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Multiple attribute group decision making: A generic conceptual framework and a classification scheme

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ABSTRACT

The research activities in group decision making have dramatically increased over the last decade. In particular, the application of multiple attribute decision-making methods to group decision-making problems occupies a vast area in the related literature. However, there is no systematic classification scheme for these researches. This paper presents a generic conceptual framework and a classification scheme for multiple attribute group decision-making methods. The proposed framework consists of three main stages: the structuring and construction stage, the assessment stage, and the selection/ranking stage, providing not only an outline for classification but also a road map for the researchers working on this topic. Furthermore, top cited papers are classified based on this classification scheme in order to clarify the state of the art and to identify future research directions. As a result, eight significant suggestions for future research are identified.

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1. Introduction

We continuously make decisions in our private and professional life. On making these decisions we determine our needs, consider various criteria, evaluate alternatives, and process all this information to reach a final result. When more than one individual takes part in such a decision, it becomes a group decision making (GDM) problem [77]. The complexity of the analysis increases dramatically when moving from a single decision maker to a multiple decision maker setting [50]. The problem no longer depends on the preferences of a single decision maker; nor does it simply involve the summing up of preferences of multiple decision makers.

In the recent years, the interest is on the multiple attribute group decision making (MAGDM) methods, which are used to solve multiple attribute decision making (MADM) problems with multiple decision makers, increases dramatically [110]. In a MAGDM setting, decision makers (experts, stakeholders, participants, etc.) provides evaluations regarding to performances of the alternatives under multiple criteria. Decision makers may have different backgrounds and knowledge on the problem on hand [127]. Since many multiple dimensional decision problems of different fields requires multiple experts and/or decision makers, MAGDM methods are receiving considerable interest in many different research fields [105] such as energy [53,87], logistics [63], safety management [52], facility location [18], business process management [26], supplier selection [70], sustainable development [114], etc.

There are numerous journal articles related to MAGDM. According to a quick literature review, details of which are given in Section 4, it is seen that the number of MAGDM approaches, and therefore the interest in this topic, has increased over the years [122]. However, to our best knowledge, there is no generic conceptual framework and classification scheme nor a taxonomy or literature review for this topic.

The aim of the paper is two-fold. The first is to propose a generic conceptual framework for MAGDM process. A generic conceptual framework that provides basic concepts and their relations in a GDM process will help academicians and practitioners who need to develop a new MAGDM method and/or apply an MAGDM method to a problem. Identifying the conceptual content of the field can be seen as an important step of theory building [104]. Therefore, this framework is important for understanding and analyzing the MAGDM methods as well as evaluating the stages (of an MAGDM method) that need improvement. In this way, it can improve MAGDM practice by facilitating the process of method choice so that the methods selected fit the characteristics of the problem situation [78]. It will also support the researchers in their effort to develop and design new MAGDM methods. Moreover, a framework can be used to classify the related literature to see the state of art and show the required future direction of study in the field. After describing the generic conceptual framework, we have presented examples related to the usage of the framework. Furthermore, we have also used the proposed framework in the developed classification scheme.

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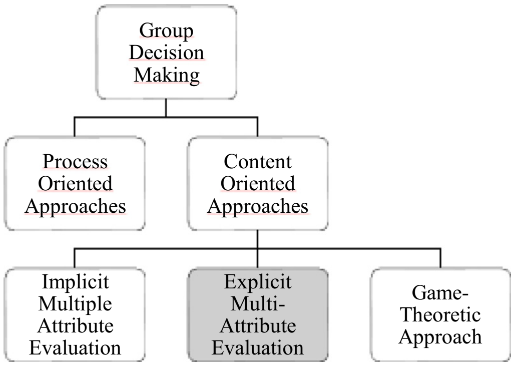

Fig. 1. Classification of group decision-making methods.

The second aim is to introduce a classification scheme for MAGDM literature and review MAGDM literature to present a panorama of the state of the art and highlight possible research directions. A classification scheme enables systematic analyses of research papers or methods in terms of different classification criteria. The research papers or methods, can be categorized and reviewed by labeling their general characteristics, approaches, and fundamental properties. After presenting the classification scheme MAGDM literature, we have conducted a literature review based on this scheme. Finally, we sum-up all observations, analysis, and reviews of MAGDM literature for advising possible research directions on the topic.

This paper is organized as follows: The following section gives the basic definitions on GDM and MAGDM. Subsequently, the conceptual framework for the MAGDM Process is presented in the third section. The fourth section presents the details of the classification scheme. The analysis of the literature is presented in the fifth section. Research directions are given in the sixth section. Finally, the paper concludes in the seventh section.

2. Group decision making: basic information

GDM or collaborative decision making, is defined as a decision situation in which there is more than one individual (also referred to as decision maker, group member, voter, stakeholder, expert etc.) involved [77]. These individuals have their own attitudes and motivations, recognize the existence of a common problem, and attempt to reach a collective decision. There are various levels of GDM problems, from a couple deciding which film to watch, to the citizens of a country deciding which president to elect.

Saaty [99] states that when a group of people makes a decision, that decision carries a lot more weight than when just one person makes it, adding that GDM is a gift and an opportunity to create greater influence through the working together of many minds. Especially in complex systems where diversity of values and interest is high (i.e., pluralistic and conflicting/coercive systems) [25], it is not possible for a single decision maker to consider all relevant aspects of a problem. As a result, group settings are required for many real life decision-making processes.

GDM includes such diverse and interconnected fields as preference analysis (e.g., [83]), utility theory (e.g., [49]), social choice theory (e.g., [109]), committee decision theory, theory of voting (e.g., [79]), game theory (e.g., [108]), expert evaluation analysis (e.g., [115]), aggregation of qualitative factors (e.g., [32]), economic equilibrium theory, etc. Among these diverse areas, our focus in this paper is MAGDM. In order to clarify the place of MAGDM, GDM approaches are classified as seen in Fig. 1.

The two main categories in this classification are process oriented approaches and content oriented approaches [10]. Process oriented approaches focus on the process of making a group decision. The main objective is to generate new ideas to understand and structure the problem. Content oriented approaches, on the other hand, focus on the content of the problem, attempting to find an optimal or satisfactory solution, given certain social or group constraints or objectives. Among the three classes of content oriented approaches (Fig. 1), in implicit multiple attribute evaluation (or Social choice theory), decision makers evaluate the alternatives and provide their unique choice of a candidate or ranking of the candidates. Their criteria or the method of giving the decision is not required nor considered in aggregating the choices of the decision makers. Game theory, on the other hand, is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers.

When it comes to the interest of our paper, explicit multiple attribute evaluation refers to MADM with multiple decision makers. Therefore, it is also called MAGDM or multi-expert multiple attribute decision making. The term MADM is often used interchangeably with MCDM. "Multiple attributes", and "multiple criteria", describe decision situations in the presence of multiple and conflicting criteria. Although there is different understanding in the use of terms MADM and MCDM, MCDM is the accepted designation for all methodologies dealing with multiple objective decision making (MODM) and/or MADM [50,113]. Therefore, MADM is a subset of MCDM. On the other hand, the main difference between MADM and MODM is related to the definition of alternatives. In MODM criteria is defined implicitly by a mathematical programming structure that results with continuous alternatives, while in MADM, the set of decision alternatives is defined explicitly by a finite list of alternative actions where discrete alternatives exit [51]. Since our interest is the GDM methods for analyzing finite list of alternatives, and not multiple objective programming, we used term MADM instead of MCDM.

All the MADM problems share the common characteristics such as multiple criteria, conflict among criteria, incommensurable units, alternatives, and preference decision [58,146]. With the involvement of multiple decision makers, MADM becomes MAGDM. Unlike the implicit multi attribute evaluation, decision makers explicitly provide criteria and their evaluations of the alternatives with respect to the criteria in MAGDM.

There are various books in the literature related to MAGDM. Hwang and Lin [50] present one of the earliest and most comprehensive studies on GDM under multiple criteria, providing information related to almost all concepts of group decision making including the MAGDM methods. They describe basic approaches for MAGDM under the heading of "The group decision process in the phases of evaluation and selection". Bui [10] is another early text in the literature. It analyses, designs, implements and evaluates a decision support system for multi-criteria group decision support, giving information related to MAGDM methods along with the other aspects of group decision making. Lu et al. [77] present multiple objective group decision-making methods focusing on fuzzy set theory applications. It provides basic fuzzy set theory based methods to solve MAGDM problems. Zhu [158], a more recent book, gives extended information related to group aggregation methods based on uncertainty preference information. It focuses on three aspects of decision making, namely consistency of uncertain preferences and method for handling inconsistent preferences, the aggregation of the decision makers' multiple uncertainty preferences, and the aggregating method of the timing characteristics' multiple structure uncertain preference information. Saaty [99] presents a structured approach for group decision-making, suggesting the use of AHP and ANP as MAGDM method in the process. There are also some books in the literature that devote a full chapter to MAGDM methods, such as Tzeng and Huang [113], Pedrycz et al. [90], etc.

There are also numerous papers in the literature on MAGDM. We conducted an extended analysis on them and developed the generic conceptual framework and literature review as presented in the following sections.

