-2 fuzzy set in X are called a type-2 fuzzy number and an interval type-2 fuzzy number, respectively.

Definition 3. As trapezoidal fuzzy numbers are well known to the wider audience, it is worth mentioning that triangular fuzzy numbers are their special case. It is the case when there is just one modal value. While the upper membership function and lower membership function of $\tilde{\tilde{A}}$ are two triangular type-1 fuzzy numbers, then $\tilde{\tilde{A}}$ is referred to as a triangular interval type-2 fuzzy number, $\tilde{\tilde{A}} = \left(\tilde{A}^U, \tilde{A}^L\right)$ so that:

$$\tilde{\tilde{A}} = \left(\tilde{A}^U, \tilde{A}^L\right) = \left((a_1^U, a_2^U, a_3^U, \alpha), (a_1^L, a_2^L, a_3^L, \beta)\right), \quad (2.2)$$

where the lower and upper bound in the domain is denoted as a_1^U, a_3^U respectively, and a_1^L, a_3^L respectively. The modal values are a_2^U, respectively, and a_2^L, respectively. The values of the membership function are defined as $(\alpha, \beta) \in [0,1]$.

Definition 4. Let us consider two IT2TFNs, $\tilde{\tilde{A}}$, and $\tilde{\tilde{B}}$

$$\tilde{\tilde{A}} = \left((a_1^U, a_2^U, a_3^U, \alpha_1), (a_1^L, a_2^L, a_3^L, \beta_1)\right), \tilde{\tilde{B}} = \left((b_1^U, b_2^U, b_3^U, \alpha_2), (b_1^L, b_2^L, b_3^L, \beta_2)\right) \quad (2.3)$$

The arithmetic operations are introduced by Mendel [75]. The addition operation, which is denoted as, $\tilde{\tilde{A}} + \tilde{\tilde{B}}$ can be defined as:

$$\tilde{\tilde{A}} + \tilde{\tilde{B}} = \begin{pmatrix} (a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \\ (a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \end{pmatrix}, \quad (2.4)$$

The subtraction operation, which is denoted as, $\tilde{\tilde{A}} - \tilde{\tilde{B}}$ can be defined as:

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \begin{pmatrix} (a_1^U - b_3^U, a_2^U - b_2^U, a_3^U - b_1^U; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \\ (a_1^L - b_3^L, a_2^L - b_{32}^L, a_3^L - b_1^L; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \end{pmatrix}, \quad (2.5)$$

The multiplication operation, which is denoted as, $\tilde{\tilde{A}} \cdot \tilde{\tilde{B}}$ can be defined as:

$$\tilde{\tilde{A}} \cdot \tilde{\tilde{B}} = \begin{pmatrix} (a_1^U \cdot b_1^U, a_2^U \cdot b_2^U, a_3^U \cdot b_3^U; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \\ (a_1^L \cdot b_1^L, a_2^L \cdot b_2^L, a_3^L \cdot b_3^L; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \end{pmatrix}, \quad (2.6)$$

The division operation, which is denoted as, $\tilde{\tilde{A}} : \tilde{\tilde{B}}$ can be defined as:

$$\tilde{\tilde{A}} : \tilde{\tilde{B}} = \begin{pmatrix} (a_1^U : b_3^U, a_2^U : b_2^U, a_3^U : b_1^U; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \\ (a_1^L : b_3^L, a_2^L : b_2^L, a_3^L : b_1^L; \min(\alpha_1, \alpha_2), \min(\beta_1, \beta_2)) \end{pmatrix}, \quad (2.7)$$

Definition 5. Let us discuss triangular interval type-2 fuzzy numbers, $\tilde{\tilde{A}}$, and crisp value k:

$$k \cdot \tilde{\tilde{A}} = \begin{pmatrix} (k \cdot a_1^U, k \cdot a_2^U, k \cdot a_3^U; \alpha_1), \\ (k \cdot a_1^L, k \cdot a_2^L, k \cdot a_3^L; \beta_1) \end{pmatrix}, \quad (2.8)$$

$$\left(\tilde{\tilde{A}}\right)^{-1} = \begin{pmatrix} \left(\frac{1}{a_3^U}, \frac{1}{a_2^U}, \frac{1}{a_1^U}; \alpha_1\right) \\ \left(\frac{1}{a_3^L}, \frac{1}{a_2^L}, \frac{1}{a_1^L}; \beta_1\right) \end{pmatrix}, \quad (2.9)$$

2.2. Determining the relative importance of attributes and their values

This section is used for clarification of elements that are needed for determining the relative importance of attributes and their values. This issue is scoped to the linguistic expressions and basic features used for modeling type 2 fuzzy sets. Also, the different approaches to defining the weights vector are discussed. As a part of activities needed for determining the relative importance of attributes and their values, the fuzzy group decision-making problem may be employed, so it is also discussed (see Table A1 in Appendix A1). The grouping of data presented in table A1 is based on the following. Firstly, the features of IT2FNs are presented, then the aggregation procedures are denoted. In the end, the proposed IT2FMADM techniques or proposed approaches for the determination of attributes' weights vectors are presented.

It is worth mentioning that the fuzzy group decision-making problem is used for determining criteria values, too (see Table A2 in Appendix A2). The grouping of data presented in table A2 is taking into the account features of IT2FNs, and the aggregation procedures.

The analysis of both tables from Appendix A1 and Appendix A2 is presented in section 3, Results and discussion of the research.

2.3. Determining of attributes' weight

The weights vector of attributes can be determined by using the different approaches. The activities needed for this are summarized in figure 1.

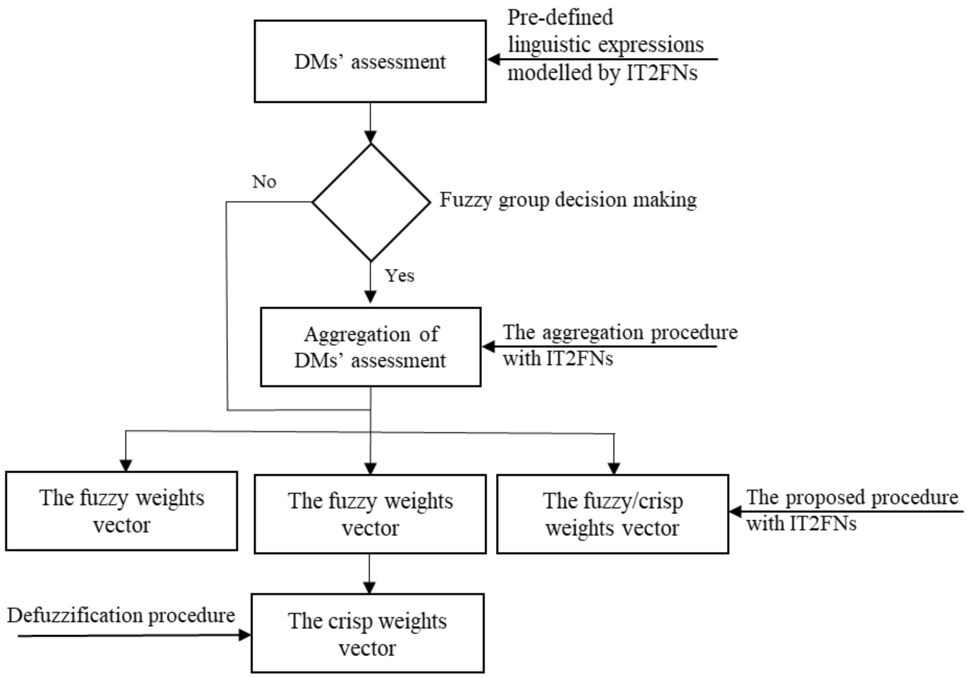

Figure 1 - A flowchart of activities needed for determining attributes' weights

In many conducted research, the weights of attributes are based on using aggregation operators, Delphi techniques, IT2FAHP, and IT2FBWM as it is presented in the next sections. The flowchart starts with the DMs' assessment whether it is a single decision-making or group decision-making approach. If the research is based on group decision-making, then three different paths are possible to be executed. First, scholars may decide to continue with the fuzzy weights vector obtained by applying the different aggregation procedures (e.g., fuzzy arithmetic mean, fuzzy geometric mean). The other option is to perform the defuzzification procedure and continue with the crisp weights vector. The third option is to perform the proposed procedure with IT2FNs (e.g., IT2FAHP, IT2FBWM) and to continue with the fuzzy/crisp weights vector.

2.3.1 The assessment in a direct way

A significant number of scholars suggest that is it appropriate to determine the weights vector in a direct manner [19,26,27,34–36,39,42,45,46,49,59,68,70].

In conventional MADM, the weights vector is given as normalized. Therefore, some authors have performed the normalization of assessed attributes' relative importance [21,38,43,51,65] by using a linear normalization procedure. In this way, the weights of attributes are described by IT2FNs. The normalized weights vector can be given [56] by using the procedure for comparison of IT2FNs [74], so in this way, the weights of attributes are described by crisp values.

Some scholars believe that obtaining the weights of attributes can be delivered through the several rounds where DMs are making their assessment [60,67]. Hence, the weights vector can be given by using the Delphi technique that is extended with IT2TFNs [60,67].

2.3.2 Interval Type 2 Fuzzy Analytical Hierarchy Process - IT2FAHP

A significant number of scholars think that DMs can make their assessment in a more precise way if they analyze each pair of attributes by analogy to AHP [14]. In the literature, there are many papers with the fuzzy pair-wise matrix of the attributes' relative importance described with IT2FNs [76]. It can be said that the fuzzy pair-wise comparison matrix is consistent only if the appropriate pair-wise comparison matrix is consistent. That is why many scholars have transformed the fuzzy pair-wise comparison matrix into a corresponding pair-wise comparison matrix by using different defuzzification procedures, such as (i) the center of area method [77], (ii) the proposed procedure by Kahraman et al. [76], (iii) the proposed procedure by Debnath and Biswas [50]. In all of the papers, the consistency check is determined by applying the eigenvector method by analogy to the conventional AHP method [14]. The weights vector is given by application of (i) synthetic analysis [78] extended with IT2TFNs and (ii) procedure based on the employment of fuzzy geometric mean [76].

