Aggregation Methods in Group Decision Making: A Decade Survey

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Overview paper

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A number of aggregation method has been proposed to solve various selected problems. In this work, we make a survey of the existing aggregation method which were used in various fields from 2006 until 2016. The information of the aggregation method retrieved from some academic databases and keywords that appeared through international journals from 2006 to 2016 are gathered and analyzed. It is observed that eighteen over ninety five of journal articles or nineteen percent applied the Choquet integral to the selection process. This survey shows this method most prominent compared to the other aggregation method and it is a good indication to the researchers to expand the appropriate aggregation method in MCDM. Besides that, this paper will give the useful information for other researches since the information given in this survey provides the latest evidence about the aggregation operator

Povzetek: Predstavljena je analiza metod za združevanje odločitev skupine.

1 Introduction

Decision making is one of the most widely used management processes in dealing with real world problems which is typically characterized by complex and difficult task. Multiple criteria decision making (MCDM) has been one of the fastest growing knowledge areas in decision sciences and has been used extensively in many disciplines. For example, Roy [1] developed a multi criteria decision analysis for renewable energy sources where it deals with the process of making decisions in the presence of multiple objective. Many researchers used other diverse methods of MCDM to solve the decision problem [2]. Basically, MCDM is a branch of operation research models and a well-known field of decision making. Both quantitative as well as qualitative criteria and attributes can be solved using the methods and it can analyze conflict in criteria and decision makers as well [3]. MCDM problems usually divided into two types: continuous and discrete. MCDM problems have two categories: multi-objective decision making (MODM) and multi-attribute decision making (MADM). By MODM methods, the decision variable values can be determined in a continuous or integer domain as it has a large number of alternative choices. Thus, MADM methods are generally discrete, with a limited number of specified alternatives. Each matrix has four main parts, namely: (a) alternatives, (b) attributes, (c) weight or relative importance of each attribute and (d) measures of performance of alternatives with respect to the attributes [4].

MCDM deals with the problem of helping the decision maker to choose the best alternative according to several criteria. In order to meet this objective, an MCDM method has basically four steps that support making the most efficient and rational decisions. According to Pohekar and Ramachandran [3], the first basic step is structuring the decision process, alternative selection and criteria formulation. The second step is displaying tradeoff among criteria and determine criteria weights. Applying value judgment concerning acceptable tradeoffs and evaluation is the third step in most MCDM. Methods. The fourth step is calculating the final aggregation prior to make a decision. Some literature also suggests that MCDM can be divided into two phase process. The first phase is called as the rating phase where aggregation of the values of criteria for each alternative is made. Ranking or ordering between the alternatives with respect to the global consensus degree of satisfaction is another phase in MCDM. It can be seen that aggregation is one of the fundamental phases in MCDM. Many MCDM methods such as ELECTRE I, II, PROMETHEE use criteria weights in their aggregation process. Weights of criteria play an important role for measuring overall preferences of alternatives. It is necessary to aggregate the available information in order to make decisions. In other words, a central problem in multi-criteria problems are an aggregation of the satisfactions to the individual criteria to obtain a measure of satisfaction to the overall collection of criteria [5]. The overall evaluation value is then used to help select alternatives. It can be seen that aggregation is the fundamental prerequisite of the decision making, in which descriptions on how to aggregate individual experts' preference information on alternatives is succinctly made [6].

Aggregation is easily defined as the process of combining several numerical scores with respect to each criterion by using an aggregation operator in order to produce a global score [7]. Detyniecki [8] defines an aggregation as 'mathematical object that has the function of reducing a set of numbers into a unique representative value'. Xu [9] defines aggregation is an essential process of gathering relevant information from multiple source. According to the [10], aggregation is made to summarize information in decision making. Omar and Fayek [11] defines aggregation in the multi-criteria decision making environments as a process of combining the values of a set of attributes into one representative value for the entire set of attributes. Aggregation is important in the decision making problem because it is used to derive a collective decision made by the decision makers by representing in the individual opinions. In addition, aggregation of individual judgments or preference is used to transform experts' judgment knowledge and expertise in relative weight.

The interest in the importance of aggregation is enhanced by judgments or preferences made by a group of decision makers. In group decision problem where number of decision makers are multiple, it is assumed that there exists a finite number of alternatives, as well as a finite set of experts. Each expert has their own opinions and may have a variety of ideas about the performance of each alternative and cannot estimate his/her preferences with crisp numerical value. Hence, a more realistic approach to be used to represent the situation of the human expert, instead of using the crisp numerical values. Thus, each variable involved in the problem may be represented in linguistic terms. Under those circumstances, aggregation methods are the key to tackle the mechanism to realize the comprehensive features of group decision making [12]. Several related research have been conducted to deal with multiplicity features in group decision making. Many researchers have studied aggregation operation using different aggregation methods. The way aggregation functions are used depends on the nature of the profile that is given to each user and the description of items [13]. In the real world of decision making problems, decision makers like to pursue more than one aggregation methods to measure the aggregation information. In these kinds of problems, many aggregation methods have been developed in this area for the recent years for judging the alternatives. For example, Ogryczak [14] proposed reference point method and implemented to the fair optimization method in analyzing the efficient frontier. The method was proposed based on the augmented max-min aggregation.