3. A generic conceptual framework for MAGDM process

In order to develop a generic conceptual framework for MAGDM, we conducted an extended analysis of the related literature and the methods used in previous studies through reading the papers over and over again, taking inspiration from the following works and their accounts of particular stages of the framework: Hwang and Lin's [50] group decision process in the phases of evaluation and selection; Ölçer and Odabaşı's [86] model; and the content of a course as given by Kabak [57]. The readers should notice that the framework presented in this section is not an approach or a methodology for MAGDM. It is a framework showing the stages and steps of MAGDM methods and all the possible differentiations and different perspectives within the stages and the steps. Therefore, by the help of this framework, academicians and practitioners may see the stages and different kinds of perspectives encountered in MAGDM while evaluating or selecting a method as well as developing a new one for a particular problem. At the end of this section, we provide examples about how the framework can be used to analyze a method.

One more important property of the generic framework is related to its content. It covers only the MAGDM methods, approaches, etc. (i.e. explicit multi attribute evaluation) where as other GDM approaches such as process oriented approaches, implicit multi-attribute evaluation (i.e., voting and social choice functions), and game theoretic approaches are out of the scope (see Fig. 1).

Literature analysis shows that MAGDM methods are composed of three main stages: (1) Structuring and construction stage, (2) Assessment stage, and (3) Selection/ranking stage (Fig. 2). We explain these stages with examples from the literature in the following.

3.1. Structuring and construction stage

In structuring and construction stage, the problem is structured as an MAGDM problem by identifying the decision goal and forming a committee of decision makers. Although this part is mentioned in some of the articles, they do not usually provide or propose any accurate approach for this part. For instance, Chen et al. [20] state that the first step of the methodology is to form a committee of decision makers, and then identify the evaluation criteria, and similarly, Ölçer and Odabaşı [86] propose the first step as forming a committee of decision makers and then identifying the selection attributes with their types and listing all possible alternatives, but neither study applies an approach to realize this step.

Different from the MADM problems, in MAGDM decision makers may be assigned weights. Especially when decision makers level of expertise, background, or knowledge, are not similar, they may have different influence in overall result. Therefore, they can be assigned weights that reflect their importance or reliability to solve the problem [13,86,147]. Importance weights of decision makers can be included in the process in several stages based on how they are determined. If a moderator assigns weights to decision makers [123,133] then it is appropriate to place this step in the structuring and construction stage. In some methods, decision makers are assigned weight for each criterion [86], or evaluate each other to assign degree of expertise [97], in which case this step is placed in the assessment stage. In other methods, decision maker weights are assigned based on consensus measure [140], in which case it is placed in the selection and ranking stage (see Fig. 2).

The MAGDM model is constructed through determining the alternatives, criteria, and performance values, which is the decision matrix in classical decision models. For MAGDM problems, however, the set of criteria may be different for the decision makers, and in some problems criteria are not available where decision makers evaluate the alternatives directly. Therefore, determination of alternatives is the first stage, while determination of criteria and performance values takes place in the assessment stage of the framework (see Fig. 2).

3.2. Assessment stage

The assessment is conducted with two main approaches depending on usage of criteria (see Fig. 2 *Assessment Stage*). Classically, in most of the MAGDM problems criteria are explicitly presented. In some problems decision makers do not give information about the criteria they use though, and only provide their preference through the ranking or by comparing the alternatives [119,134,157]. If only ranking of the alternatives or first choices are available, then social choice theory is an appropriate approach and would be beyond the scope of the proposed framework. However, for the situations where multiple comparisons of the alternatives such as pairwise comparisons are available, MADM approaches may be appropriate. For instance, in Xu [134], Jiang et al. [55] decision makers provide their preferences on the alternative set through pair-wise comparisons using multiplicative, fuzzy or intuitionistic preference relations. This is therefore included in the framework as alternative based assessment.

3.2.1. Criteria based assessment

In criteria based assessment (see Fig. 2) decision maker may use an agreed set of criteria or their own individual sets of criteria. For the first case, the set of criteria is formed through a group work [64,82,106] or imposed by the problem owner or a privileged decision maker [102]. Then decision makers identify the weights of criteria through a group work which produces a group's importance weights [42,151], or decision makers may identify their own individual weights [43,59,128,155], or a moderator assign importance weights to criteria [31,74,86,123]. Notice that in some methods [6], criteria are not assigned weight at all.

Further, decision makers provide evaluations of the alternatives with respect to the criteria. In order to aggregate the evaluations there are two processes in the literature. In the first one, the decision maker evaluations are aggregated to a single decision matrix through which the collective preference is found [8,61,94,124,153]. In the second one, individual preferences (i.e. ranking of the alternatives) are found to begin with, and their preferences are aggregated subsequently [54,62]. Most of the papers in the literature prefers aggregation of the evaluations to a single decision matrix as it prevents the loss of information through the process. If decision makers' ranking of the alternatives are first found and then aggregated by a social choice function, the cardinality of the individual preferences can be lost.

In the individual criteria case the decision makers determine their own criteria or select the criteria from a predetermined set [32]. When decision makers have different interests, expertise, or will not consider all the aspects of the problem, they may use their own set of criteria. Especially for the big size multiple dimensional problems, such as energy policy development, sustainable development evaluation etc. individual sets of criteria may be preferred by the decision makers. For instance; Dong et al. [32] propose a MAGDM approach for a complex and dynamic MAGDM where the decision makers have the individual sets of attributes and the individual sets of alternatives. Lourenzutti and Krohling [76] discusses heterogeneous MAGDM with individual sets of criteria.

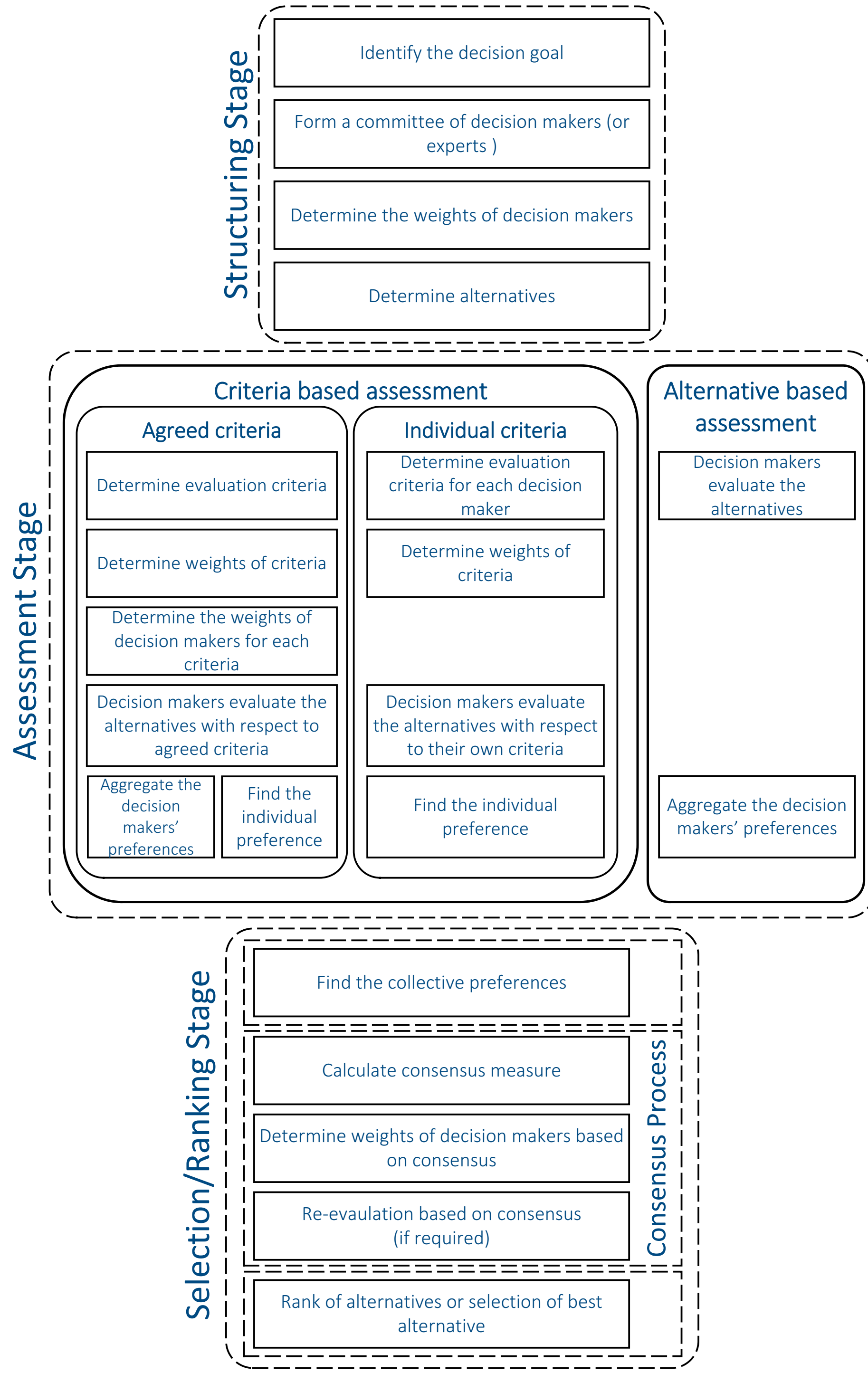

Fig. 2. A generic conceptual framework for MAGDM process.

In the individual criteria settings, the importance weights are also determined for each decision maker individually. After the alternatives are evaluated with respect to the criteria, the individual preferences are found and then are aggregated to a collective preference ordering.