2.3.3 Interval Type 2 Fuzzy Best Worst Method - IT2FBWM

In the treated scientific area, there are many papers where the determining of attributes' weights is based on IT2FBWM [55,57,69,72]. In IT2FBWM, all attributes are compared regarding the best and worst items by using pre-defined linguistic expressions. In this way, two fuzzy pair-wise comparison matrices, whose elements are IT2FNs, are constructed. A fuzzy nonlinear optimization model to obtain the weights vector of attributes is proposed, by analogy to the existing procedure [55]. The consistency level of the comparisons can be calculated as defined [16]. It can be said that IT2FBWM is somewhat similar to the IT2FAHP although many scholars think that IT2FBWM has certain advantages compared to IT2FAHP [72]. This advantage [79] is manifold: (i) there is less needed data compared to a full pairwise comparison matrix, and (ii) the obtained results of the BWM application seem to be more consistent than those of the AHP.

The next section provides the analysis of the proposed IT2FMADMs which are denoted in table 2 into defined categories [4].

2.4 Analysis of Ranking Multi-Atrubutive Decision-Making methods

The analyzed methods are joined together based on the criteria proved by [4]. Those groups are (1) The utility-based IT2FMADM, (2) The outranking IT2FMADM, (3) The compromise IT2FMADM, and (4) The other IT2FMADM.

<u>*The utility-based IT2FMADM*</u>

2.4.1 Interval Type 2 Fuzzy Additive Ratio ASsessment - IT2FARAS

While applying IT2FARAS in the scope of research [68], the weighted normalized fuzzy decision matrix can be constructed by using a linear normalization procedure [74] and fuzzy algebra rules [75]. The optimality function of benefit/cost attributes as well as the utility degree of benefit/cost attributes can be calculated by using the proposed formula in conventional ARAS which is enhanced with fuzzy operations. By using the defuzzification procedure proposed by [76] the crisp values of the utility degree of benefit/cost attributes can be given. In the mentioned research, the rank of considered attributes is given by using the normalized appraisal score.

2.4.2 Interval Type 2 Fuzzy Multi-Objective Optimization on the basis of Ratio Analysis - IT2FMOORA (IT2FMULTIMOORA)

The method IT2FMOORA is employed to evaluate financial service performance [53]. In the mentioned research, the fuzzy decision matrix is constructed, and by applying the defuzzification procedure [74], the fuzzy decision matrix is transformed into a decision matrix. The normalized decision matrix is given by using a vector normalization procedure [80]. The rank of alternatives is obtained by using the procedure proposed in conventional MOORA. The method IT2FMULTIMOORA is employed for the selection of a manager for the research and development department in a telecommunication company [28]. In the presented research, the elements of the decision fuzzy matrix are set through a weighted geometric average operator. The normalized fuzzy decision matrix is obtained by applying the linear normalization procedure. The fuzzy positive and fuzzy negative ideal solution is determined according to the veto concept. The rank of alternatives is based on conventional MULTIMOORA combined with fuzzy algebra rules.

2.4.3 Interval Type 2 Fuzzy „An acronym in Portuguese for interactive and multi-criteria decision-making" - IT2FTODIM

IT2FTODIM is employed for the different problems in the treated scientific area [39,43,51,65,69]. While applying the IT2FTODIM, the normalized decision matrix can be obtained by using: (i) the procedure proposed by Chen and Lee, [74] in [39,69], (ii) the linear normalization procedure enhanced with IT2FNs [65]. The weighted normalized fuzzy decision matrix can be given by using fuzzy algebra rules [69]. In the research presented by Meng et al. [51], the weighted fuzzy decision matrix is constructed by using fuzzy algebra rules. It is assumed that in the course of decreasing the calculation complexity, it is necessary to transform the fuzzy decision matrix into a decision matrix [69]. The dominance degree can be determined according to the procedure proposed in conventional TODIM. Also, the dominance degree of each alternative can be determined by applying the proposed distance measure between two IT2FNs [39]. In the research presented by Qin et al. [43], the dominance degree of each alternative is based on a new distance measure proposed in this function. The dominance degree and the of each alternative can be based on distance [43]. The calculation of the Euclidean distance between two IT2FNs [70] is applied by Mirnezami et al. [65].

In all analyzed papers, the overall dominance degree of each alternative is obtained according to the procedure proposed in conventional TODIM.

2.4.4 Interval Type 2 Fuzzy Analytical Hierarchy Process - IT2FAHP

IT2FAHP is employed for solving different problems in engineering and management [50,73]. In the mentioned research, the rank of alternatives is determined by the procedure proposed by Kahraman et al. [76]. Other research based on the AHP framework [54] employs IT2FAHPSort II for the ranking of green suppliers.

The outranking IT2FMADM

2.4.5 Interval Type 2 Fuzzy Elimination et Choix Traduisant la Realité - IT2FELECTRE

IT2FELECTRE is used in several papers [26,40,48,60]. In the mentioned research, the fuzzy weighted decision matrix can be constructed by respecting fuzzy algebra [26,48]. The weighted normalized fuzzy decision matrix can be obtained by using a linear normalization procedure [74] and fuzzy algebra rules [40,60]. By applying the defuzzification procedure [74], the fuzzy decision matrix can be transformed into a decision matrix. Determining the concordance and dis-concordance sets is based on the procedure proposed in conventional ELECTRE: (i) α-based distance method [81] in [48], (ii) distance between two (IT2FNs) in [23] and (iii) the procedure proposed in conventional ELECTREE [40,60]. In all of the analyzed papers, the concordance dominance matrix is constructed similarly just as in conventional ELECTRE. Also, the rank of alternatives is based on the dis-concordance dominance matrix.

The compromise IT2FMADM

2.4.6 Interval Type 2 Fuzzy Complex Proportional Assessment - IT2FCOPRAS

Several papers have proposed the IT2FCOPRAS method for obtaining the solution to the treated problem [29,52]. In all of the mentioned papers, the weighted fuzzy decision matrix is constructed by using fuzzy algebra rules [75]. In the research presented by Ghorabaee et al. [29], the fuzzy optimality function of benefit/cost attributes is determined. Their crisp values are given by using the defuzzification procedure proposed by Kahraman et al. [76]. In the research presented by Đurić et al. [52], the fuzzy decision matrix is transformed into a decision matrix by using the defuzzification procedure [76]. In all of the presented papers, the rank of alternative is given according to the procedure in conventional COPRAS.

2.4.7 Interval Type 2 Fuzzy Multi-attributive border approximation area comparison method - IT2FMABAC

This method is employed in several papers [58,71]. The aggregated fuzzy decision matrix is considered by Komatina et al. [71] where the aggregation of attribute values is performed by using the Order Averaging operator extended with IT2TFNs [82]. The fuzzy decision matrix is stated in the other analyzed paper [58]. In both papers, the weighted no-aggregated/aggregated normalized decision matrix is given by using the procedure proposed by Chen and Lee [74] and the fuzzy algebra rules [75]. Also, the border approximation area matrix (BAA) is given by applying a fuzzy geometric mean [58,71].

Dorfeshan and Mousavi [58] have transformed the fuzzy decision matrix into the decision matrix by using the defuzzification procedure given by Kahraman et al. [76].

Komatina et al. [71] have proposed the determination of belonging to BAA areas based on their procedure. In this case, criteria function values for each supplier are determined by using Euclidean distance and fuzzy algebra rules [71]. The rank of suppliers is given by analogy to the procedure of conventional MABAC.

2.4.8 Interval Type 2 Fuzzy Technique for Order Preference by Similarity to Ideal Solution - IT2FTOPSIS

As the TOPSIS method is widely used, IT2FTOPSIS has also been employed many times for finding an appropriate solution to research problems. While applying IT2FTOPSIS, the normalized fuzzy decision matrix can be given by using: (i) the linear normalization procedure extended with IT2FNs [38], (ii) the linear normalization procedure [74] in [27,35,45,57,59,61,64,66,67,70], (iii) center area method in [32].

Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) can be determined: (i) by the applied procedure [83] in [61,67,70], and (ii) by the veto concept [56,66]. For a similar purpose, Yang et al. [61] employed the distance proposed in Chen [84] and Liu and Jin [85]. Euclidean distance between two IT2TFNs is applied in Komatina et al. [67].

According to mentioned authors' suggestions, the weighted normalized fuzzy decision matrix [38] and the weighted fuzzy decision matrix [20,21,27,34,37,42,44,45,57,59,66,70] can be given by using fuzzy algebra rules.

To decrease the scope of calculations, some authors believe that it is necessary to transform the fuzzy decision matrix into a decision matrix. This transformation can be applied by employing the defuzzification procedures: (i) proposed by Kahraman et al. [76] in [20,38,64], (ii) the center area method [32], (iii) proposed by Lee and Chen [86] in [21,30,34,37,42,44–46,59,62,63].

The closeness coefficient can be determined by using Hamming distance [46]. Determining the closeness coefficient can be: (i) based on the α-level [87] in [70], (ii) based on on the α-level [81] in [35], (iii) procedure proposed in conventional TOPSIS extended with IT2TrFNs and defuzzification procedure [76], (iv) similarity measures [66].

In the rest of the analyzed research, the authors suggest the employment of Euclidean distance. The rank of the alternative is determined according to the values of the closeness coefficient.