Aggregation operations on fuzzy sets are operations by which several fuzzy sets are combined together in some way to produce a single representative either fuzzy or crisp set. Therefore, aggregation operation needs aggregation operator to deal with the situation where the aggregation operator is commonly tools that can be used to combine the individual preference information into overall preference information and deriving collective preference values for each alternative. That is to say, the information aggregation is to combine individual experts' preference coming from different sources into a unique representative value by using an appropriate aggregation technique [15]. Aggregation operations are used to rank the alternative decisions an expert or decision support system, which are established and applied in fuzzy logic systems. The information aggregation has received much attention from practitioners and researchers due to its practical and significance in academic [16][17][18][19][20][21].

The first overview of the aggregation operators in 2003 by Xu and Da [22]. The study is reviewed of the existing main aggregation operators and proposed some new aggregation operators that is induced ordered weighted geometric averaging (IOWGA) operator, generalized induced ordered weighted averaging (GIOWA) operator and hybrid weighted averaging (HWA) operator. In 2008, a review of aggregation functions which focus on some special classes of averaging, conjunctive and disjunctive is reviewed by Mesiar et al. [23]. Furthermore, Martinez and Acosta in 2015 [24] have made a review an aggregation operators taking into account of mathematical properties and behavioral measures such as disjunctive degree (orness), dispersion, balance operator, divergence instead of general mathematical properties whose verification might be desirable in certain cases: boundary condition, continuity, increasing, monotonicity etc. Since then, it is important to make a review of the aggregation operator which provide the latest method which will be used to solve the aggregation in MCDM. Obviously, there is no review paper on aggregation operator from year to year.

Our aim in this survey article is to provide an accessible overview of some key methods of aggregation in MCDM. We focus on development of type of aggregation methods that have attracted many researchers in this area without neglecting some technical details of the aggregation methods.

Throughout this survey, the terms aggregation function, aggregation operator, surveys on aggregation in MCDM, an overview of aggregation operation will refer to find the journal articles as well. The collected journals which is regarding the aggregation is retrieving from the various fields such as engineering, medical, operation research, image processing, selection problems, project management selection and etc.

This paper is structured as follows. Section 2 begins by laying out the various methods of aggregation since 2006 until now. Section 3 presents an analysis out of the survey. Section 4 suggests some works that can be extended as future research direction. The last chapter concludes.

2 Review of aggregation method

This chapter reviews aggregation methods that have been developed to aggregate information in order to choose a desirable solution, decision makers have to aggregate their preference information by means of some proper approaches. This review is made by analyzing the method used based on the journals and conference proceedings that are collected from selected popular academic databases such as SpringerLink, Scopus, ScienceDirect, IEEE Xplore Digital Library, ACM Digital Library, and Wiley Online Library from the year 2006 until the year 2016.

The class of aggregation is huge, making the problem of choosing the right method for a given application is a difficult one [25]. In this paper, we review the methods of aggregation and its various applications. Firstly, we segregate the aggregation methods by the basic ones which is the most often used aggregation operators. For example, the average (arithmetic mean), geometric mean and harmonic mean. Then, we proceed to the next aggregation operator by presenting a generalization of the classical one such as Bonferroni Mean (BM), power aggregation operator, fuzzy integral, hybrid aggregation operator, prioritized average operator and the linguistic aggregation operator [26].

2.1 Basic operators

2.1.1 Arithmetic mean operator

In real life decision situation, the aggregation problems in the MCDM are solved using the scoring techniques such as the weighted aggregation operator based on multi attribute theory. The classical weighted aggregation is usually known by the weighted average (WA) or simple additive weighting method. A very common aggregation operator is the ordered weighted averaging (OWA) operator which provides a parameterized family aggregation operator between the minimum, the maximum, the arithmetic average, and the median criteria whose originally introduced by Yager [27]. There are two features have been used to characterize the OWA operators. The first is the orness character and the second is the dispersion. The OWA has been widely used because of its ability to model linguistically expressed aggregation. Since the OWA operator is coming out, the approach has been employed by the most authors in a wide range of applications such as engineering, neural networks, data mining, decision making, and image processing as well as expert systems [28]. However, OWA operator was assumed that the available information includes crisp number or singletons. In the real decision making situation, it is found this may not be the crisp number. Sometimes, the available information is vague or imprecise and it is not possible to analyze it with the crisp numbers. Then, it is necessary to use another approach that is able to represent the uncertainty such as the use of fuzzy numbers (FNs). With the use of FNs, it is possible to analyze the real situation into the fuzzy value. Here is the definition of OWA.

Definition 1: An OWA operator of dimension n is a mapping OWA: $R^n \to R$ that has associated weighting vector w of dimension n with $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$, such that [27]:

$$\mathrm{OWA}\left(a_1, a_2, ..., a_n\right) = \sum_{j=1}^{n} w_j b_j$$

where b_j is the j th largest of the a_i.

There are some of the authors that being used OWA as aggregation operators such that Xu [29] developed the intuitionistic fuzzy ordered weighted averaging (IFOWA) operator, and the intuitionistic fuzzy hybrid averaging (IFHA) operator. Xu and Chen [30] investigated the interval-valued intuitionistic fuzzy multi-criteria group decision making based on arithmetic aggregation operators such as the interval-valued intuitionistic fuzzy weighted arithmetic aggregation (IIFWA) operator, the interval-valued intuitionistic fuzzy ordered weighted aggregation (IIFOWA) operator and the interval-valued intuitionistic fuzzy hybrid aggregation (IIFHA) operator.