3.2.2. Alternative based assessment

In alternative based assessment (see Fig. 2), decision makers evaluates alternatives directly via pairwise comparisons without explicitly presenting the criteria. This type of assessment may be preferred when there are high number of decision makers, the criteria are not clear or impractical to consider, or in dynamic problems where the preferences of decision makers are updated several times (e.g., in consensus processes). In alternative based assessment, decision makers may use different representation formats to express their opinions. For instance Cabrerizo et al. [15] use fuzzy preference relation to represent pairwise preference relations among the alternatives. On the other hand, Fan et al. [37] assume two different formats such as multiplicative preference relation and fuzzy preference relation. Then the decision maker evaluations are aggregated to a single collective relation. For instance, Fan et al. [37] propose a goal programming methodology to aggregate different formats of relations; while Jiang et al. [55] use intuitionistic multiplicative preference relations to find collective relation.

3.3. Selection/Ranking stage

The final stage of the framework is selection/ranking of alternatives (see Fig. 2). In this stage, initially a collective preference ordering is calculated based on the results of the assessment stage. Classical MADM methods, as well as aggregation operators based methods, can be used if decision maker evaluations are aggregated to a single decision matrix. For instance, Chen et al. [20] uses fuzzy TOPSIS-like approach to get the assessment of alternatives from aggregated fuzzy ratings with respect to criteria. Hatami-Marbini and Tavana [43] use a fuzzy ELECTRE method after aggregating decision maker ratings to a decision matrix. Wei [124] introduced some induced geometric aggregation operators to aggregate and rank intuitionistic fuzzy information.

If individual preferences of decision makers are formed in the previous stage, social choice functions can be applied to find collective preference [60,68]. For instance, Li et al. [75] extend Cook and Seiford's social choice function to MAGDM considering criteria and decision maker weights to get a unique ranking.

After calculating a collective preference ordering, some methodologies are applied in the consensus process (see Fig. 2), which is defined as a dynamic and iterative group discussion process, coordinated by a moderator helping experts bring their opinions closer [14]. This process is an iterative process with several consensus rounds, in which the decision makers adjust their preferences following the consensus rules [67]. In this process, initially, the degree of existing decision maker consensus is measured. If the consensus degree is lower than a specified threshold, the moderator will urge decision makers to discuss their opinions further in an effort to bring them closer. Otherwise, the consensus process is finalized. In some methods, the consensus measure is used to obtain importance weights for decision makers [140]. Fedrizzi and Pasi [38] present a review of well-known fuzzy logic based approaches to model flexible consensus reaching dynamics. Dong et al. [32] claims that complete agreement is not always necessary in practice and underlines the use of soft consensus measures. According to Dong et al. [32] there are diverse soft consensus methods in the literature such as methods that processes different representation structure, methods featuring minimum adjustments or cost, methods based on consistency and consensus measures, methods consider the behaviors/attitudes of decision makers, and methods developed for dynamic/Web contexts. In recent studies, Li et al. [67] personalized individual semantics model for the consensus reaching process of a linguistic GDM problem. Dong et al. [30] designed a consensus process for GDM problems with heterogeneous preference presentation structures. Dong et al. [32] developed a consensus process for the complex and dynamic MAGDM problems that consists of individual sets of criteria, individual sets of alternatives and individual preferences. Zhao et al. [156] proposed a consensus improving model for GDM problems with dual hesitant fuzzy preference relations.

The final step of the selection/ranking stage is ranking, selection, classification and prioritization of the alternatives or selecting the best of a set of superior alternatives based on the collective preferences (see Fig. 2).

3.4. Examples of analyzing the methods using the framework

In order to show how the framework can be used to analyze the methods in the literature, two examples are given. The first method is Kannan et al.'s [61] fuzzy TOPSIS group decision-making approach to select green suppliers for an electronics company. It is one of the most cited and recent papers in MAGDM context. Kannan et al. [61] developed 7 step-algorithm of decision making method. We determined where these steps correspond to the stages of the framework in Fig. 3. According to these relations, we can clearly see that the method has introduced steps in all three stages of the framework. Additionally, the method makes a criteria based assessment with agreed criteria. The method devoted the most effort to aggregation of decision makers' preferences while problem definition through forming committee of decision makers, determining evaluation criteria, and determining weights of criteria are planned to get in Step 1, where any methodology or approach has not been introduced. We can also see that the method does not provide consensus process and does not attach weights to decision makers.

The second analyzed method is Ma et al.'s [80] Fuzzy MCGDM Process (FMP) model (see Fig. 4) that is designed to handle information expressed in linguistic terms, boolean values, as well as numeric values to assess and rank a set of alternatives within a group of decision makers. As can be seen in Fig. 4, steps of the FMP model could be attached to the proposed framework in all three stages. It uses a criteria-based assessment with agreed criteria. Different from most of the methods in the literature; FMP assigns weights to decision makers and define criteria in a hierarchical structure. We can conclude that FMP approach focuses on the structuring and construction stage and early steps of the assessment stage as well as the aggregation step and the selection/ranking stage. Consensus process is not applied in the model and there is no approach defined for identifying the goal and forming a committee of decision makers.

Notice that these results shows the properties of the analyzed methods in Kannan et al.'s [61], and Ma et al.'s [80] based on the proposed framework and do not indicate any weakness or arguments related to their originality.

4. A classfication scheme for MAGDM

In this section we develop a classification scheme for classifying the literature on MAGDM. By the help of such a classification, MAGDM methods can be categorized and reviewed by describing their general characteristics, approaches, and fundamental properties.

In this study, MAGDM related literature is first classified based on six basic factors: MADM Methodology, preference information representation, MAGDM process, preference information type, consensus, and application type. Accordingly, a classification scheme is proposed, as given in Fig. 5.

4.1. MADM methodology

Classical MADM methods can be classified into four main categories [22,58]: Non-compensatory methods, value based methods, analytic hierarchical process (AHP) methods, and outranking methods.

A decision making method is compensatory if trade-offs between attribute values are permitted, otherwise it is non-compensatory. In a non-compensatory method, a superiority in one attribute cannot be offset by an inferiority in some other attribute(s). Non-compensatory methods are credited for their simple logic and computation. Max-min, max-max methods, conjunctive /disjunctive methods, ordered weighted averaging (OWA) [142] method and their fuzzy extensions are examples of non-compensatory methods. In this study, we have classified the basic non-compensatory methods in this part, other more structured non-compensatory methods that depends on pairwise outranking relations such as ELECTRE, PROMETHEE etc. are classified in "outranking methods"

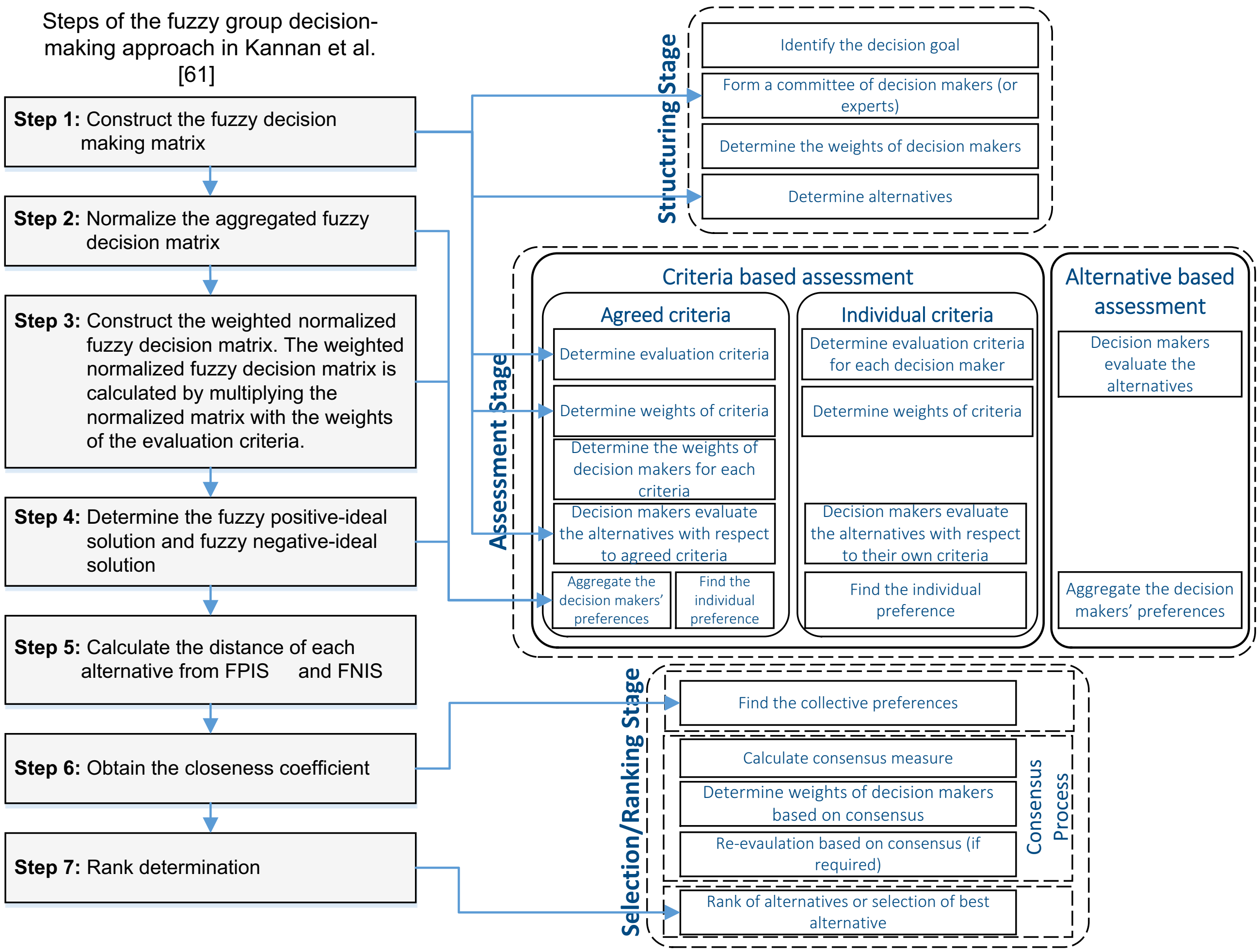

Fig. 3. Correspondence of Kannan et al.'s [61] method to the framework.