2.4.9 Interval Type 2 Fuzzy VIekriterijumsko KOmpromisno Rangiranje - IT2FVIKOR

The method IT2FVIKOR has been used several times in the treated scientific area. While performing the calculations based on IT2FVIKOR, the normalized fuzzy decision matrix can be given by using the procedure proposed by Chen and Lee [74] in [72]. In this case, the weighted normalized fuzzy decision matrix is constructed by applying the fuzzy algebra rules.

Determining FPIS and FNIS can be based on the veto concept [72]. Respecting the procedure proposed by Kuo and Liang [83], FPIS and FNIS are determined in delivered research [19,47,55]. Another procedure for determining FPIS and FNIS is introduced by Ghorabaee et al. [36], so it is based on the previously defined procedure [83].

The group utility value can be calculated by using the proposed procedure extended with IT2FNs [72]. The distance developed by Chen and Lee, [74] is used for determining the minimum individual regret value.

According to Ghorabaee et al. [19] and Ghorabaee et al. [36], the group utility value and minimum individual regret can be determined by applying the procedure proposed in conventional VIKOR extended with IT2TrFNs. Also, there is an assumption introduced by Qin et al. [35] that the group utility value and minimum individual regret can be determined by applying the defined procedure [88]. Soner et al. [47] have determined the group utility value and minimum individual regret by the proposed distance measures.

The rank of alternative is given according to the fuzzy VIKOR index by combining MADM and IT2FNs [74] by Ghorabaee et al. [19]. The rank of alternative is given according to the crisp VIKOR index in the rest of the analyzed papers.

The compromise solution is given by using the procedure proposed in conventional VIKOR combining two conditions [35,55,72].

<u>*The other IT2FMADM*</u>

2.4.10 Interval Type 2 Fuzzy Weighted Aggregated Sum Product Assessment - IT2FWASPAS

Two papers have proposed the application of the IT2FWASPAS method [41,49]. In the mentioned research [49], the normalized fuzzy decision matrix is constructed according to the procedure proposed by Chen and Lee [74]. On the other hand, Ghorabaee et al. [41] have used the linear normalization procedure. WSM measures are used for determining attributes' rank [41,49], and corresponding scalar values of WSM measures are obtained by using the procedure proposed in [41].

2.4.11 Interval Type 2 Fuzzy Decision-Making Trial and Evaluation Laboratory - IT2FDEMATEL

One research paper has proposed the application of the IT2FDEMATEL method [33]. The rank of alternatives is obtained through the conventional DEMATEL procedure enhanced with the IT2TrFNs.

3. Results and discussion of the research

The first part of the discussion is appointed to the comparative analysis of the treated IT2FMADM techniques. Having in mind the classification given by [5], the pairwise comparison IT2FMADM and all other IT2FMADM can be compared.

The pairwise comparison IT2FMADM (e.g., IT2FAHP, IT2FBWM) employs the relative importance of the attributes which represent the element of the decision matrix. All other MADM techniques support obtaining the values of the attributes by the DMs' assessment or through the evidence data, resulting in fuzzy values or crisp values.

If utility-based IT2FMADM techniques (e.g., IT2FCOPRAS) are compared to all other IT2FMADM techniques, it may be considered that their main advantage is decreased complexity of calculations needed for the normalization of data. Their main disadvantage is that in the process of alternatives' ranking, the type of the attribute must be considered carefully since there are going to be distinguished as cost and benefit types.

If outranking-based IT2FMADM techniques (e.g., IT2FTODIM, IT2FELECTRE) are compared to distance-based IT2FMADM techniques (e.g., TOPSIS, VIKOR), it may be considered that their main advantage is decreased complexity of calculations needed for obtaining the rank of alternatives. On the other hand, the employment of distance-based IT2FMADM techniques has an advantage over the employment of outranking-based IT2FMADM techniques in terms of obtaining a compromise solution.

It should be noticed that the mentioned IT2FMADM techniques are developed on different mathematical foundations, so it makes their comparative analysis very complex. Their application can be determined by the domain of interest and the preferences of scholars. Analysis and discussion of the proposed research are scoped to the following criteria: (1) the analysis of the number of DMs participating in the delivered research (figure 1 and figure 2); (2) the features of IT2FNs used for modeling the relative importance of attributes as well as their values (figure 3, figure 4, figure 5, and figure 6); (3) The frequency of IT2FMADM for determining the attributes weights' vector (figure 7); (4) The frequency of IT2FMADM for determining the rank of alternatives (figure 8). The analyzed characteristics are granulation and the domain of IT2FNs. The shape of the membership function is not discussed since many authors have employed the trapezoidal membership function.

The domain of the analyzed research is scoped to the areas of engineering and management. Figure 1 provides insight into how the decision-making process within the research for describing the relative importance of the attributes has been conducted. Similarly, figure 2 explains how the decision-making process within the research for describing the attributes' values.

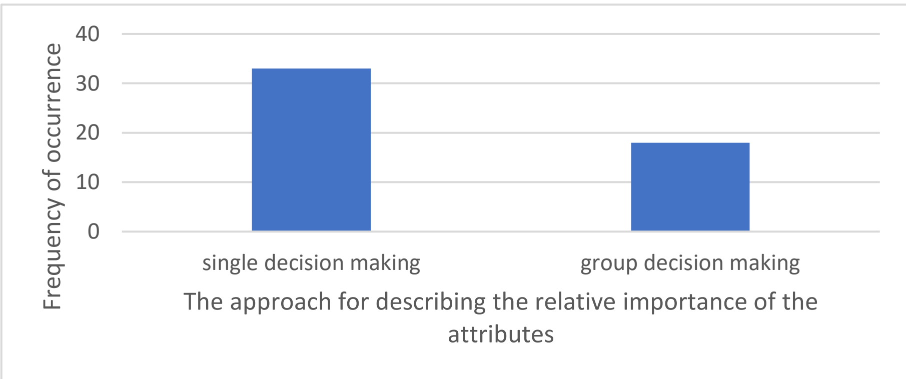

Figure 1. The decision-making process within the research for describing the relative importance of the attributes

Figure 1 indicates that the problem of determining the relative importance of the attributes is set as a single decision-making problem. From the analytical perspective, it should be noticed that this approach includes reaching a consensus while there are more DMs. This is suitable when there are some rules on how to make an assessment in compliance with described guidelines. As a significant number of engineering and management problems do not have clearly described assessment guidelines, it is appropriate to use a group decision-making approach to obtain a more precise assessment. Everyday business operations are exposed to increasing complexity and uncertainty which applies to different industries, so companies strive to develop managers and decision-makers to overcome difficulties. However, due to resource scarcity and organizational culture, it is not always possible to have senior managers that are oriented to group thinking and sharing responsibility. Also, the individual decision-making process is less complex from a mathematical point of view and can be executed more efficiently compared to group decision making which, in practice, demands more time for collecting input data.

The problems in engineering and management often exist in the presence of uncertainty due to changes in the business, organizational structure, and market conditions. As is shown in Figure 2, while assessing attributes' values, it is expected that more research is conducted through the single decision-making approach.

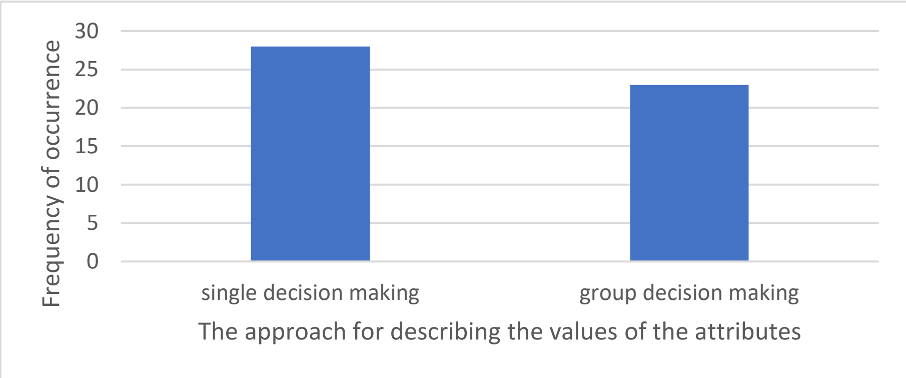

Figure 2. The decision-making process within the research for describing the attributes' values

The further analysis is oriented to the granulation of linguistic expressions used for describing the relative importance of the attributes (figure 3) and the attributes' value (figure 4).

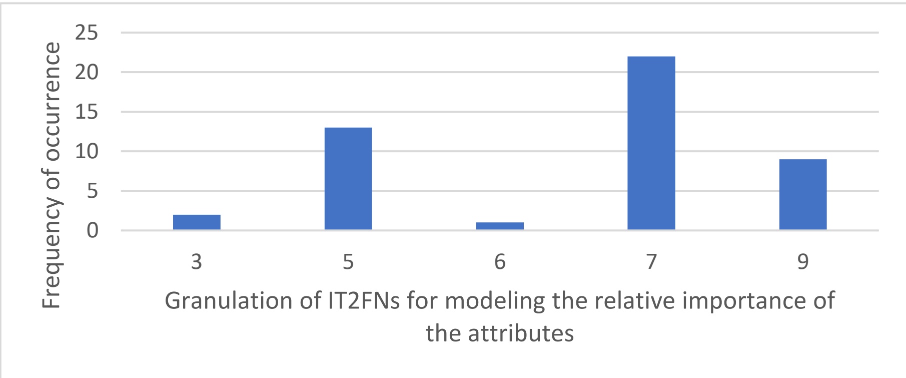

Figure 3. Granulation of linguistic expressions for describing the relative importance of the attributes

The granulation is associated with the size of the treated problem. While problems that include a lower number of attributes can be described by using at least 3 linguistic expressions, large-scale problems may employ more linguistic expressions. The engineering and management research analysis shows that problems with a larger number of attributes indicate the employment of 9 expressions. The majority of researchers, however, have employed 5 or 7 expressions believing that these numbers would be suitable.