Li and Li [31][32] developed the generalized OWA operators using IFSs to solve MADM in which weights and ratings of alternatives on attributes are expressed in IFS. Chang et al. and Merigo et al. [33][34]proposed the fuzzy generalized ordered weighted averaging (FGOWA) operator as it is an extension of the GOWA operator for the uncertain situation where the information given is in the form of fuzzy numbers. Zhao et al. [35] developed some new generalized aggregation operators such as generalized intuitionistic fuzzy weighted averaging (GIFWA) operator, generalized intuitionistic fuzzy ordered weighted averaging (GIFOWA) operator, generalized intuitionistic fuzzy hybrid averaging (GIFHA) operator, generalized interval-valued intuitionistic fuzzy weighted averaging (GIIFWA) operator, generalized interval-valued intuitionistic fuzzy hybrid average (GIIFHA) operator where the proposed method is the extension of the GOWA operators taking into account of the characterization both of intuitionistic fuzzy sets by a membership function and non membership function and interval-valued intuitionistic fuzzy sets whose fundamental characteristic is the values of its membership function is represented by the interval numbers rather than exact numbers.

Shen et al. [36] presented a new arithmetic aggregation operator which is induced intuitionistic trapezoidal fuzzy ordered weighting aggregation operator and applied to group decision making. Furthermore, in 2011, Casanovas et al. [37] introduced the uncertain induced probabilistic ordered weighted averaging weighted averaging (UIPOWAWA) operator where it provides a parameterized family of aggregation operators between minimum and maximum in a unified framework between probability, the weighted average and the induced ordered weighted averaging (IOWA) operator. Merigo [38] developed a new aggregation model that unifies the weighted average (WA) and the induced ordered weighted average (IOWA) operator that is called induced ordered weighted averaging-weighted average (IOWAWA) operator by considering the degree of importance that each concept has in the aggregation.

Xu and Wang [39] proposed a new aggregation operator which calling induced generalized intuitionistic fuzzy ordered weighted averaging (I-GIFOWA) operator by considering the characteristics of both the generalized IFOWA and the induced IFOWA operator. In order to deal with the intuitionistic fuzzy preference information in group decision making, the induced generalized intuitionistic fuzzy ordered weighted averaging (I-GIFOWA) operator based on GIFOWA and the I-IFOWA operator. Yu [40] introduced generalized intuitionistic trapezoidal fuzzy weighted averaging operator to aggregate the intuitionistic trapezoidal fuzzy information. Xia et al. [41] proposed several new hesitant fuzzy aggregation operators by extending quasi-arithmetic means to hesitant fuzzy sets under group decision making. Zhou et al. [42] introduced a new operator for aggregating the interval-valued intuitionistic fuzzy values which called the continuous interval-valued intuitionistic fuzzy ordered weighted averaging (C-IVIFOWA) operator. Both intuitionistic fuzzy ordered weighted averaging (IFOWA) operator and the continuous ordered weighted averaging (C-OWA) operator has combined to control the parameter and employed to diminish the fuzziness and improve the preciseness of the decision making.

2.1.2 Geometric mean operator

The geometric mean operator is the traditional aggregation operator that proposed to aggregate information given on a ratio scale measurement in MCDM models. The main characteristics are its guaranties the reciprocity property of the multiplicative preference relations used to provide ratio preferences [43].

Definition 2: An OWG operator of dimension n is a mapping OWG: $R^{+n} \rightarrow R^{+}$ that has associated weighting vector $w=\left(w^1, w^2,\ldots, w^n\right)^T$ with $w_j > 0$ and $\sum_{j=1}^{n} w_j = 1$, such that [43]:

$$\mathrm{OWG_w}\left(a_1, a_2,\ldots, a_n\right)=\prod_{j=1}^{n} b_j^{w_j}$$

where b_j is the j th largest of the $a_j\left(j=1,2,\ldots,n\right)$.

Some authors used geometric mean as aggregation operator. For example, Wu et al. [44] defined same families of geometric aggregation operators to aggregate trapezoidal IFNs (TrIFNs). Xu and Yager [45], Xu and Chen [46], Wei [47], Das et al. [48] developed some geometric aggregation operators based on IFS, such as intuitionistic fuzzy weighted geometric (IFWG) operator, intuitionistic fuzzy ordered weighted geometric (IFOWG) operator and intuitionistic fuzzy hybrid geometric (IFHG) operator. Tan [49] developed a generalized intuitionistic fuzzy geometric aggregation operator for multiple criteria decision making by considering the interdependent or interactive characteristics and preferences.

Wei [50], Xu [51] and Xu and Chen [52] proposed approach based on interval-valued intuitionistic fuzzy weighted geometric (IIFWG) operator, the interval-valued intuitionistic fuzzy ordered weighted geometric (IIFOWG) operator and the interval-valued intuitionistic fuzzy hybrid geometric (IIFHG) operator in different point of view. Verma and Sharma [53] proposed geometric Heronian mean (GHM) under hesitant fuzzy environment by developing some new GHM such that hesitant fuzzy generalized geometric Herinian mean (HFGGHM) operator and weighted hesitant fuzzy generalized geometric Herinian mean (WHFGGHM) operator.