Value based methods are scoring methods in which a vector of an alternative's performances with respect to attributes is transformed to an appropriate scalar for ranking purposes. Among the others, the simple additive weighting (SAW) (also called weighted average) is probably the most widely accepted and used MADM method in real-world settings [44]. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and VIKOR (VIšekriterijumsko Kompromisno Rangiranje) are some other value based methods that rank alternatives according to their closeness to ideal. Chu et al.'s study [24] provides a comparison analysis of SAW, TOPSIS and VIKOR. The literature also includes fuzzy set theory application of these methods. For instance, Wang [118] presents a fuzzy MADM model by generalizing the SAW method under fuzzy environment. Sanayei et al. [102] develop an extended fuzzy VIKOR method for solving MAGDM problems, Liao and Xu [65] present a VIKOR-based method for hesitant fuzzy MADM problems and Qin [95] extends VIKOR method for MADM problems under interval type-2 fuzzy environment. In the literature, many recent papers suggest to the fuzzy extension of the TOPSIS method [6,35,56,141,143].

Pairwise comparison methods depend on the decision maker's pairwise comparisons of alternatives for each attribute. The classical method in this class is the AHP method that uses pairwise comparisons in a hierarchical structure of the criteria and alternatives. Saaty [100] extends AHP to Analytical Network Process (ANP) to define the problem in a network setting instead of a hierarchy. Although pairwise comparison methods can also be classified as value based method, it is placed in a different part because these kinds of methods such as the AHP method is strictly different from other value based methods with their integrated approach that includes reciprocal comparisons, combine individual judgements, and obtain representative group judgments [101]. Additionally, with its reciprocal comparisons, AHP is one of the highest ranked methods used to measure the influence of the intangible factors in decision making and GDM [101]. There are also other recent extensions of AHP and ANP such as Deng et al. [27], Hashemi [41], and Chen et al. [21].

Outranking methods depend on outranking relations between alternatives. Outranking relation is a binary relation defined on the set of alternatives such that "*h* outranks *k*" if there are enough arguments to decide that "*h* is at least as good as *k*", while there is no essential argument to refute that statement. ELECTRE, PROMETHEE and their variants are the most well-known outranking methods. Other examples of the studies utilizing a outranking method are Durbach [34], Fernandez and Olmedo [39], Shen et al. [105] and Segura and Maroto [103].

There are also numerous other methods in the MADM literature. These methods can be classified in one of the four classes defined above. For instance, The TODIM method (an acronym in Portuguese of Interactive and Multicriteria Decision Making) [40], which is used frequently in the recent literature, depends on the dominance relations between the alternatives and thus can be classified as outranking method. MACBETH (Measuring Attractiveness by a categorical Based Evaluation Technique) [29], which allows

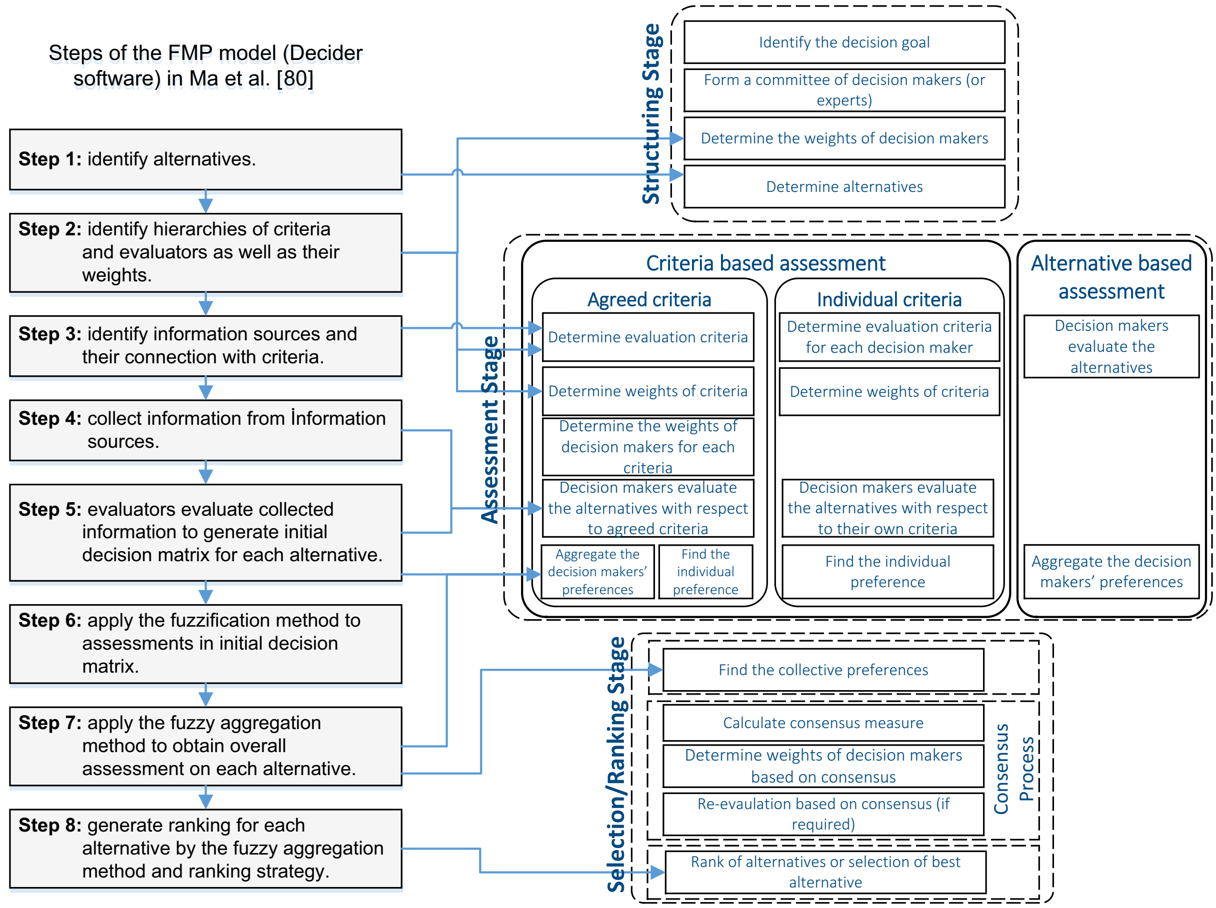

Fig. 4. Correspondence of Ma et al.'s [80] method to the framework.

a decision maker to evaluate alternatives by making qualitative comparisons regarding their differences of attractiveness in multiple criteria, is a pairwise comparison method. LINMAP (Linear Programming Technique for Multidimensional Analysis of Preference) is one of the classic methods for solving MAGDM problems [120], which is based on pairwise comparisons of alternatives given by the decision makers and provides the best alternative as the solution that has the shortest distance to the ideal solution.

Notice that some papers in the literature use hybrid methodologies integrating two or more of the above given methods. For instance, Deng [28] and Taylan et al. [111] integrate Fuzzy AHP and TOPSIS, while Liu et al. [71] integrate fuzzy VIKOR and fuzzy AHP and Peng and Xiao [91] combine PROMETHEE with ANP under hybrid environment. These papers are classified within both related classes.

4.2. Preference information representation

The decision makers provide their preference information for attributes using different preference formats: real numbers (crisp), ordered language model, 2-tuple model, fuzzy sets and numbers (Classical Fuzzy sets, intuitionistic, hesitant, Type-2 fuzzy sets), and others. As the preference information type directly affects how the information is gathered from decision makers as well as the methodology to be used for aggregations, it is important to classify the literature in this respect.

Classically, decision makers use real numbers to make evaluations. In some situations decision makers may prefer to use linguistic expressions according to ordered discrete term sets such as fuzzy linguistic terms [149]. Linguistic 2-tuples [46] enrich the linguistic representation by treating the linguistic domain continuously. The last class of preference information representation is fuzzy sets. Different types of fuzzy sets such as classical fuzzy sets (with a membership degree), intuitionistic (with a membership and a non-membership degree) [3], hesitant (with multiple membership degrees) [112], type-2 (with a membership of fuzzy sets) [149] and their interval-valued extensions (such as interval-valued fuzzy sets and interval-valued intuitionistic fuzzy sets) are preferred in the literature.

In general, preference information on alternatives provided by decision makers is represented in the same format, while for a some studies in the literature [69,76,81,121,129,152] the decision makers present their preferences as different types of information (numerical, linguistic, interval-valued etc.).

4.3. MAGDM process

This factor classifies the studies according to the assessment stage in MAGDM process presented in the second section. The assessment is conducted with two main approaches depending on usage of criteria: criteria based assessment and alternative based assessment. There are two approaches in criteria based assessment; the agreed criteria approach and the individual criteria approach. Details of these concepts can be seen in Fig. 2 and Section 3.2.