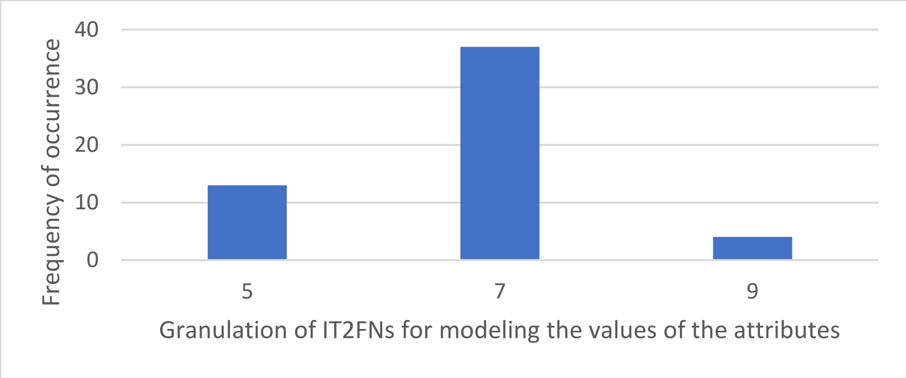

Figure 4. Granulation of linguistic expressions for describing the attributes' value

Figure 4 explains the frequency of usage of 5, 7, or 9 linguistic expressions for determining the attributes' value. The selection of the appropriate number of expressions can be described in a similar way that is analyzed in determining the relative importance of the attributes. It is easy to see that many authors propose 7 linguistic expressions for determining attributes' value. It is worth mentioning that some authors have employed more linguistic expressions for describing uncertainties in attributes' values [52,56]. It may be used as a reference for further research.

Figure 5 and Figure 6 present the applied domains within the research for describing the relative importance of the attributes, and attributes' value, respectively.

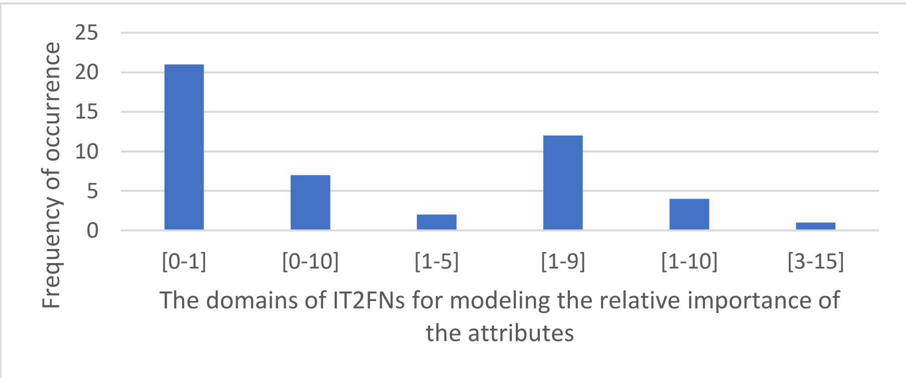

Figure 5. The domains applied within the research for describing the relative importance of the attributes

Determining the domain applied within the research for describing the relative importance of the attributes, and the attributes' value can be set as a task itself.

The analysis of Figure 5 and Figure 6 clearly shows that many authors propose the domain on an interval between 0 and 1. It is expected since the employment of this domain decreases the calculation complexity in determining the weights' vector of treated attributes and there is no need to conduct the normalization procedure of the fuzzy decision matrix. On the other hand, some methods, such as IT2FAHP and IT2FBWM do not support the employment of the domain between 0 and 1. This represents the main constraint of the analyzed domain.

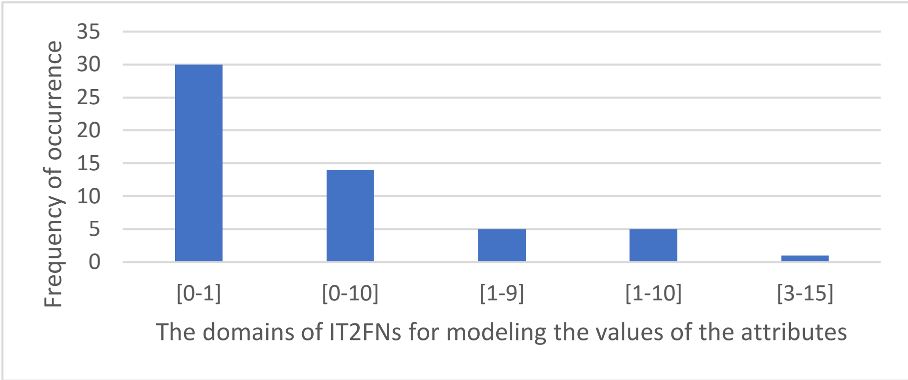

Figure 6. The domains applied within the research for describing the attributes' value

The methods used for determining the attributes' weights vector are presented in Figure 7. Due to MADM's suitability for the named purpose, many authors employ IT2FAHP and IT2FBWM to determine the attributes' weights vector. IT2FAHP is a well-known method, and it can be smoothly applied while the attributes have a hierarchical structure. The main lack of this method is the need for obtaining well-defined input data in matrix shape if the treated problem is large scale. That practically means that the decision-maker could be fully loaded, and his/her focus could be questioned. This is related to the consistency of the assessment. Obtaining input data for the IT2FBWM is less complex compared to the IT2FAHP. On the other hand, IT2FBWM implies the need for more complex calculations compared to IT2FAHP.

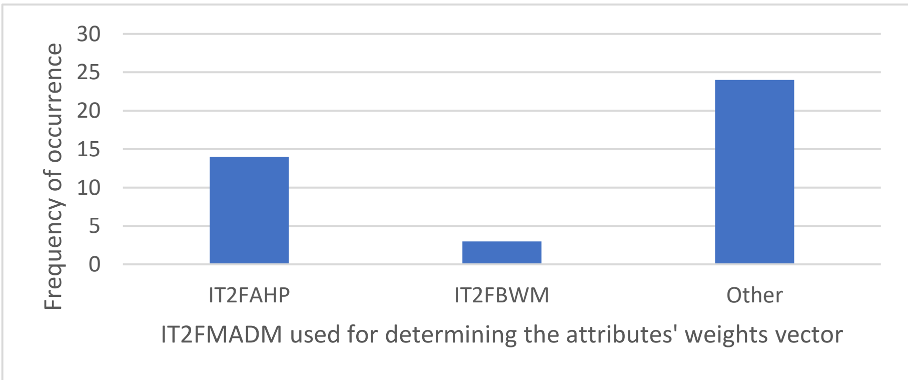

Figure 7. The methods used for determining the attributes' weights vector

The majority of authors use different fuzzy operators for determining the attributes' weights vector (figure 7). The advantage of this approach can be explained since the complexity of calculations is significantly decreased compared to IT2FBWM and IT2FAHP. According to the authors' opinion, the main lack of applying fuzzy operators could be a slightly decreased preciseness of the assessment compared to the named MADM methods.

Figure 8 denotes the frequency of methods' appearances in the executed research presented in Table 2.

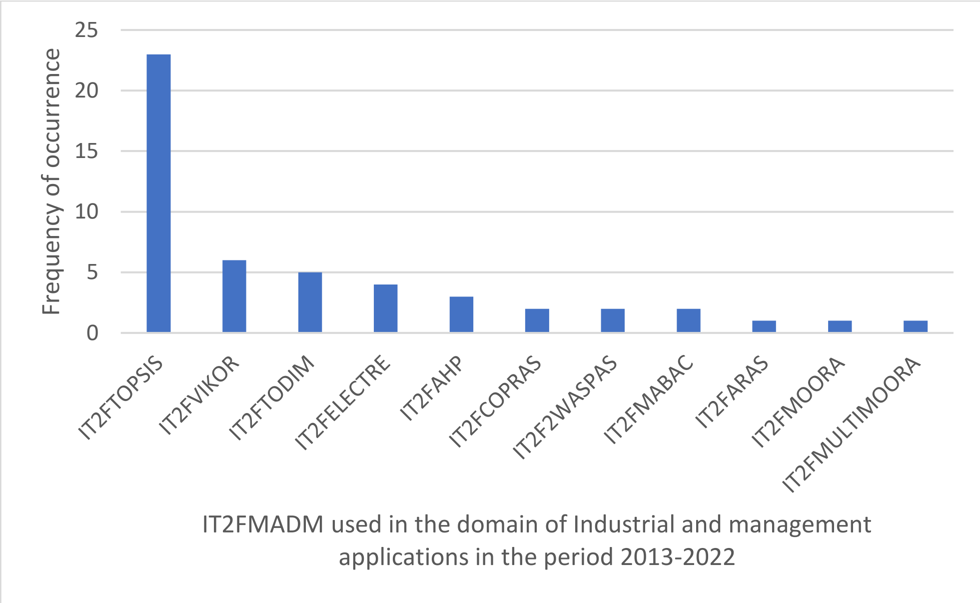

Figure 8. A brief explanation of the usage of IT2FMADM techniques

Figure 8 denotes the frequency of IT2FMADM for determining the rank of alternatives in the domain of engineering and management from 2013 to 2023 according to the Springer, Science Direct, Emerald, Wiley, ProQuest, Taylor, and Francis platforms. It is easy to see that IT2FTOPSIS has been used most frequently.

Each of the analyzed MDM is employed on a different mathematical foundation. So it is inappropriate to compare the results delivered by their calculations. The proposed analysis cannot tell if IT2FTOPSIS is the most suitable for the application in the presented domain. Future research could confirm or dispute that.