2.1.3 Harmonic mean operator

Harmonic mean is the reciprocal of the arithmetic mean of reciprocal which is a conservative average to be used to provide for aggregation lying between the max and min operators and is widely used as a tool to aggregate central tendency data which is usually expressed in exact numerical values [54].

Definition 3: An ordered weighted harmonic mean operator of dimension n is a mapping OWHM: $R^n \rightarrow R$ that has associated weighting vector $w=\left(w_1, w_2,\ldots, w_n\right)^T$ with $w_j > 0$ and $\sum_{j=1}^{n} w_j = 1$, such that [54]:

$$\mathrm{OWHM_w}\left(a_1, a_2,\ldots, a_n\right)=\frac{1}{\sum_{j=1}^{n} \frac{w_j}{a_{\sigma(j)}}}$$

where $(\sigma(1), \sigma(2), \ldots \sigma(n))$ is a permutation of $(1,2,\ldots,n)$, such that $\alpha_{\sigma(j-1)} \geq \alpha_{\sigma(j)}$ for all $j=2,\ldots,n$.

Some researchers proposed harmonic mean as a method to solve aggregation in the decision making problem. For example, Xu [55] developed some fuzzy harmonic mean operators, such as fuzzy weighted harmonic mean (FWHM) operator, fuzzy ordered weighted harmonic mean (FOWHM) operator, fuzzy hybrid harmonic mean (FHHM) operator. The aim of this paper is to extend the induced ordered weighted harmonic mean (IOWHM) operator to fuzzy environment and propose a new operator called the fuzzy induced ordered weighted harmonic mean (FIOWHM) operator.

Wei and Yi [56] proposed an aggregation operator including trapezoidal fuzzy ordered weighted harmonic averaging (ITFOWHA) operator and applied to the decision making.

Wei [57] proposed a new aggregation operator called fuzzy induced ordered weighted harmonic mean (FIOWHM) for fuzzy multi criteria group decision making. Zhou et al. [58] proposed the generalized hesitant fuzzy harmonic mean operators including the generalized hesitant fuzzy weighted harmonic mean operator (GHFWHM), the generalized hesitant fuzzy ordered weighted harmonic mean operator (GHFOWHM), the generalized hesitant fuzzy hybrid harmonic mean operator (GHFHHM) using the technique of obtaining values in the interval to the group decision making under hesitant fuzzy environment.

Liu et al. [59] proposed a generalized interval-valued trapezoidal fuzzy numbers (GIVFTN) is an extended of ordered weighted harmonic averaging operators to solve the problems in multiple attribute group decision making.

2.2 Bonferroni mean (BM)

The Bonferroni mean (BM) originally introduced by Bonferroni [60]. The classical Bonferroni mean is an extension of the arithmetic mean and its generalized by some researchers based on the idea of the geometric mean [61]. The BM is differ from the other classic means such as the arithmetic, the geometric and the harmonic because this mean reflect the interdependent of the individual criterion meanwhile on the classic means the individual criterion is independent [62]. The BM was originally introduced by Bonferroni [60], which was defined as follows:

Definition 4: Let $p, q \geq 0$, and $a_i(i = 1,2,...,n)$ be a collection of nonnegative numbers. If

$$B^{p,q}(a_1, a_2, ..., a_n) = \left(\frac{1}{n(n-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{n} a_i^p a_j^q \right)^{\frac{1}{p+q}}$$

Then $B^{p,q}$ is called the Bonferroni mean (BM).

The Bonferroni mean (BM) operator is suitable for aggregating crisp data and can capture the expressed interrelationships among criteria, which plays a crucial role in multi-criteria decision making problems [63]. Since the BM introduced, this aggregation operator has received much attention from researchers and practitioners. Among them are, Yager [64] generalized the BM for enhancing its model capability and further Xu and Yager [65] developed intuitionistic fuzzy BM (IFBM) and applied the weighted IFBM to multi criteria decision making. Beliakov et al. [66] gave a systematic investigation of a family of composing aggregation functions which generalize the Bonferroni Mean (BM).

Zhu et al. [67] explored the geometric Bonferroni mean (GBM) by considering both BM and the geometric mean (GM) under hesitant fuzzy environment. Xia et al. [68] developed the Bonferroni geometric mean, which is a generalization of the Bonferroni mean and geometric mean and can reflect the interrelationships among the aggregated arguments. Wei et al. [69] developed two aggregation operators called the uncertain linguistic Bonferroni mean (ULBM) operator and the uncertain linguistic geometric Bonferroni mean (ULGBM) operator for aggregating the uncertain linguistic information in the multiple attribute decision making (MADM) problems. Park and Park [70] extend the works Sun and Sun [61] by considering the interactions of any three aggregated arguments instead of any two to develop generalized fuzzy weighted Bonferroni harmonic mean (GFWBHM) operator and generalized fuzzy ordered weighted Bonferroni harmonic mean (GFOWBHM) operator. Verma [71] proposed a new generalized Bonferroni mean operator called generalized fuzzy number intuitionistic fuzzy weighted Bonferroni mean (GFNIFWBM) operator which is able to aggregate the fuzzy number intuitionistic fuzzy correlated information.