4.4. Preference information type

In MADM methods, preference information related to criteria weights, decision maker weight and performance estimation is

A Classfication Scheme for MAGDM

1. MADM methodology
- a. Non-compensatory methods
- b. Value based methods
- c. Pairwise comparison methods
- d. Outranking methods

2. Preference information representation
- a. Real numbers (crisp)
- b. Ordered language model
- c. 2-tuple model
- d. Fuzzy sets and numbers
  - d1. Classical fuzzy sets
  - d2. Intuitionistic fuzzy sets
  - d3. Hesitant fuzzy sets
  - d4. Type-2 fuzzy sets
- e. Other

3. MAGDM process
- a. Criteria based assessment
  - a1. Agreed criteria
  - a2. Individual criteria
- b. Alternative based assessment

4. Preference information type
- 4.1 Weight estimation (for criteria)
  - a. None
  - b. Rating
  - c. Pairwise comparison
- 4.2 Weight estimation (for decision makers)
  - a. None (homogeneous)
  - b. Rating
  - c. Pairwise comparison
- 4.3 Performance estimation
  - a. Rating
  - b. Pairwise comparison

5. Consensus
- a. Consensus included
- b. Consesus is not included

6. Application
- a. Illustrative example
- b. Real world application

Fig. 5. A Classification scheme for MAGDM literature.

supplied in different formats. Criteria weights that are employed in most of the MAGDM methods show the relative importance of the criteria with respect to the decision goal. Assigning weights to decision makers is not as common as for criteria weights; however, it may not be appropriate for the problems where decision makers have varied knowledge, experiences and proficiency, to assign equal importance to all group members or decision makers, and in these cases a different rate of importance (weight) is assigned to each decision-maker.

Although there are subjective weighting techniques such as Entropy, Regression Analysis, and Critic method in the MADM literature, the information required regarding the relative importance (i.e., weights) of each attribute or decision maker is usually supplied by experts using ordinal (rank order by which relative degree of difference is not allowed) or cardinal (numerical or verbal expressions that allow relative degree of difference) scales. In this respect, there are different approaches such as Rating (rate each attribute in a given scale), Point Allocation (allocate -distribute- a certain amount to alternatives), Ratio, Ranking, Pairwise Comparison, and Trade-off to acquire information from decision makers. These approaches can be classified in two main groups: rating and pairwise comparison.

In rating type methods, experts evaluate the criteria (or decision makers, alternatives) directly using various kinds of preference representation methods (see Section 3.2). In most of the methods, a scale is provided for the decision maker to achieve a unified scale for all decision makers. The objective evaluations of the alternatives can also be considered as a rating type preference information.

In pairwise comparisons (also known as preference relation), experts evaluate the criteria (or decision makers, alternative) in pairwise manner by focusing on only two criteria at each time. In this evaluation, decision makers compare two criteria that lead to the preference of one criterion over the other or to a state of indifference between them. Pairwise comparison is the main approach of AHP which is one of the most common approaches in decision making literature.

4.5. Consensus

Consensus seeking is a group decision making process that not only seeks the agreement of most participants, but also the resolution or palliation of minority disapprovals. The consensus process is necessary to obtain a final ranking or selection with a certain level of agreement between the decision makers. Clearly, it is preferable that the set of decision makers reaches a high degree of consensus before applying the selection process [14]. Please see Section 3.3 for detailed information. We added this factor to classify the literature according to whether consensus is used or not.

4.6. Application type

In addition to the development of a model for decision making process, researchers provide an experimentation phase to illustrate the applicability of their research. Applications in studies are considered as real-world applications and illustrative examples.

4.7. Illustrative classifications

We selected 10 papers from the literature, five of them are among the top cited ones and the remaining five are the among the recent papers, to illustrate the use of the classification scheme. Please see Table 1 for the classifications.

5. Analysis of the literature

In order to analyze MAGDM literature, we made a search on Web of Science database with the keywords ("group decision making") and ("attribute" or "criteria" or "criterion") on January 5th, 2017. [122]. We found a total of 1453 articles. Moreover, for comparison reasons we also identified Decision Making Articles (DMA) in the same database with the keywords ("decision making").

The accumulation of MAGDM articles and DMA listed on Web of Science database is shown in Fig. 6. The results clearly show the increasing trend in for both MAGDM articles and DMA, with the number of articles increasing dramatically over the last 10 years. More specifically, for MAGDM articles there was a nearly tenfold increase between 2005 and 2016 (from 26 to 256), while DMA increased by approximately four times in the same period (from 4614 to 17,726). This result shows that the interest in MAGDM has increased more than that in decision making over the last decade.

When the articles are classified according to the journals they are published in, Expert Systems with Applications is found to have the highest number of articles (109 out of 1453 articles). Journal of Intelligent & Fuzzy Systems, Applied Soft Computing, Group Decision and Negotiation, Information Sciences, European Journal

Table 1
Classification of selected papers according to the proposed scheme.

Study	MADM methodology	Preference information representation	MAGDM process	Preference information type			Consensus	Application
				Criteria weights estimation	Decision maker weight estimation	Performance estimation		
Chen [19]	Value based method	Classical fuzzy sets	Agreed criteria	Rating	None	Rating	Not included	Illustrative example
Boran et al. [8]	Value based method	Intuitionistic fuzzy sets	Agreed criteria	Rating	Rating	Rating	Not included	Illustrative example
Bordogna et al. [9]	Non-compensatory method	Ordered language model	Agreed criteria	None	None	Rating	Included	None
Xu [133]	Non-compensatory method, Value based method	Ordered language model	Agreed criteria	None	Rating	Rating	Not included	Illustrative example
Shih et al. [107]	Value based method	Real numbers (crisp)	Agreed criteria	Rating	None	Rating	Not included	Illustrative example
Dong et al. [32]	Value based method	Classical fuzzy sets, Ordered language model, Real numbers	Individual criteria	Rating	Rating	Rating	Included	Illustrative example
Liao et al. [66]	Pairwise comparison method	Hesitant fuzzy sets	Agreed criteria	Pairwise comparison	Rating	Pairwise comparison	Included	Illustrative example
Qin et al. [96]	Outranking methods	Type-2 fuzzy sets	Agreed criteria	Rating	Rating	Rating	Not included	Illustrative example
Büyüközkan et al. [11]	Value based method	Type-2 fuzzy sets	Agreed criteria	Rating	None	Rating	Not included	Real world application
Wu et al. [127]	Non-compensatory method, Value based method	2-tuple linguistic model	Agreed criteria	Rating	None	Rating	Included	Illustrative example

Table 2
Journal perspective (journals with fifteen or more relevant publications).

Rank	Journal	Frequency	Frequency (%)
1	Expert Systems with Applications	109	7.50
2	Journal of Intelligent & Fuzzy Systems	72	4.96
3	Applied Soft Computing	60	4.13
4	Group Decision and Negotiation	55	3.79
5	Information Sciences	51	3.51
6	European Journal of Operational Research	50	3.44
7	Knowledge-Based Systems	49	3.37
8	Applied Mathematical Modelling	45	3.10
9	International Journal of Computational Intelligence Systems	36	2.48
10	Computers & Industrial Engineering	29	2.00
11	International Journal of Uncertainty Fuzziness and Knowledge-Based Systems	27	1.86
12	International Journal of Intelligent Systems	26	1.79
13	Mathematical Problems in Engineering	25	1.72
14	Technological and Economic Development of Economy	24	1.65
15	International Journal of Information Technology & Decision Making	23	1.58
16	Soft Computing	22	1.51
17–18	International Journal of Fuzzy Systems	18	1.24
17–18	Journal of Applied Mathematics	18	1.24
19–20	International Journal of Advanced Manufacturing Technology	17	1.17
19–20	Omega-International Journal of Management Science	17	1.17
21	Fuzzy Sets and Systems	15	1.03
	Others	665	45.77
	Total	1453	100%

of Operational Research and Knowledge-Based Systems have published a considerable number of articles related to MAGDM. The list of the journals that have published 15 or more articles is presented in Table 2. It is interesting to note that journals presented in Table 2 include only 54% of all relevant articles (an additional 50 different journals published 5 or more articles related to MAGDM). These evaluations show that the diversity of application areas of MAGDM articles is very high.

In order to make a more detailed analysis we examined the top 200 most cited articles using the proposed classification scheme (Fig. 5). From the analysis of the literature, the following results were identified.

5.1. MADM methodology

The majority of the studies fall into the value based methods. Value based approaches are considered in approximately 47% of papers (Fig. 7). Most of these studies use simple additive weighting, and TOPSIS. Non-compensatory methods, such us max-min, OWA operator etc., accounted for 34% of papers. Pairwise comparison methods and outranking methods constituted 14% and 5% of the papers, respectively.

5.2. Preference information representation

The majority of the top cited articles use fuzzy sets and numbers for representing preference information (62% of papers), and most of these articles employ classical fuzzy sets rather than intuitionistic or hesitant fuzzy sets. Real numbers are preferred by 18% of the articles. See Fig. 8 for classification results based on preference information representation.