5. Conclusions

The starting point of this research is an intention to provide insight into research in the field of MADM encompassing the application of IT2 fuzzy sets in the domain of engineering and management within the period between 2013 and 2023. If compared to papers of authors that have performed reviews of MADM applications in the field of management, the following may be stated. While Mardani et al. [1] have conducted the review on two decades from 1994 to 2014, this research covers the decade between 2013 and 2022. Mardani et al. [1] have covered a similar field of MADM application in terms of management and business emphasizing the employment of conventional MADM techniques and MADM techniques enhanced with type 1 fuzzy sets. The focus of the review [1] was to present the frequency of occurrence of each MADM technique and the trend of technique application. Celik et al. [22] conducted a review of papers employing IT2FMADM techniques between 2007 and 2015 embracing different application domains. This research [22] proposed the frequency of occurrence of each MCDM and the trend of their application. Compared to the mentioned review papers [1,22], our research sets focus on the analysis of IT2FNs features used for modeling the relative importance and values of the attributes, as well as the application frequency IT2FMADM techniques.

The main contribution of the research to the literature may be summarized as follows: (1) it determines the two-stage MADM techniques that have been integrated with IT2FNs; (2) it represents two application areas, engineering, and management; (3) the trend in research of IT2FMADM will stay stable remain in the future, (4) within the presented research, the sample of 41 papers, in the treated areas, is analyzed according to the following features: (i) the membership function shapes, (ii) the granulation, (iii) the domains of IT2FNs, (5) the frequency of IT2FADM employed for ranking the attributes' weights, as well as the frequency of IT2FADM employed for determining the alternatives rank, is analyzed.

Theoretical implications of the research are oriented to the exploitation of results within future research in this application. Different authors will have a kind of recommendations on how to determine the relative importance and values of attributes in different engineering and management problems.

The main constraint of the research is the size of the sample since papers are derived from the search covering Springer, Science Direct, Emerald, Wiley, ProQuest, Taylor, and Francis research platforms. Future research should expand the search and cover more different scientific databases. Also, future research should cover the research different domains of IT2FADM and compare them with the obtained data. Bearing in mind the number of papers in the previous decade per year, it may be concluded that there is an ongoing trend that the number of research papers employing IT2FMADM is increasing. The research hotspots in the domain are oriented to sustainability and risk management, while industrial applications are oriented to industrial engineering applications.

Author Contributions: Conceptualization, A.A. and D.T.; methodology, A.A. and D.T.; formal analysis, A.A. and D.T.; investigation, A.A. and D.T.; resources, A.A.; data curation, D.T; writing—original draft preparation, A.A., and D.T., visualization, A.A. and D.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: "The authors declare no conflict of interest."

Appendix A1

Table A1. The linguistic expressions and corresponding of IT2FNs and their feature which are used to describe the relative importance of attributes

Authors	Type of IT2FNs	Granulation/ The domain	The aggregation operators	The determination of attribute weights
Celik et al. [27]	IT2TrFN	5/[0-10]	Fuzzy arithmetic mean	Fuzzy weights vector
Baležentis and Zeng [28]	IT2TrFN	9/[0-1]	-	Crisp weights vector
Chen and Hong [30]	IT2TrFN	7/[0-1]	Method for comparison of IT2FNS combined with arithmetic mean	Weight attributed to the largest variable/Crisp weights vector
Ghorabaee et al. [29]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Abdullah and Zulkifli [33]	TrFN	9/[1-9]	-	FAHP and fuzzy geometric mean/defuzzification are performed by using the centroid defuzzification method [89]/crisp weights vector
Ghorabaee [19]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Kilic and Kaya [32]	IT2TrFN	5/[1-9]		IT2FAHP and fuzzy geometric mean/defuzzification are performed by using the center of area method [77]/crisp weights vector
Cebi and Otay [34]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Qin et al. [31]	IT2TFN	5/[0-10]	-	Fuzzy weights vector
Qin et al. [43]	IT2TrFN	7/[0-10]	type 2 fuzzy weighted aggregation method	KM algorithm [90]
Özkan et al. [37]	IT2TrFN	5/[1-9]		IT2FAHP and fuzzy geometric mean/aggregation performed by using fuzzy arithmetic mean/fuzzy weights vector
Liao [38]	IT2TrFN	5/[0-1]	-	Fuzzy weights vector
Sang and Liu [39]	crisp			Crisp weights vector
Ghorabaee et al. [36]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Qin et al. [35]	IT2TrFN	7/[0-10]	-	Fuzzy weights vector
Ghorabaee et al. [41]	IT2TrFN	7/[0-1]		Entropy method/fuzzy weights vector
Celik et al. [40]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean	-
Buyoukozkan [42]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Gorener et al. [44]	IT2TrFN	5/[1-9]	-	IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Deveci et al. [45]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Mousakhani [46]	IT2TrFN	7/[0-1]	Fuzzy geometric mean	Fuzzy weights vector
Soner et al. [47]	IT2TrFN	9/[1-10]		IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Zhong and Yao [48]	IT2TrFN	7/[0-1]	-	The information entropy/crisp weights vector
Deveci et al. [49]	IT2TrFN	5/[0-10]	Fuzzy arithmetic mean	Fuzzy weights vector
Celik and Akyuz [20]	IT2TrFN	9/[1-10]	-	IT2FAHP and fuzzy geometric mean/defuzzification procedure [76]/crisp weights vector

Authors	Type of IT2FNs	Granulation/ The domain	The aggregation operators	The determination of attribute weights
Debnath and Biswas [50]	IT2TrFN	5/[1-9]	-	IT2FAHP and fuzzy geometric mean/ the proposed defuzzification procedure/fuzzy weights vector
Meng et al. [51]	IT2TrFN	7/[0-1]		The linear normalization procedure
Xu et al. [54]	crisp	/	/	AHP/crisp vector weights
Dinçer et al. [53]	IT2TrFN	7/[0-1]	-	IT2DEMATEL combined with IT2FANP and defuzzification procedure [76]/crisp weights vector
Wu et al. [55]	IT2TrFN	9/[1-9]	-	IT2FBWM and fuzzy geometric mean and defuzzification by using the centroid area method [91]
Aleksić et al. [56]	IT2TrFN	3/[1-5]	Fuzzy averaging mean	Ranking of IT2FNs[74]/crisp weights vector
Yucesan et al. [57]				BWM/crisp weights vector
Đurić et al. [52]	IT2TrFN	3/[1-5]		IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Dorfeshan and Mousavi [58]	IT2TrFNs	7/[0-1]		IT2FWASPAS/crisp weights vector
Bera et al. [59]	IT2TrFN	7/[0-1]	-	Fuzzy weights vector
Mohamadghasemi et al. [26]	(GIT2FN)	7/[3-15]	-	crisp weights vector
Ayyildiz et al. [60]	IT2TrFN	9/[1-10]	-	IT2FAHP and fuzzy geometric mean/defuzzification procedure/linear normalization procedure/crisp weights vector
Kiraci and Akan [21]	IT2TrFN	5/[1-9]		IT2FAHP and fuzzy geometric mean/ defuzzification are performed by using the center of area method[77]/arithmetic mean/crisp weights vector
Pourmand et al. [62]	IT2TrFN	7/[0-1]	-	IT2FTOPSIS combined with the ranking of IT2FNs [74] and linear normalization procedure/Crisp weights vector
Özdemir and Üsküdar [63]	IT2TrFN	5/[1-9]	-	IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Deveci et al. [64]	IT2TFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Mirnezami et al. [65]	-			-
Komatina et al. [67]	IT2TFN	9/[0-1]	-	IT2FDelphi technique
Karagöz et al. [68]	IT2TFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Kaya and Aycin [92]	IT2TrFN	5/[1-9]		IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Celik et al. [69]	IT2TrFN	9/[1-10]		IT2FBWM based on [55]/fuzzy weights vector
Zhang et al. [70]	IT2TrFN	5/[0-10]	Fuzzy arithmetic mean	Fuzzy weights vector
Sharaf [66]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean	Fuzzy weights vector
Komatina et al. [71]	IT2TFN	5/[1-9]		IT2FAHP and fuzzy geometric mean/fuzzy weights vector
Aleksić et al. [72]	IT2TFN	6/[1-9]	Geometric mean	IT2FBWM [55]

Authors	Type of IT2FNs	Granulation/ The domain	The aggregation operators	The determination of attribute weights
Ecer [73]	IT2TFN	5/[1-9]	-	IT2FAHP and fuzzy geometric mean/fuzzy weights vector