2.3 Power aggregation operators

Yager [17] was first introduced a power average (PA) operator which uses a non-linear weighted average aggregation tool and a power ordered weighted average (POWA) operator to provide aggregation tools which allow exact arguments to support each other in the aggregation process. The weighting vectors of the PA operator and the POWA operator depend on the input arguments and allow arguments being aggregated to support and reinforce each other. In contrast with most aggregation operators, the PA and POWA operators incorporate information regarding the relationship between the values being combined. Recently, these operators have received much attention in the literature.

Definition 5: The power average (PA) operator is mapping PA: $R^n \rightarrow R$ defined by the following formula [17]:

$$PA(a_i | i = 1,2,...n) = \frac{\sum_{i=1}^{n} (1 + T(a_i)) a_i}{\sum_{i=1}^{n} (1 + T(a_i))}$$

where $T(a_i) = \sum_{\substack{j=1 \\ j \neq i}}^{n} Sup(a_i, a_j)$

and $Sup(a_i, a_j)$ is the support for a_i from a_j. The support satisfies the following three properties:

(1) $Sup(a_i, a_j) \in [0,1]$;

(2) $Sup(a_i, a_j) = Sup(a_j, a_i)$;

(3) $Sup(a_i, a_j) \geq Sup(a_s, a_t)$ if $|a_i - a_j| < |a_s - a_t|$

Motivated by the success of the PA and POWA, Xu and Yager [72] proposed a power geometric average (PG) operator and a power ordered weighted average (POWGA) operator. Besides that, power aggregation operators have been further extended to accommodate multi attribute group decision making (MAGDM) under different uncertain environments. For instance, Xu and Cai [73] developed the uncertain power ordered weighted average (UPOWA) operator on the basis of the PA operator and the UOWA operator, Xu [74] introduced the uncertain ordered weighted geometric average (UOWGA) operator based on the PG operator and the UOWA operator.

Xu [75] under intuitionistic fuzzy and interval-valued intuitionistic fuzzy decision making environments, the linguistic power aggregation operators by Zhou et al. [76], generalized argument-dependent power operators by Zhou and Chen [15] to accommodate intuitionistic fuzzy preferences and power aggregation operators under interval-valued dual hesitant fuzzy linguistic environment and the power aggregation operators by Wan [77] under trapezoidal intuitionistic fuzzy decision making environments.

Zhang [78] developed a wide range of hesitant fuzzy power aggregation operators for hesitant fuzzy information such as the hesitant fuzzy power average (HFPA) operators, the hesitant power geometric (HFPG) operators, the generalized hesitant fuzzy power average (GHFPA) operators, the generalized hesitant fuzzy power geometric (GHFPG) operators, the weighted generalized hesitant fuzzy power average (WGHFPA) operators, the generalized hesitant fuzzy power geometric (WGHFPG) operators, the hesitant fuzzy power ordered weighted average (HFPOWA) operators, the hesitant fuzzy power ordered weighted geometric (HFPOWG) operators, the generalized hesitant fuzzy power ordered weighted average (GHPOWA) operators and the generalized hesitant fuzzy power ordered weighted geometric (GHPOWG) operators.

However, the arguments of these power aggregation operators are exact numbers. In practice, we often confront situations in which the input arguments cannot be expressed in the form of exact numerical values instead, they have to take in the form of interval numbers Qi et al. [79], intuitionistic fuzzy numbers (IFNs) [80][81][82], interval-valued intuitionistic fuzzy numbers (IVIFNs) [83], linguistic variables [84][85][86], uncertain linguistic variables [67][87], or 2-tuples [88], hesitant fuzzy sets (HFS) [81]. Gou et al. [81] developed a family of hesitant fuzzy power aggregation operators, for instance the hesitant fuzzy power weighted average (HFPWA), hesitant fuzzy power weighted geometric (HFPWG) generalized hesitant fuzzy power weighted average (GHFPWA), generalized hesitant fuzzy power weighted geometric (GHFPWG) operators for multi-criteria group decision making problems.

Wang et al. [88] proposed a dual hesitant fuzzy power aggregation operators based on Archimedean t-conorm and t-norm for dual hesitant fuzzy information. Das and Guha [89] proposed some new aggregation operators such as trapezoidal intuitionistic fuzzy weighted power harmonic mean (TrIFWPHM) operator, trapezoidal intuitionistic fuzzy ordered weighted power harmonic mean (TrIFOWPHM) operator, trapezoidal intuitionistic fuzzy induced ordered weighted power harmonic mean (TrIFIOWPHM) operator and trapezoidal intuitionistic fuzzy hybrid power harmonic mean (TrIFhPHM) operator to aggregate the decision information.

2.4 Fuzzy integral

Another types of aggregation operators is fuzzy integrals (FI). There are many types of FI, and most of the well-known fuzzy integral are Choquet and Sugeno integral.

2.4.1 Choquet integral

One of the popular aggregation operator fuzzy integrals is the Choquet integral which is introduced by Choquet [90]. Choquet integral is defined as a subadditive or superadditive to integrate functions with respect to the fuzzy measures [91].