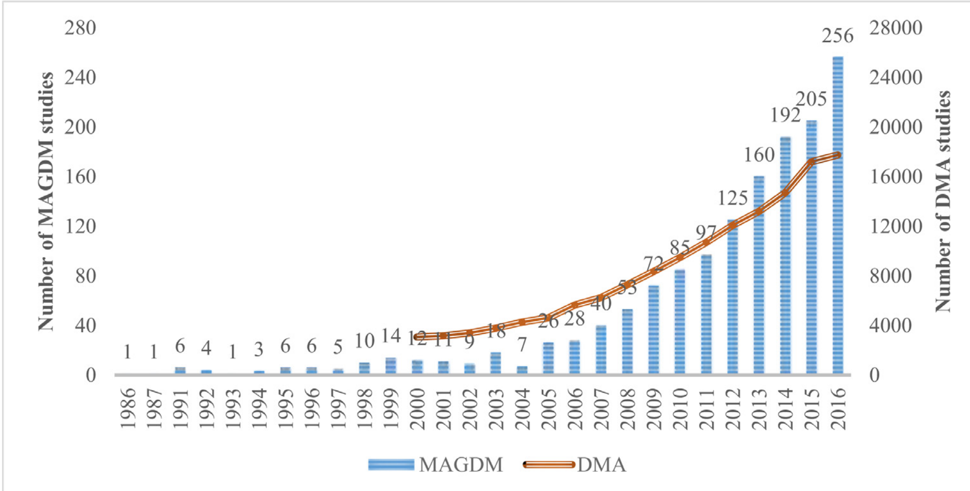

Fig. 6. Distribution of MAGDM papers between 1986 and 2016.

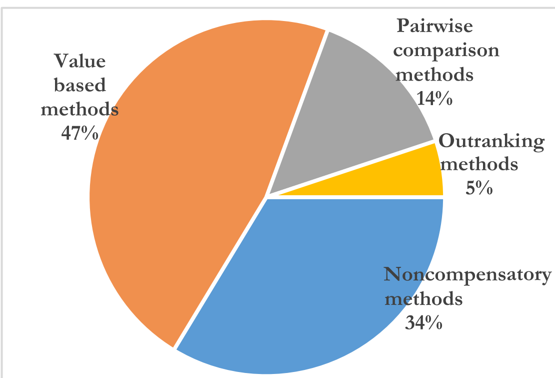

Fig. 7. Classification based on MADM methodology.

5.3. MAGDM process

The classification based on MAGDM process revealed an interesting result. Most of the studies (90%) use criteria based assessment with agreed criteria, while a few studies (9%) consider alternative based assessment (Fig. 9). In the analyzed literature, there were just three studies [36,48,155] involving individual based assessment.

5.4. Preference information type

Rating is the most preferred means of preference information type not only for performance estimation, but also for criteria weights estimation and decision maker weight estimation (See Fig. 10). Besides, in the majority of articles weight is not assigned to decision makers which are therefore considered to be homogenous.

5.5. Consensus

The majority of studies in the literature do not include consensus process (82%) (Fig. 11).

5.6. Application type

Illustrative examples are used in 72% of the articles. Only 28% of the articles consider real world problems (Fig. 12).

We identified that there are common illustrative examples in the literature applied by several other studies (see Table 3). For instance the investment company example in Herrera and Herrera-Viedma [45] is applied in many papers such as Ye [144,124,125], Liu and Jin [72], Wei et al. [126], and Xu and Wang [130] etc.

5.7. Cross sectional analysis

We conducted a cross sectional analysis to find out how different MADM methodologies represent preference information.

Over half of the non-compensatory method studies (57%) used fuzzy sets and numbers to represent preference information. In particular, the majority of these fuzzy studies use intuitionistic fuzzy numbers (29%) (Fig. 13).

A vast majority of value based methods (68%) use fuzzy sets and numbers, especially classical fuzzy numbers (50%) which are the most preferred type (Fig. 14).

Most of the pairwise comparison method studies (68%) use fuzzy sets and numbers as preference information representation (Fig. 15). Unlike the other MAGDM methods, over half of the outranking method studies (60%) use real numbers (crisp) as preference information representation (Fig. 15).

5.8. Use of fuzzy sets in recent years

Since the number of fuzzy set based methods in the literature has been increasing in recent years, we have magnified the different types of fuzzy set applications. According to the results presented in Figs. 16 and 17, intuitionistic fuzzy sets has become the most preferred preference information type in the last two years' articles, while the use of hesitant fuzzy sets, type 2 fuzzy sets and neutrosophic sets is also increasing.

6. Research directions

The trend in the number of papers shows a growing interest in MAGDM methods. Furthermore, since different journals with different aims and scopes publish MAGDM related articles, these methods are receiving considerable interest in many different research fields. Classification of MAGDM literature based on the proposed scheme leads to some observations and the identification of some deficiencies, which may provide insight into the current status and further development of MAGDM. We have identified eight points for future directions of MAGDM as follows:

(1) *Use of fuzzy set theory along with its extensions for solving real-life GDM problems*. Due to the fact that information is

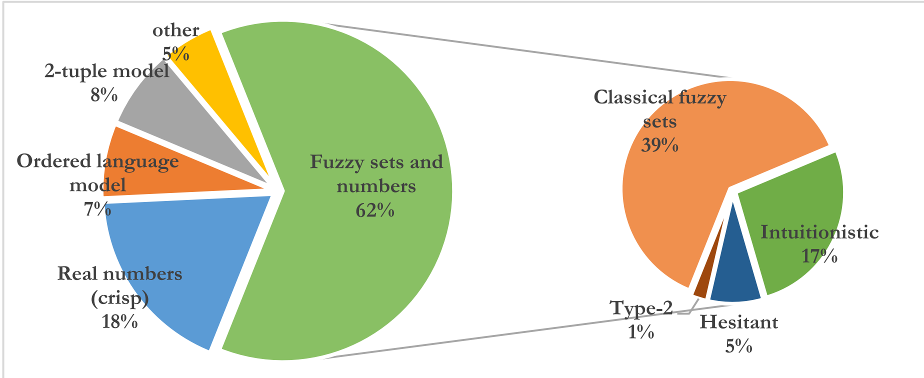

Fig. 8. Classification based on preference information representation.

Table 3
Common illustrative examples in the literature.

Source of the example	Title of the example	Articles using the example
Yoon et al. [145]	Determining what kind of air conditioning systems should be installed in a library	[140]; [135]; [89]; [139]
Ngwenyama and Bryson [85]	The prioritization of a set of information technology improvement projects	[136]; [23]
Herrera and Herrera-Viedma [45]	An investment company deciding on the best option for the investment of a sum of money	[144]; [125]; [72]; [126]; [130]
Chan and Kumar [17]	Finding the best global supplier for the most critical parts used in an assembly process	[137]; [88]; [131]
Wang and Lee [117]	A software selection problem	[138]; [153]; [94]
Ashtiani et al. [2]	Selecting project manager for a telecommunication company R&D department	[73]; [5]
Cao and Wu [16]	Selecting the most appropriate robot for a car company's manufacturing process	[154]; [155]

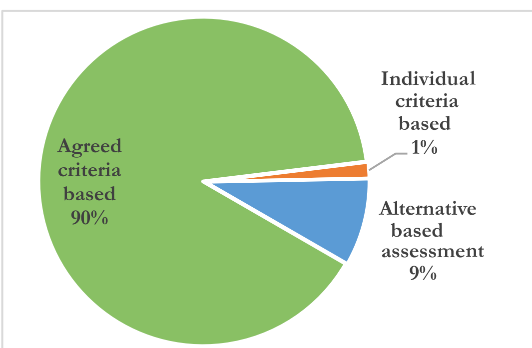

Fig. 9. MAGDM Process.

often uncertain, incomplete or unreachable, the application of fuzzy techniques in GDM is increasing rapidly. Especially we have seen a significant increase in extension of fuzzy sets such as intuitionistic fuzzy sets, hesitant fuzzy sets, type-2 fuzzy sets, and neutrosophic sets and their application to MAGDM over recent years. Rodriguez et al. [98] presented an overview of hesitant fuzzy sets and underlined that hesitant fuzzy sets are preferred for obtaining information from experts in the decision making context of real-world problems. Xu [132] mentioned that intuitionistic preference relations are a useful tool in expressing decision makers' preferences over alternatives. If a DM does not have a precise or sufficient level of knowledge of the problem, and is unable to state explicitly the degree to which one alternative is better than others, he/she can use intuitionistic fuzzy values instead of certain values. On the other hand, Type-2 fuzzy sets involve more uncertainties than classical fuzzy sets, which provide more degrees of freedom to decision makers to represent their evaluations. So fuzzy set theory along with its extensions are important tools for solving real-life GDM problems to deal with uncertainty originated from the vagueness of decision maker evaluations. More recently, neutrosophic sets, where each element of the universe has the degrees of truth, indeterminacy and falsity, has applied to some GDM related papers in the year 2016. It can deal with the problems with uncertain, imprecise, incomplete and inconsistent information that exist in scientific and engineering situation [92] where MAGDM approaches can be applied.