Appendix A2

Table A2. The determining attributes' values

Authors	Type of IT2FNs	Granulation/ The domain	The aggregation operators
Celik et al. (2013) [27]	IT2TrFN	5/[0-10]	Fuzzy arithmetic mean
Baležentis and Zeng (2013) [28]	IT2TrFN	9/[0-1]	The weighted geometric average operator
Chen and Hong (2014) [30]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean
Ghorabaee et al. (2014) [29]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean
Abdullah and Zulkifli (2015) [33]	IT2TrFN	5/[0-1]	-
Cebi and Otay (2015) [34]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean
Qin et al. (2015) [31]	IT2TrFN	7/[0-1]	-
Ghorabaee et al. (2016)[19]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Kilic and Kaya (2015) [32]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Özkan et al. (2015) [37]	IT2TrFN	5/[1-9]	Fuzzy arithmetic mean
Liao (2015) [38]	IT2TrFN	5/[0-1]	-
Sang and Liu (2015) [39]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Qin et al. (2015) [35]	IT2TrFN	5/[0-10]	
Ghorabaee et al. (2015) [36]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Ghorabaee et al. (2016) [41]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Buyoukozkan (2016) [42]	IT2TrFN	7/[0-1]	fuzzy arithmetic mean
Celik et al (2016) [40]	IT2TrFN	7/[1-10]	Fuzzy arithmetic mean
Qin et al. (2017) [43]	TrFN	7/[0-1]	-
Soner et al. (2017) [47]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean
Deveci et al. (2017) [45]	IT2TrFN	7/[0-10]	Fuzzy arithmetic mean
Gorener et al. (2017) [44]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Zhong and Yao (2017) [48]	IT2TrFN	7/[0-1]	-
Mousakhani (2017) [46]	IT2TrFN	7/[0-10]	Fuzzy geometric mean
Debnath and Biswas (2018) [50]	IT2TrFN	5/[1-9]	-
Celik and Akyuz (2018) [20]	IT2TrFN	7/[0-1]	-
Deveci et al. (2018) [49]	IT2TrFN	9/[0-10]	Fuzzy arithmetic mean
Meng et al. (2019) [51]	IT2TrFN	7/[0-1]	-
Dinçer et al. (2019) [53]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Xu et al. (2019) [54]	IT2TrFN	5/[0-1]	-
Yucesan et al. (2019) [57]	IT2TrFN	-/[0-1]	Fuzzy arithmetic mean
Aleksić et al. (2019) [56]	IT2TrFN	7/[0-1] and 5/[0-1]	-
Đurić et al (2019) [52]	IT2TrFN	5/[0-1] and 7/[0-1]	-
Wu et al. (2019) [55]	IT2TrFN	7/[0-10]	The interval typ2 2 fuzzy weighted average operator
Dorfeshan and Mousavi, 2020 [58]	IT2TrFN	7/[0-1]	-
Bera et al. (2020) [59]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Mohamadghasemi et al. (2020) [26]	GIT2FN	7/[3-15]	-
Ayyildiz et al. (2020) [60]	IT2TrFN	9/[1-10]	Fuzzy arithmetic mean

Authors	Type of IT2FNs	Granulation/ The domain	The aggregation operators
Kiraci and Akan (2020) [21]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Pourmand et al. (2020) [62]	IT2TrFN	7/[0-1]	-
Özdemir and Üsküdar (2020) [63]	IT2TrFN	7/[0-1]	Fuzzy arithmetic mean
Deveci et al. (2020) [64]	IT2TFN	7/[0-10]	-
Mirnezami et al. (2021) [65]	IT2TrFN	7/[0-1]	-
Sharaf, (2021) [66]	IT2TrFN	7/[0-1]	-
Zhang et al. (2022) [70]	IT2TrFN	5/[0-10]	
Komatina et al. (2021) [67]	IT2TFN	7/[1-9]	-
Karagöz et al. (2021) [68]	IT2TFN	7/[1-10]	Fuzzy arithmetic mean
Kaya and Aycin (2021)[92]		7/[0-10]	-
Celik et al. (2021) [69]	IT2TrFN	9/[1-10]	-
Komatina et al. (2022) [71]	IT2TFN	7/[1-9]	-
Aleksić et al. (2022) [72]	IT2TFN	5/[1-10]	
Ecer, F. (2022) [73]	IT2TFN	5/[1-9]	-

References

1. Mardani, A.; Jusoh, A.; Zavadskas, E.K. Fuzzy Multiple Criteria Decision-Making Techniques and Applications – Two Decades Review from 1994 to 2014. *Expert Systems with Applications* **2015**, *42*, 4126–4148, doi:10.1016/j.eswa.2015.01.003.
2. Behzadian, M.; Khanmohammadi Otaghsara, S.; Yazdani, M.; Ignatius, J. A State-of the-Art Survey of TOPSIS Applications. *Expert Systems with Applications* **2012**, *39*, 13051–13069, doi:10.1016/j.eswa.2012.05.056.
3. Danesh, D.; Ryan, M.J.; Abbasi, A. Multi-Criteria Decision-Making Methods for Project Portfolio Management: A Literature Review. *International Journal of Management and Decision Making* **2018**, *17*, 75–94, doi:10.1504/IJMDM.2018.088813.
4. Sousa, M.; Almeida, M.F.; Calili, R. Multiple Criteria Decision Making for the Achievement of the UN Sustainable Development Goals: A Systematic Literature Review and a Research Agenda. *Sustainability* **2021**, *13*, 4129, doi:10.3390/su13084129.
5. Zayat, W.; Kilic, H.S.; Yalcin, A.S.; Zaim, S.; Delen, D. Application of MADM Methods in Industry 4.0: A Literature Review. *Computers & Industrial Engineering* **2023**, *177*, 109075, doi:10.1016/j.cie.2023.109075.
6. Zavadskas, E.K.; Turskis, Z.; Antucheviciene, J.; Zakarevicius, A. Optimization of Weighted Aggregated Sum Product Assessment. *Elektronika ir Elektrotechnika* **2012**, *122*, 3–6, doi:10.5755/j01.eee.122.6.1810.
7. Hwang, C.-L.; Yoon, K. Methods for Multiple Attribute Decision Making. In *Multiple Attribute Decision Making: Methods and Applications A State-of-the-Art Survey*; Hwang, C.-L., Yoon, K., Eds.; Lecture Notes in Economics and Mathematical Systems; Springer: Berlin, Heidelberg, 1981; pp. 58–191 ISBN 978-3-642-48318-9.
8. Opricovic, S. Multicriteria Optimization of Civil Engineering Systems. PhD Thesis, Faculty of Civil Engineering, University of Belgrade: Belgrade, 1998.
9. Zavadskas, E.K.; Kaklauskas, A.; Šarka, V. The New Method of Multicriteria Complex Proportional Assessment of Projects. **1994**, *1*, 131–139.
10. Brauers, W.K.M.; Zavadskas, E.K. The MOORA Method and Its Application to Privatization in a Transition Economy. *Control and Cybernetics* **2006**, *35*, 445–469.

11. Zavadskas, E.K.; Turskis, Z. A New Additive Ratio Assessment (ARAS) Method in Multicriteria Decision-making. *Ukio Technologinis ir Ekonominis Vystymas* **2010**, *16*, 159–172, doi:10.3846/tede.2010.10.
12. Roy, B. Classement et choix en présence de points de vue multiples. *Revue franįaise d'informatique et de Recherche opérationnelle* **1968**, *2*, 57–75.
13. Saaty, T.L. Decisions with the Analytic Network Process (ANP).; August 1996.
14. Saaty, T.L. The Modern Science of Multicriteria Decision Making and Its Practical Applications: The AHP/ANP Approach. *Operations Research* **2013**, *61*, 1101–1118, doi:10.1287/opre.2013.1197.
15. Gomes, L.; Lima, M. TODIM: Basics and Application to Multicriteria Ranking of Projects with Environmental Impacts. *Foundations of Computing and Decision Sciences* **1992**, *16*, 113–127.
16. Rezaei, J. Best-Worst Multi-Criteria Decision-Making Method. *Omega* **2015**, *53*, 49–57, doi:10.1016/j.omega.2014.11.009.
17. Pamučar, D.; Ćirović, G. The Selection of Transport and Handling Resources in Logistics Centers Using Multi-Attributive Border Approximation Area Comparison (MABAC). *Expert Systems with Applications* **2015**, *42*, 3016–3028, doi:10.1016/j.eswa.2014.11.057.
18. Fontela, E.; Gabus, A. *DEMATEL, Innovative Methods*; Battelle Geneva Research Institute: Geneva, 1974;
19. Ghorabaee, M.K. Developing an MCDM Method for Robot Selection with Interval Type-2 Fuzzy Sets. *Robotics and Computer-Integrated Manufacturing* **2016**, *37*, 221.
20. Celik, E.; Akyuz, E. An Interval Type-2 Fuzzy AHP and TOPSIS Methods for Decision-Making Problems in Maritime Transportation Engineering: The Case of Ship Loader. *Ocean Engineering* **2018**, *155*, 371–381, doi:10.1016/j.oceaneng.2018.01.039.
21. Kiracı, K.; Akan, E. Aircraft Selection by Applying AHP and TOPSIS in Interval Type-2 Fuzzy Sets. *Journal of Air Transport Management* **2020**, *89*, 101924, doi:10.1016/j.jairtraman.2020.101924.
22. Celik, E.; Gul, M.; Aydin, N.; Gumus, A.T.; Guneri, A.F. A Comprehensive Review of Multi Criteria Decision Making Approaches Based on Interval Type-2 Fuzzy Sets. *Knowledge-Based Systems* **2015**, *85*, 329–341, doi:10.1016/j.knosys.2015.06.004.
23. Zadeh, L.A. The Concept of a Linguistic Variable and Its Application to Approximate Reasoning-III. *Information Sciences* **1975**, *9*, 43–80, doi:10.1016/0020-0255(75)90017-1.
24. Zimmermann, H.-J. *Fuzzy Set Theory—and Its Applications*; Springer Science & Business Media, 2011; ISBN 978-94-010-0646-0.
25. Dereli̇, T.; Baykasoglu, A.; Altun, K.; Durmuşoğlu, A.; Türkşen, İ. Industrial Applications of Type-2 Fuzzy Sets and Systems: A Concise Review. *COMPUTERS IN INDUSTRY* **2011**, *62*, doi:10.1016/j.compind.2010.10.006.
26. Mohamadghasemi, A.; Hadi-Vencheh, A.; Lotfi, F.H.; Khalilzadeh, M. An Integrated Group FWA-ELECTRE III Approach Based on Interval Type-2 Fuzzy Sets for Solving the MCDM Problems Using Limit Distance Mean. *Complex Intell. Syst.* **2020**, *6*, 355–389, doi:10.1007/s40747-020-00130-x.
27. Celik, E.; Bilisik, O.N.; Erdogan, M.; Gumus, A.T.; Baracli, H. An Integrated Novel Interval Type-2 Fuzzy MCDM Method to Improve Customer Satisfaction in Public Transportation for Istanbul. *Transportation Research Part E: Logistics and Transportation Review* **2013**, *58*, 28–51, doi:10.1016/j.tre.2013.06.006.
28. Baležentis, T.; Zeng, S. Group Multi-Criteria Decision Making Based upon Interval-Valued Fuzzy Numbers: An Extension of the MULTIMOORA Method. *Expert Systems with Applications* **2013**, *40*, 543–550, doi:10.1016/j.eswa.2012.07.066.