Definition 6. Let f be a real-valued function on X, the Choquet integral of f with respect to a fuzzy measure g on X is defined as [90]:

$$(C)\int f dg = \sum_{i=-1}^{n}\left[f(x_{(i)}) - f(x_{(i-1)})\right] g(A_{(i)}) \quad (1)$$

or equally by

$$(C)\int f dg = \sum_{i=-1}^{n}\left[g(A_{(i)}) - g(A_{(i+1)})\right] f(x_{(i)}) \quad (2)$$

where the parentheses used for indices represent a permutation on X such that $f(x_{(1)}) \leq \cdots \leq f(x_{(n)})$, $f(x_{(0)}) = 0$, $A_{(i)} = \{x_{(i)}, \ldots, x_{(n)}\}$, and $A_{(n+1)} = \phi$.

The Choquet integral is a very useful way of measuring the expected utility of an uncertain event

[92]. It is a tool to model the interdependence or correlation among different elements where a new aggregation operators can be defined. Choquet integral has been proposed by many authors as an adequate aggregation operator that extends the weighted arithmetic mean or OWA operator by taking into consideration the interactions among the criteria.

Yager [93] extended the idea of order induced aggregation to the Choquet aggregation and introduced the Choquet ordered averaging (I-COA) operator. Mayer and Roubens [94] aggregated the fuzzy numbers through the Choquet integral. In the other field, Hlinena et al. [95] used Choquet integral with respect to Lukasiewicz filters to present a partial solution to look for an appropriate utility function in a given setting. Ming-Lang et al. [96] proposed analytic network process (ANP) technique to get the relationships of feedback of criteria and Choquet integral is used to eliminate the interactivity of the expert subjective judgment problem and apply in the case study of selection of optimal supplier in supply chain management strategy (SCMS).

Buyukozkan and Ruan [97] proposed a two-addative Choquet integral to the software development experts and managers to enable them to position their projects in terms of associated risks. Murofushi and Sugeno [91] used the Choquet integral to propose the interval-valued intuitionistic fuzzy correlated averaging operator and interval-valued intuitionistic fuzzy correlated geometric operator to aggregate interval-valued intuitionistic fuzzy information and applied them to a practical decision making problem. Angilella et al. [98] proposed a non-additive robust ordinal regression on a set of alternatives by evaluating the utility in terms of Choquet integral which represent the interaction among thecriteria modelled by the fuzzy measure. Huang et al. [99] applied a generalized Choquet integral with a signed fuzzy measure based on the complexity to evaluate the overall satisfaction of the patients.

Demirel et al. [100] proposed generalization Choquet integral by taking consideration of information fusion between criteria and linguistic terms and fuzzy ANP as a fuzzy measure which can handle the dependent criteria and hierarchical problem structure and applied to the multi-criteria warehouse location.

Tan and Chen [101] proposed intuitionistic fuzzy Choquet integral based on t-norms and t-conorms meanwhile Tan [102] extended the TOPSIS method by combining the interval-valued intuitionistic fuzzy geometric aggregation operator with Choquet integral-based Hamming distance to deal with multi-criteria interval-valued intuitionistic fuzzy group decision making problems.

Bustince et al. [103] proposed a new MCDM method for interval-valued fuzzy preference relation which was based on the definition of interval-valued Choquet integrals. Yang and Chen [104] introduced some new aggregation operator including the 2-tuple correlated averaging operator, the 2-tuple correlated geometric operator and the generalized 2-tuple correlated averaging operator based on the Choquet integral. Belles-sampera [10] developed the extensions of the degree of balance, the divergence, the variance indicator and Renyi entropies to characterize the Choquet integral.

Islam et al. [105] proposed Choquet integral using goal programming to multi-criteria based learning which combines both experts' knowledge and data.

In addition, Choquet integral is applied in the hesitant fuzzy environment. Some authors that used the Choquet integral in the hesitant fuzzy environment are Yu et al. [106], Xia et al. [40]. For example, Yu et al. [106] proposed Choquet integral aggregation operator for hesitant fuzzy elements (HFEs) and applied it to the MCDM problems, Xia et al. [40] applied the Choquet integral to get the weights of criteria for group decision making, Peng et al. [107] proposed Choquet integral methods which is an approach to multi-criteria group decision making (MCGDM) problem to rank the alternatives where the criteria are interdependent or interactive. Wang et al. [108] developed some Choquet integral aggregation operators with interval 2-tuple linguistic information and applied them to MCGDM problems.

2.4.2 Sugeno integral

Sugeno integral is one of the fuzzy integral which introduced by M. Sugeno in the year of 1974 [109]. Sugeno integral is proposed to compute an average value of some function with respect to a fuzzy measure. In particular, the Sugeno integral uses only weighted maximum and minimum functions [16]. The definition of Sugeno integral [109] as follows:

Definition 7: The (discrete) Sugeno Integral of a function $f : X \to [0,1]$ with respect to μ is defined as

$$\int f(x)d\mu = \max_{1\le i\le n}\left(\min\left(f(x_i), \mu(A_i)\right)\right)$$

where $\{f(x_1), f(x_2), f(x_3), ..., f(x_n)\}$ are the ranges and they are defined as $f(x_1) \le f(x_2) \le f(x_3) \le .... \le f(x_n)$.

In recent years, some authors and practitioners that used Sugeno integral are Mendoza and Melin [110], Liu et al. [111], Tabakov and Podhorska [112], Dubois et al. [113].

Mendoza and Melin [110] extended the Sugeno integral with the interval type-2 fuzzy logic. The generalization composed the modifying the original equations of the Sugeno measures and Sugeno integral. This method is used to combine the simulation vectors into only one vector and lastly the system will be decided the best choice of recognition in the same manner than made with only one monolithic neural network, but the problem of complexity resolved.