(2) *Importance of methods offering consensus process within the MAGDM literature*. The consensus process is necessary to obtain a final aggregated preference with a certain level of agreement between the decision makers. However, methods in the literature usually aggregate the preferences of experts without taking into account the level of agreement between experts, which may lead to solutions that are not well supported by some experts. Therefore, since it provides an approach to deal with this kind of problem, methods offering consensus process will be valuable in the MAGDM literature. Cabrerizo et al. [12] identified some challenges related to consensus process that have arisen as a consequence of the new features of the modern real-world applications. It specifically underlines the need for consensus approaches in social networks, the development of software systems to carry out decision processes by visualizing the consensus state, and the improvement of the consensus approaches in heterogeneous contexts. Instead of the consistency based estimation methods, Wu et al. [127] introduced trust estimation method. It uses the trust relationship in the social network of a group of decision makers to estimate the incomplete preference values in individual decision matrices. Furthermore, visual based consensus models for MAGDM in incomplete information can be very useful to see decision makers' relative consensus position within the group. Dong [32] emphasized the use of soft consensus measures for the practical problems where complete agreement is not necessary and mentioned the integrations of consensus rules and frameworks to MAGDM methods. Recently, several studies ([115]; Yucheng [33,67]) based on confidence and consistency degree have been conducted and they open the door

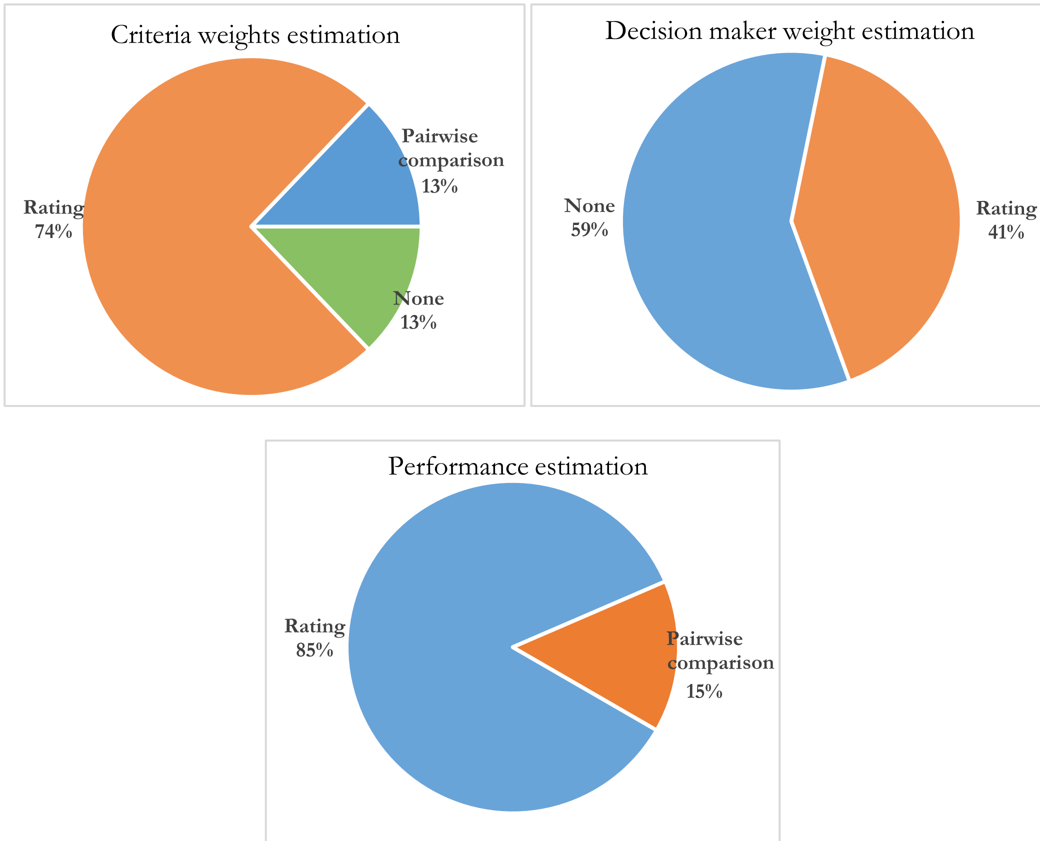

Fig. 10. Preference Information Type.

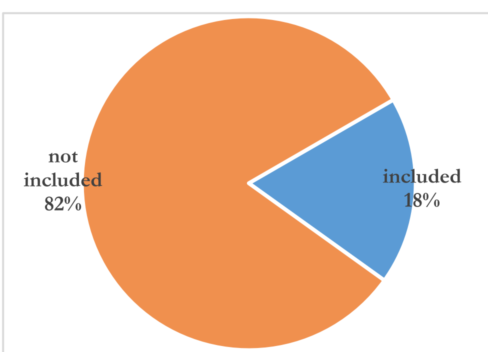

Fig. 11. Classification based on consensus process.

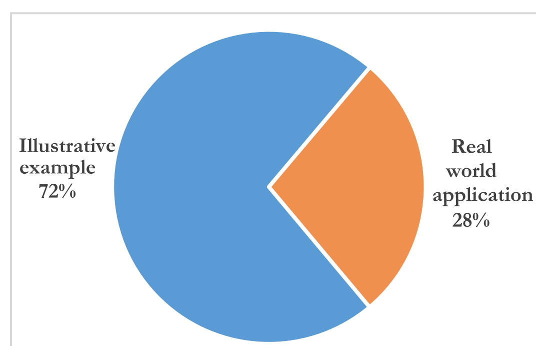

Fig. 12. Classification based on application type.

to the development of new methodologies for GDM consensus process. Interested readers can also see Herrera-Viedma et al.'s [47] study for the current trends in the development of consensus model.

(3) *Application of the MAGDM methods to real life problems*. Most of the articles use illustrative examples to show applicability of their methods. However, although this kind of analysis proves the superiority of a method over the existing ones, it does not provide any information regarding the advantages or limitations of the methods in real life problems. Therefore, application of current or new methods to real life problems will make a significant contribution to the literature, as they will highlight the practical advantages, disadvantages and limitations of the methods. In this way, Rodriguez [98] also underlined the trend of applying theoretical models to real problems.

(4) *Requirement for methods that permit individual criteria*. One other important result of the literature classification is the lack of methods for criteria based assessment methods that enable the use of experts' own criteria (i.e., the class of individual criteria). In some real life GDM problems, especially in pluralistic problem situations (implying multiple views and values of stakeholders within a shared common core), experts may prefer to use their own criteria based on their expertise. For instance, in engineering evaluation processes, different criteria need to be evaluated, which can be of both a quantitative and qualitative nature, and the experts provide their knowledge in a different domain or scale [81]. On the other hand, policy making decisions in the field of energy, sustainable development etc. include various aspects where one expert cannot have full expertise in all aspects. To be more specific, the clean energy problem defined in

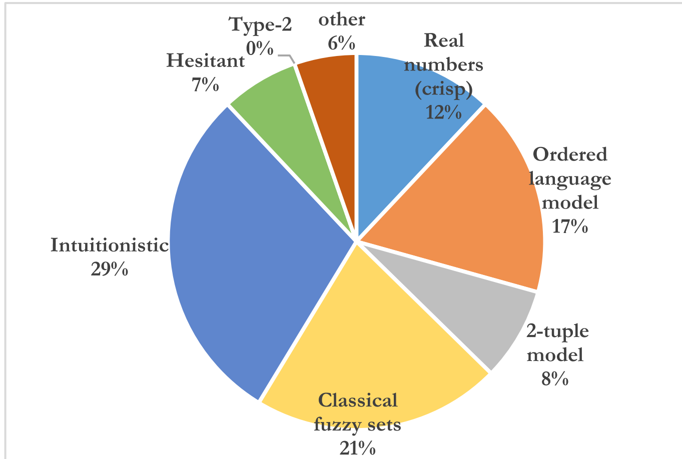

Fig. 13. Classification of non-compensatory methods according to the preference information representation.

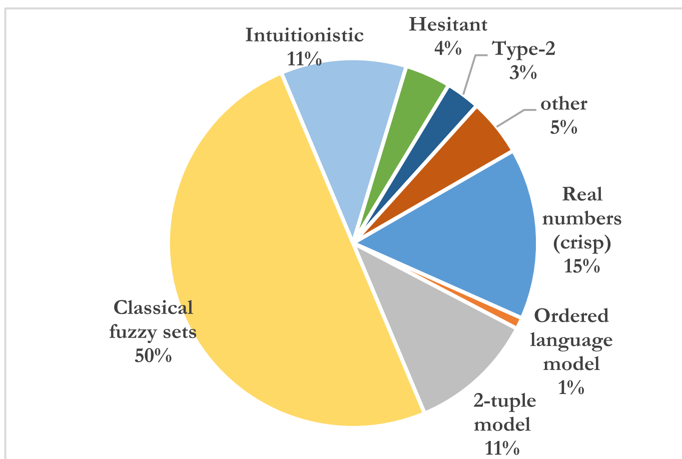

Fig. 14. Classification of value based methods according to the preference information representation.

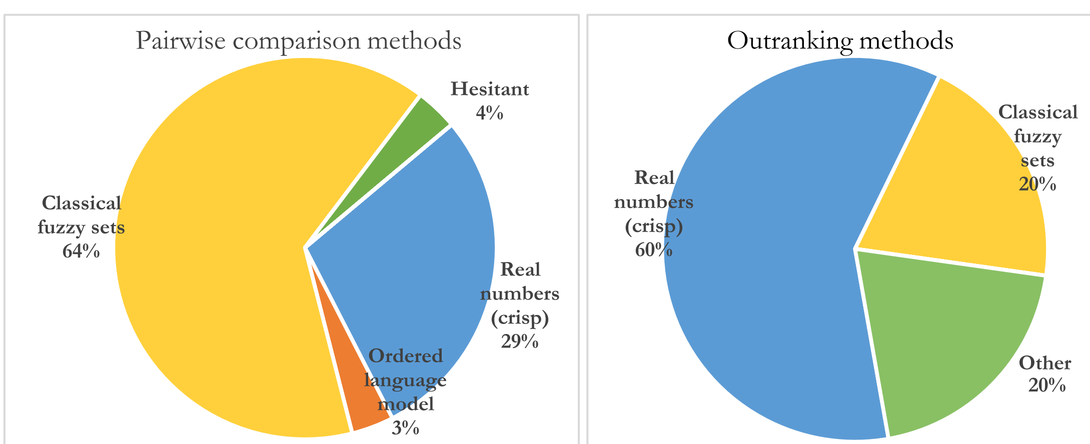

Fig. 15. Classification of Pairwise comparison methods and Outranking methods according to the Preference Information Representation.