29. Ghorabaee, M.K.; Amiri, M.; Sadaghiani, J.S.; Goodarzi, G.H. Multiple Criteria Group Decision-Making for Supplier Selection Based on COPRAS Method with Interval Type-2 Fuzzy Sets. *The International Journal of Advanced Manufacturing Technology* **2014**, *75*, 1115.
30. Chen, S.-M.; Hong, J.-A. Fuzzy Multiple Attributes Group Decision-Making Based on Ranking Interval Type-2 Fuzzy Sets and the TOPSIS Method. *IEEE Transactions on Systems, Man, and Cybernetics: Systems* **2014**, *44*, 1665–1673, doi:10.1109/TSMC.2014.2314724.
31. Qin, Y.; Zhang, Z.; Liu, X.; Li, M.; Kou, L. Dynamic Risk Assessment of Metro Station with Interval Type-2 Fuzzy Set and TOPSIS Method. *Journal of Intelligent & Fuzzy Systems* **2015**, *29*, 93–106, doi:10.3233/IFS-151573.
32. Kiliç, M.; Kaya, İ. Investment Project Evaluation by a Decision Making Methodology Based on Type-2 Fuzzy Sets. *Applied Soft Computing* **2015**, *27*, 399–410, doi:10.1016/j.asoc.2014.11.028.
33. Abdullah, L.; Zulkifli, N. Integration of Fuzzy AHP and Interval Type-2 Fuzzy DEMATEL: An Application to Human Resource Management. *Expert Systems with Applications* **2015**, *42*, 4397–4409, doi:10.1016/j.eswa.2015.01.021.
34. Cebi, F.; Otay, İ. Multi-Criteria and Multi-Stage Facility Location Selection under Interval Type-2 Fuzzy Environment: A Case Study for a Cement Factory. *International Journal of Computational Intelligence Systems* **2015**, *8*, 330–344, doi:10.1080/18756891.2015.1001956.
35. Qin, J.; Liu, X.; Pedrycz, W. An Extended VIKOR Method Based on Prospect Theory for Multiple Attribute Decision Making under Interval Type-2 Fuzzy Environment. *Knowledge-Based Systems* **2015**, *86*, 116–130, doi:10.1016/j.knosys.2015.05.025.
36. Ghorabaee, M.K.; Amiri, M.; Sadaghiani, J.S.; Zavadskas, E.K. Multi-Criteria Project Selection Using an Extended VIKOR Method with Interval Type-2 Fuzzy Sets. *Int. J. Info. Tech. Dec. Mak.* **2015**, *14*, 993–1016, doi:10.1142/S0219622015500212.
37. Özkan, B.; Kaya, İ.; Cebeci, U.; Başlıgil, H. A Hybrid Multicriteria Decision Making Methodology Based on Type-2 Fuzzy Sets For Selection Among Energy Storage Alternatives. *International Journal of Computational Intelligence Systems* **2015**, *8*, 914–927, doi:10.1080/18756891.2015.1084715.
38. Liao, T.W. Two Interval Type 2 Fuzzy TOPSIS Material Selection Methods. *Materials & Design* **2015**, *88*, 1088–1099, doi:10.1016/j.matdes.2015.09.113.
39. Sang, X.; Liu, X. An Interval Type-2 Fuzzy Sets-Based TODIM Method and Its Application to Green Supplier Selection. *The Journal of the Operational Research Society* **2016**, *67*, 722–734, doi:10.1057/jors.2015.86.
40. Celik, E.; Gumus, A.; Erdogan, M. A New Extension of the ELECTRE Method Based Upon Interval Type-2 Fuzzy Sets for Green Logistic Service Providers Evaluation. *JOURNAL OF TESTING AND EVALUATION* **2016**, *44*, doi:10.1520/jte20140046.
41. Ghorabaee, K.M.; Zavadskas, E.K.; Amiri, M.; Esmaeili, A. Multi-Criteria Evaluation of Green Suppliers Using an Extended WASPAS Method with Interval Type-2 Fuzzy Sets. *Journal of Cleaner Production* **2016**, *137*, 213–229, doi:10.1016/j.jclepro.2016.07.031.
42. Büyüközkan, G.; Parlak, I.B.; Tolga, A.C. Evaluation of Knowledge Management Tools by Using An Interval Type-2 Fuzzy TOPSIS Method. *International Journal of Computational Intelligence Systems* **2016**, *9*, 812–826, doi:10.1080/18756891.2016.1237182.
43. Qin, J.; Liu, X.; Pedrycz, W. An Extended TODIM Multi-Criteria Group Decision Making Method for Green Supplier Selection in Interval Type-2 Fuzzy Environment. *European Journal of Operational Research* **2017**, *258*, 626–638, doi:10.1016/j.ejor.2016.09.059.

44. Görener, A.; Ayvaz, B.; Kuşakcı, A.O.; Altınok, E. A Hybrid Type-2 Fuzzy Based Supplier Performance Evaluation Methodology: The Turkish Airlines Technic Case. *Applied Soft Computing* **2017**, *56*, 436–445, doi:10.1016/j.asoc.2017.03.026.
45. Deveci, M.; Demirel, N.Ç.; Ahmetoğlu, E. Airline New Route Selection Based on Interval Type-2 Fuzzy MCDM: A Case Study of New Route between Turkey- North American Region Destinations. *Journal of Air Transport Management* **2017**, *59*, 83–99, doi:10.1016/j.jairtraman.2016.11.013.
46. Mousakhani, S.; Nazari-Shirkouhi, S.; Bozorgi-Amiri, A. A Novel Interval Type-2 Fuzzy Evaluation Model Based Group Decision Analysis for Green Supplier Selection Problems: A Case Study of Battery Industry. *Journal of Cleaner Production* **2017**, *168*, 205–218, doi:10.1016/j.jclepro.2017.08.154.
47. Soner, O.; Celik, E.; Akyuz, E. Application of AHP and VIKOR Methods under Interval Type 2 Fuzzy Environment in Maritime Transportation. *Ocean Engineering* **2017**, *129*, 107–116, doi:10.1016/j.oceaneng.2016.11.010.
48. Zhong, L.; Yao, L. An ELECTRE I-Based Multi-Criteria Group Decision Making Method with Interval Type-2 Fuzzy Numbers and Its Application to Supplier Selection. *Applied Soft Computing* **2017**, *57*, 556–576, doi:10.1016/j.asoc.2017.04.001.
49. Deveci, M.; Canıtez, F.; Gökaşar, I. WASPAS and TOPSIS Based Interval Type-2 Fuzzy MCDM Method for a Selection of a Car Sharing Station. *Sustainable Cities and Society* **2018**, *41*, 777–791, doi:10.1016/j.scs.2018.05.034.
50. Debnath, J.; Biswas, A. Analytic Hierarchy Process Based on Interval Type-2 Intuitionistic Fuzzy Sets with Their Application to Multicriteria Decision Making. *Intelligent Decision Technologies* **2018**, *12*, 359–370, doi:10.3233/IDT-180341.
51. Meng, Q.; Liu, X.; Song, Y.; Wang, W. An Extended Generalized TODIM Method for Risk Assessment of Supply Chain in Social Commerce under Interval Type-2 Fuzzy Environment. *Journal of Intelligent & Fuzzy Systems* **2019**, *37*, 8551–8565, doi:10.3233/JIFS-190061.
52. Đurić, G.; Mitrović, Č.; Komatina, N.; Tadić, D.; Vorotović, G. The Hybrid MCDM Model with the Interval Type-2 Fuzzy Sets for the Software Failure Analysis. *Journal of Intelligent & Fuzzy Systems* **2019**, *37*, 7747–7759, doi:10.3233/JIFS-182541.
53. Dinçer, H.; Yüksel, S.; Martínez, L. Interval Type 2-Based Hybrid Fuzzy Evaluation of Financial Services in E7 Economies with DEMATEL-ANP and MOORA Methods. *Applied Soft Computing* **2019**, *79*, 186–202, doi:10.1016/j.asoc.2019.03.018.
54. Xu, Z.; Qin, J.; Liu, J.; Martínez, L. Sustainable Supplier Selection Based on AHPSort II in Interval Type-2 Fuzzy Environment. *Information Sciences* **2019**, *483*, 273–293, doi:10.1016/j.ins.2019.01.013.
55. Wu, Q.; Zhou, L.; Chen, Y.; Chen, H. An Integrated Approach to Green Supplier Selection Based on the Interval Type-2 Fuzzy Best-Worst and Extended VIKOR Methods. *Information Sciences* **2019**, *502*, 394–417, doi:10.1016/j.ins.2019.06.049.
56. Aleksic, A.; Runic Ristic, M.; Komatina, N.; Tadic, D. Advanced Risk Assessment in Reverse Supply Chain Processes: A Case Study in Republic of Serbia. *Adv produc engineer manag* **2019**, *14*, 421–434, doi:10.14743/apem2019.4.338.
57. Yucesan, M.; Mete, S.; Serin, F.; Celik, E.; Gul, M. An Integrated Best-Worst and Interval Type-2 Fuzzy TOPSIS Methodology for Green Supplier Selection. *Mathematics* **2019**, *7*, 182, doi:10.3390/math7020182.
58. Dorfeshan, Y.; Mousavi, S.M. A Novel Interval Type-2 Fuzzy Decision Model Based on Two New Versions of Relative Preference Relation-Based MABAC and WASPAS Methods (with an Application in Aircraft Maintenance Planning). *Neural Comput & Applic* **2020**, *32*, 3367–3385, doi:10.1007/s00521-019-04184-y.