Liu et al. [111] extended the componentwise decomposition theorem of lattice-valued Sugeno integral by introducing the concept of interval fuzzy-valued, intuitionistic fuzzy-valued and interval intuitionistic fuzzy-valued Sugeno integral. As a result, the intuitionistic fuzzy-valued Sugeno integrals and the interval fuzzy-valued Sugeno integrals are mathematically equivalent. It shows that the interval intuitionistic fuzzy-valued Sugeno integral can be decomposed into the interval fuzzy-valued and intuitionistic fuzzy-valued Sugeno integrals or the original Sugeno integrals.

Tabakov and Podhorska [112] proposed fuzzy Sugeno integral as an aggregation operator of an ensemble of fuzzy decision trees in order to classify the corresponding HER-2/neu classes. They used three different fuzzy decision trees which are built over different image characteristics, colour values and structural factors and texture information. The fuzzy Sugeno integral has been used as an aggregation operator to design fuzzy trees and the final medical decision support information generated.

Dubois et al. [113] proposed two new variants of weighted minimum and maximum where the criteria weights play an important role of tolerance. The Sugeno integral is proposed to the residuated counterparts, which means, the weight support on subsets of criteria. Then, the dual aggregation operations called disintegrals are evaluated in terms of its defects rather than in terms of its positive features proposed. The maximal disintegral is when no defects at all are present and maximal integral when all the merits are sufficiently present.

2.5 Hybrid aggregation operators

The hybrid aggregation operator has been proposed by several authors. It is important to propose more than one aggregation operator so that a wide range of fuzzy aggregation operators can be used in a wide range of application in decision making problems. For instance, Jianqiang and Zhong [114] developed the intuitionistic trapezoidal weighted average arithmetic average operator and the intuitionistic trapezoidal weighted geometric average operator.

Zhang and Liu [115] proposed the weighted arithmetic averaging operator and the weighted geometric average operator to aggregate triangular fuzzy intuitionistic fuzzy information and applied it to the decision making problem.

Then, Merigo and Casanovas [116] proposed fuzzy generalized hybrid aggregation operators where further generalize the fuzzy geometric hybrid averaging (FGHA) and the fuzzy induced geometric hybrid average (FIGHA) by using quasi-arithmetic means and the new result are Quasi-FHA and the Quasi-FIHA operator.

Xia and Xu [117] first proposed fuzzy weighted averaging (HFWA), hesitant fuzzy weighted geometric (HFWG) operators, generalized hesitant fuzzy weighted averaging (GHFWA), generalized hesitant fuzzy weighted geometric (GHFWG) operators in solving decision making problems.

Yu et al. [118] proposed the interval-valued intuitionistic fuzzy prioritized weighted average (IVIFPWA) operator and interval-valued intuitionistic fuzzy prioritized weighted geometric (IVIFPWG) operator to aggregate the IVIFNs.

Verma and Sharma [119] developed some prioritized weighted aggregation operators for aggregating trapezoid fuzzy linguistic information motivated by the idea of prioritized weighted average introduced by Yager [122] such that the trapezoid linguistic prioritized weighted average (TFLPWA) operator, the trapezoid linguistic prioritized weighted geometric (TFLWG), and the trapezoid linguistic prioritized weighted harmonic (TFLWH) operator.

Liao and Xu [120] introduced some new aggregation operators including the generalized hesitant fuzzy hybrid weighted averaging operator, the generalized hesitant fuzzy hybrid weighted geometric operator, and the generalized quasi hesitant fuzzy hybrid weighted geometric operator and their induced forms.

In 2016, Verma [121] proposed a new aggregation operator that based on the generalization of mean called generalized trapezoid fuzzy linguistic prioritized weighted average (GTFLPWA) operator for fusing the trapezoid fuzzy linguistic information. The prominent characteristics of the proposed operator does not only take into account the prioritization among the attributes and decision makers but also has a flexible parameter.

2.6 Prioritized operator

Prioritized Average (PA) operator is one of the aggregation operators which has a great interest among scholars. In practical situations, decision-makers usually consider different criteria priorities. To deal with this issue, Yager [122] developed prioritized average (PA) operators by modeling the criteria priority on the weights associated with the criteria, which depend on the satisfaction of higher priority criteria. The PA operator has many advantages over other operators. For example, the PA operator does not need to provide weight vectors and, when using this operator, it is only necessary to know the priority among the criteria.

Wei [123] extended the prioritized aggregation operator to hesitant fuzzy sets and developed some prioritized hesitant fuzzy operators in multicriteria decision making. As Yager [122] only discussed the criteria values and weights in the real number domain, thus Wang et al. [124] developed some prioritized aggregation operators for aggregating interval-valued hesitant fuzzy linguistic information.