Zhang et al. [150] includes technical, economic, environmental and social aspects that take attention or interests of different stakeholders. For example, investors may focus on the efficiency of the technology, the government may be more concerned with safety, CO2 emissions, etc. and the public are more likely to be concerned about safety and job creation. If a comprehensive list of the key evaluation criteria is compiled, as is done in Zhang et al. [150], the stakeholders or experts are forced to evaluate criteria that are not within their area of interest or, more critically, expertise. This may result in irrelevant expert judgments that lead to inaccurate solutions. Therefore, in such problems, methods should permit individual criteria instead of a unique list of agreed criteria. Although the literature has some recent studies in this

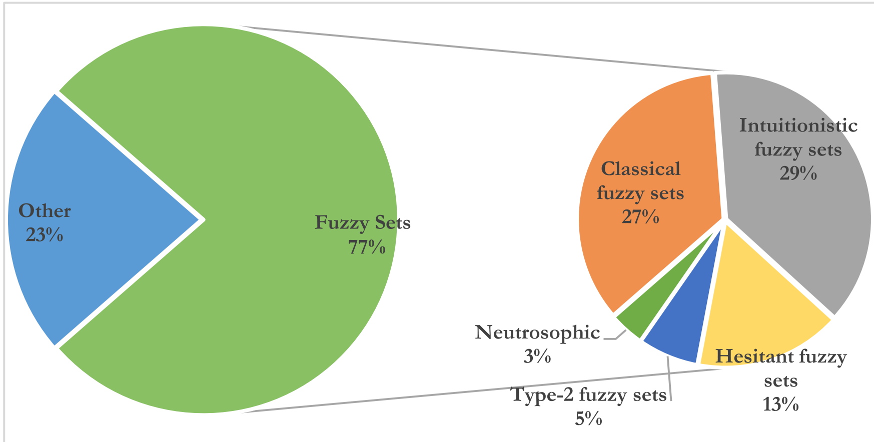

Fig. 16. Classification based on preference information type for 2015 and 2016.

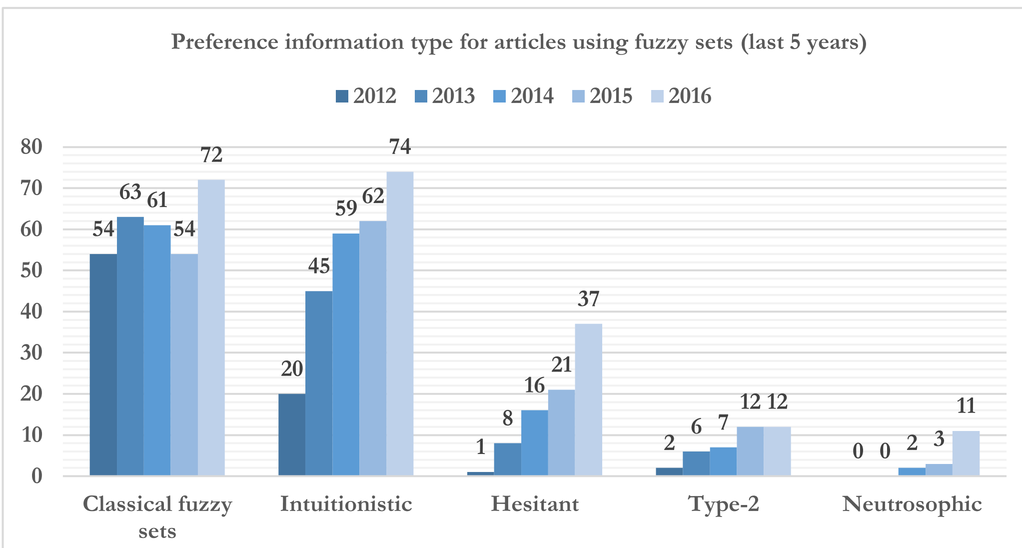

Fig. 17. Classification based on preference information type for articles using fuzzy sets.

context, such as Lourenzutti and Krohling [76] and Dong et al. [32], development of such methods offering a challenging research direction within the GDM context.

(5) *Use of pairwise comparisons as preference information type*. According to the literature survey, preference information is gathered mostly by ratings. However, as Badri [4] states, pairwise comparison generally gives more accurate results since decision makers focus on finding the relative importance of only two criteria at each time. decision makers are also not affected by external factors and are knowledgeable about the criteria (or alternatives or decision makers) they evaluate. As is also mentioned in [116] pairwise comparison methods are more accurate than non-pairwise methods. It follows that the use of pairwise comparisons (or so called preference relations) may increase in future studies. Interested readers may refer to Ureña et al. (2015) for different types of preference relations in decision making.

(6) *Use of different formats for evaluations*. As mentioned in Section 4.2, in most GDM approaches decision makers' judgments are represented in the same format. But in practical GDM applications, since decision makers can participate in decision tasks at a different time and in various locations, and due to their different cultural and educational backgrounds, each decision maker may prefer to supply information in the format of his/her own preference [37]. If experts are forced to provide knowledge in a predetermined format, as is the case in most of the literature, results may be inaccurate [58,81]. Different types of formats include numerical, linguistic, interval-valued, 2-tuple, fuzzy sets etc. If the decision makers provide information in different formats, the problem becomes more complex due to the multiformity of decision maker evaluations and interesting in practical application of GDM theory [68]. In general, MAGDM problems with several formats of evaluations are called heterogeneous MAGDM problems [152]. It has variety of application areas such as social science, natural science, economy, management etc. Therefore, the GDM methods that allow the use of different formats may be especially valuable for practical problems. Besides, in the fuzzy linguistic evaluation, multi-granular modeling has been frequently used in GDM in recent years. The multi-granular fuzzy linguistic modeling allows the use of several linguistic term sets in fuzzy linguistic modeling. Using multi-granular information can be quite valuable due to its capability of allowing each expert to express his/her preferences using his/her own linguistic term set [84].

In addition to the above given research directions which follow from the literature review, we have also identified some more open research areas based on our general readings of the literature.

(1) *Development of a universal software for group decision support system* (DSS). As explained before, GDM is a complex task because of involvement of multiple decision makers, multiple attribute, multiple stages, etc. Similarly, the methods used for GDM are also complex with multiple stages, feedbacks, complex calculations, information obtained from multiple experts etc. Therefore, academicians or practitioners all use software support in applying this method. However, most of the time a new model (software) is developed for each individual case. It would be better to develop a universal software model for group DSS which could be applied to different methods in different problems. Software providing this kind of flexibility would enable the problem owner to define the problem using the directions in the software and to generate the results without any support from an analyst. In cases where experts do not have the possibility of gathering together, for instance, the software could collect evaluations from the experts through web or mobile applications. Improved software would adapt to the problem, problem owner and decision makers while defining the problem and receiving information from the experts. Although there have been some attempts at developing mobile or web-based DSS [1,93] and multiple expert extension of some commercial software (e.g. expert choice, http://expertchoice.com/, see [7] for a list of popular decision support software products), since they are designed to apply a single method and force decision makers to adapt the software (rather than adapting to decision makers), to the best of our knowledge, the need for a universal is not met.

(2) *Weighting decision makers*. As mentioned in Section 4.4, weighting the criteria and decision makers is an important part of the MAGDM process. However, there is no study that summarizes or provides accurate methods for weighting decision makers in particular. According to the literature review, only 41% of the top cited papers take into account the weights for decision makers (see Fig. 10). Besides, all of them uses a rating scale to directly assign weights to decision makers while none of them provides a comprehensive method for assignment procedure. When decision makers come from different specialty fields, and thus each of them has his/her unique characteristics with regard to knowledge, skills, experience and personality, each decision maker will have a different influence on the overall decision result. In such situations decision makers are assigned weights to reflect their importance or reliability in solving the problem. On the other hand, assigning weights to decision makers may be risky as it may directly influence their motivation. Therefore, when to use weights for decision makers and how to determine those weights will be an interesting and crucial research question for further research [148].

7. Conclusions

This paper presents a conceptual framework and a classification scheme for MAGDM literature. We have developed a three stage framework not only as an outline for classification but also as a useful tool for the researchers working on this topic in their development of new methods as well as analyzing the current methods. With the help of the proposed classification scheme we analyzed all the related literature to show the trend and diversity of research fields and then classified the top cited papers in order to show the state of the art. According to the literature analysis; the interest in MAGDM has increased dramatically in the last decade. The majority of the papers use value based methods. The fuzzy sets are most preferred information representation type. According to MAGDM process almost all methods prefer criteria based assessment with agreed criteria. On the other hand, most of the papers do not employ consensus process. According to cross sectional analysis, different from the general results, outranking method studies use real numbers, while fuzzy sets are preferred in the other methods.

Finally, we have suggested future research directions based on this literature review. To summarize, the expectations of, and suggestions for, future directions are (1) use of fuzzy set theory along with its extensions for solving real-life GDM problems; (2) greater importance within the MAGDM literature for methods offering consensus process since consensus is necessary to obtain a final ranking with a certain level of agreement between group members; (3) significant contribution to the literature by applications of current or new methods to real life problems, as they will highlight the practical advantages, disadvantages and limitations of the methods; (4) requirement for methods that permit individual criteria instead of a common list of agreed criteria; (5) possible increase in the use of pairwise comparisons as preference information type in future studies; (6) requirement for methods that can process evaluations provided in different formats; (7) development of a more universal software for group DSS and the application of different methods in different problems; (8) research into the interesting question of how to determine importance weights for decision makers offering a potentially valuable point of departure for further study.

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