59. Bera, A.K.; Jana, D.K.; Banerjee, D.; Nandy, T. Supplier Selection Using Extended IT2 Fuzzy TOPSIS and IT2 Fuzzy MOORA Considering Subjective and Objective Factors. *Soft Comput.* **2020**, *24*, 8899–8915, doi:10.1007/s00500-019-04419-z.
60. Ayyildiz, E.; Taskin Gumus, A.; Erkan, M. Individual Credit Ranking by an Integrated Interval Type-2 Trapezoidal Fuzzy Electre Methodology. *Soft Comput* **2020**, *24*, 16149–16163, doi:10.1007/s00500-020-04929-1.
61. Yang, Y.-Y.; Liu, X.-W.; Liu, F. Trapezoidal Interval Type-2 Fuzzy TOPSIS Using Alpha-Cuts. *Int. J. Fuzzy Syst.* **2020**, *22*, 293–309, doi:10.1007/s40815-019-00777-w.
62. Pourmand, E.; Mahjouri, N.; Hosseini, M.; Nik-Hemmat, F. A Multi-Criteria Group Decision Making Methodology Using Interval Type-2 Fuzzy Sets: Application to Water Resources Management. *Water Resour Manage* **2020**, *34*, 4067–4092, doi:10.1007/s11269-020-02657-7.
63. Özdemir, Y.S.; Üsküdar, A. Strategy Selection by Using Interval Type-2 Fuzzy Mcdm and an Application. *Journal of Engineering Research* **2020**, *8*, doi:10.36909/jer.v8i3.8176.
64. Deveci, M.; Cali, U.; Kucuksari, S.; Erdogan, N. Interval Type-2 Fuzzy Sets Based Multi-Criteria Decision-Making Model for Offshore Wind Farm Development in Ireland. *Energy* **2020**, *198*, 117317, doi:10.1016/j.energy.2020.117317.
65. Mirnezami, S.A.; Mousavi, S.M.; Mohagheghi, V. An Innovative Interval Type-2 Fuzzy Approach for Multi-Scenario Multi-Project Cash Flow Evaluation Considering TODIM and Critical Chain with an Application to Energy Sector. *Neural Comput & Applic* **2021**, *33*, 2263–2284, doi:10.1007/s00521-020-05095-z.
66. Sharaf, I.M. An Interval Type-2 Fuzzy TOPSIS for MAGDM Applied to Solar Power Systems. *Pak.j.stat.oper.res.* **2021**, *17*, 559–575, doi:10.18187/pjsor.v17i3.2798.
67. Komatina, N.; Djapan, M.; Ristić, I.; Aleksić, A. Fulfilling External Stakeholders' Demands—Enhancement Workplace Safety Using Fuzzy MCDM. *Sustainability* **2021**, *13*, 2892, doi:10.3390/su13052892.
68. Karagöz, S.; Deveci, M.; Simic, V.; Aydin, N. Interval Type-2 Fuzzy ARAS Method for Recycling Facility Location Problems. *Applied Soft Computing* **2021**, *102*, 107107, doi:10.1016/j.asoc.2021.107107.
69. Celik, E.; Yucesan, M.; Gul, M. Green Supplier Selection for Textile Industry: A Case Study Using BWM-TODIM Integration under Interval Type-2 Fuzzy Sets. *Environ Sci Pollut Res* **2021**, *28*, 64793–64817, doi:10.1007/s11356-021-13832-7.
70. Zhang, Z.; Zhao, X.; Qin, Y.; Si, H.; Zhou, L. Interval Type-2 Fuzzy TOPSIS Approach with Utility Theory for Subway Station Operational Risk Evaluation. *J Ambient Intell Human Comput* **2022**, *13*, 4849–4863, doi:10.1007/s12652-021-03182-0.
71. Komatina, N.; Tadić, D.; Aleksić, A.; Jovanović, A.D. The Assessment and Selection of Suppliers Using AHP and MABAC with Type-2 Fuzzy Numbers in Automotive Industry. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability* **2022**, 1748006X221095359, doi:10.1177/1748006X221095359.
72. Aleksić, A.; Milanović, D.D.; Komatina, N.; Tadić, D. Evaluation and Ranking of Failures in Manufacturing Process by Combining Best-Worst Method and VIKOR under Type-2 Fuzzy Environment. *Expert Systems* **2022**, *40*, e13148, doi:10.1111/exsy.13148.
73. Ecer, F. Multi-Criteria Decision Making for Green Supplier Selection Using Interval Type-2 Fuzzy AHP: A Case Study of a Home Appliance Manufacturer. *Oper Res Int J* **2022**, *22*, 199–233, doi:10.1007/s12351-020-00552-y.
74. Chen, S.-M.; Lee, L.-W. Fuzzy Multiple Attributes Group Decision-Making Based on the Interval Type-2 TOPSIS Method. *Expert Systems with Applications* **2010**, *37*, 2790–2798, doi:10.1016/j.eswa.2009.09.012.

75. Mendel, J.M. Type-1 Fuzzy Sets and Fuzzy Logic. In *Uncertain Rule-Based Fuzzy Systems: Introduction and New Directions, 2nd Edition*; Mendel, J.M., Ed.; Springer International Publishing: Cham, 2017; pp. 25–99 ISBN 978-3-319-51370-6.
76. Kahraman, C.; Öztayşi, B.; Uçal Sarı, İ.; Turanoğlu, E. Fuzzy Analytic Hierarchy Process with Interval Type-2 Fuzzy Sets. *Knowledge-Based Systems* **2014**, *59*, 48–57, doi:10.1016/j.knosys.2014.02.001.
77. Bellman, R.E.; Zadeh, L.A. Decision-Making in a Fuzzy Environment. *Management Science* **1970**, *17*, B141–B164.
78. Chang, D.-Y. Applications of the Extent Analysis Method on Fuzzy AHP. *European Journal of Operational Research* **1996**, *95*, 649–655, doi:10.1016/0377-2217(95)00300-2.
79. Badri Ahmadi, H.; Kusi-Sarpong, S.; Rezaei, J. Assessing the Social Sustainability of Supply Chains Using Best Worst Method. *Resources, Conservation & Recycling* **2017**, *126*, 99–106, doi:10.1016/j.resconrec.2017.07.020.
80. Pomerol, J.-C.; Barba-Romero, S. *Multicriterion Decision in Management*; International Series in Operations Research & Management Science; Springer US: Boston, MA, 2000; Vol. 25; ISBN 978-1-4613-7008-6.
81. Figueroa-García, J.C.; Chalco-Cano, Y.; Román-Flores, H. Distance Measures for Interval Type-2 Fuzzy Numbers. *Discrete Applied Mathematics* **2015**, *197*, 93–102, doi:10.1016/j.dam.2014.11.016.
82. Zhou, S.; John, R.I.; Chiclana, F.; Garibaldi, J.M. On Aggregating Uncertain Information by Type-2 OWA Operators for Soft Decision Making. *International Journal of Intelligent Systems* **2010**, *25*, 540–558, doi:10.1002/int.20420.
83. Kuo, M.-S.; Liang, G.-S. A Soft Computing Method of Performance Evaluation with MCDM Based on Interval-Valued Fuzzy Numbers. *Applied Soft Computing* **2012**, *12*, 476–485, doi:10.1016/j.asoc.2011.08.020.
84. Chen, T.-Y. A Signed-Distance-Based Approach to Importance Assessment and Multi-Criteria Group Decision Analysis Based on Interval Type-2 Fuzzy Set. *Knowl Inf Syst* **2013**, *35*, 193–231, doi:10.1007/s10115-012-0497-6.
85. Liu, P.; Jin, F. A Multi-Attribute Group Decision-Making Method Based on Weighted Geometric Aggregation Operators of Interval-Valued Trapezoidal Fuzzy Numbers. *Applied Mathematical Modelling* **2012**, *36*, 2498–2509, doi:10.1016/j.apm.2011.09.006.
86. Lee, L.-W.; Chen, S.-M. Fuzzy Multiple Attributes Group Decision-Making Based on the Extension of TOPSIS Method and Interval Type-2 Fuzzy Sets. *2008 International Conference on Machine Learning and Cybernetics* **2008**, 3260–3265, doi:10.1109/ICMLC.2008.4620968.
87. Wang, Y.-M.; Elhag, T.M.S. Fuzzy TOPSIS Method Based on Alpha Level Sets with an Application to Bridge Risk Assessment. *Expert Systems with Applications* **2006**, *31*, 309–319, doi:10.1016/j.eswa.2005.09.040.
88. Qin, J.; Liu, X. Multi-Attribute Group Decision Making Using Combined Ranking Value under Interval Type-2 Fuzzy Environment. *Information Sciences* **2015**, *297*, 293–315, doi:10.1016/j.ins.2014.11.022.
89. Wang, Y.-M. Centroid Defuzzification and the Maximizing Set and Minimizing Set Ranking Based on Alpha Level Sets. *Computers & Industrial Engineering* **2009**, *57*, 228–236, doi:10.1016/j.cie.2008.11.014.
90. Karnik, N.N.; Mendel, J.M. Centroid of a Type-2 Fuzzy Set. *Information Sciences* **2001**, *132*, 195–220, doi:10.1016/S0020-0255(01)00069-X.
91. Mendel, J.M.; Wu, H. New Results about the Centroid of an Interval Type-2 Fuzzy Set, Including the Centroid of a Fuzzy Granule. *Information Sciences* **2007**, *177*, 360–377, doi:10.1016/j.ins.2006.03.003.
92. Kayapinar Kaya, S.; Aycin, E. An Integrated Interval Type 2 Fuzzy AHP and COPRAS-G Methodologies for Supplier Selection in the Era of Industry 4.0. *Neural Comput & Applic* **2021**, *33*, 10515–10535, doi:10.1007/s00521-021-05809-x.