Recently, some researchers have focused on fuzzy prioritized aggregation operator into intuitionistic fuzzy sets (IFSs) such as Yu et al. [117], Chen [125] proposed some interval-valued intuitionistic fuzzy aggregation operators such as the interval-valued intuitionistic fuzzy prioritized weighted average (IVIFPWA) operator and the interval-valued intuitionistic fuzzy prioritized weighted geometric (IVIFPWG) operator, Verma and Sharma [126] proposed two new aggregation operators such as intuitionistic fuzzy Einstein prioritized weighted average (IFEPWA) operator and the intuitionistic fuzzy Einstein prioritized weighted geometric (IFEPWG) operator for aggregating intuitionistic fuzzy information meanwhile Liang et al. [127], Dong et al. [128] developed some new aggregation operator called generalized intuitionistic trapezoidal fuzzy prioritized weighted average operator and generalized intuitionistic trapezoidal fuzzy prioritized weighted geometric operator and apply to the multi-criteria group decision making. Verma and Sharma [129] also proposed two new prioritized aggregation operators for aggregate triangular fuzzy information called quasi fuzzy prioritized weighted average (QFPWA) operator and the quasi fuzzy prioritized weighted ordered weighted average (QFPWOWA) operator.

2.7 Linguistic aggregation operator

Often, human decision making is too complex or too weakly defined to be represented by the numerical analysis. It is always considered the available information is vague or imprecise and impossible to analyze it with numerical values. However, this may not represent the real situation found in the decision making problem. Therefore, the possible way to solve such situation, it is necessary to use a qualitative approach which is the linguistic variable to aggregate the fused information. The linguistic aggregation operators are offered when the situations of the information cannot be assessed with numerical values, but it is possible to use linguistic assessment [130]. There are some authors used the linguistic variables to aggregate the information in MCDM. For instance, Wang and Hao [131] presented a 2-tuple fuzzy linguistic evaluation model for selecting appropriate agile manufacturing system in relation to MC production. Herrera et al. [132] proposed a fuzzy linguistic methodology to deal with unbalanced linguistic term sets. Chang et al. [33] proposed a linguistic MCDM aggregation model to tackle to solve two problems which are the aggregation operators are usually independent of aggregation situation and there must be a feasible operator for dealing with the actual evaluation scores.

Xu and Chen [52] extended the well-known harmonic mean to represent the information in the linguistic situation and developed some linguistic harmonic mean aggregation operators such as the linguistic weighted harmonic mean (LWHM) operator, the linguistic ordered weighted harmonic mean (LOWHM) operator, and the linguistic hybrid harmonic mean (LHHM) operator for aggregating linguistic information.

Wei [133] proposed a method for multiple attribute group decision making based on the ET-WG and ET-OWG operators with 2-tuple linguistic information. Shen et al. [36] developed the belief structure-linguistic ordered weighted averaging (BS-LOWA), the BS linguistic hybrid averaging (BS-LHA) and a wide range of particular cases. Wei [130] extended the TOPSIS method for 2-tuple linguistic multiple attribute group decision making with incomplete weight information. Then, Merigo et al. [130] developed linguistic weighted generalized mean (LWGM) and the linguistic generalized OWA (LGOWA) operator and applied to the decision making problems.

Besides that, there are some authors that used 2-tuple linguistic variables such as Wei [134] proposed the GRA-based linear programming methodology for multiple attribute group decision making with 2-tuple linguistic assessment information. Wei [135] utilized the gray relational analysis method for 2-tuple linguistic multiple attribute group decision making with incomplete weight information. Xu and Wang [136] developed some 2-tuple linguistic power aggregation operators. Wei [137] proposed some new aggregation operators which is the 2-tuple linguistic weighted harmonic averaging (TWHA), 2-tuple linguistic ordered weighted harmonic averaging (TOWHA) and 2-tuple linguistic combined weighted harmonic averaging (TCWHA) operators for multiple attribute group decision making. Zadeh [83] developed some new linguistic aggregation operators such as 2-tuple linguistic harmonic (2TLH) operator, 2-tuple linguistic weighted harmonic (2TLWH) operator, 2-tuple linguistic ordered weighted harmonic (2TLOWH) operator and 2-tuple linguistic hybrid harmonic (2TLHH) operator to utilize to aggregate preference information considering linguistic variables in the decision making problem. Then, Li et al. [138] developed a new multiple attribute decision making approach for dealing with 2-tuple linguistic variable based on induced aggregation operators and distance measure by presenting 2-tuple linguistic induced generalized ordered weighted averaging distance (2LIGOWAD) operator which extension of the induced generalized ordered weighted distance (IGWOD) with 2-tuple linguistic variables. The 2LIGOWAD basically uses the IOWA operator represented in the form of 2-tuple linguistic variables.

Furthermore, Liu and Jin [139] introduced operational laws, expected value definitions, score functions and accuracy functions of intuitionistic uncertain linguistic variables and proposed two approaches with intuitionistic uncertain linguistic information to the weighted geometric average (IULWGA) operator and ordered weighted geometric (IULOWG) operator for multi attribute group decision making.

3 Observation

Throughout this study, hundred three journal articles have been reviewed with different aggregation methods within 2006 until 2016 searching via IEEE explore, Science Direct, Springer Link and Wiley online Library. In this paper, the methods and applications of aggregation are discussed in various fields. Based on the Table 1, the most popular aggregation operator is Choquet integral which is 17.48%, then it follows by linguistic aggregation operator (15.53%), arithmetic average operator

(14.74%), power aggregation operator and geometric mean operator (9.71%) respectively, prioritized aggregation operator (8.74), Benferroni Mean and Hybrid aggregation operator (7.77%), harmonic mean (4.85%) and Sugeno integral (3.88%). The details of the percentage are shown in the Figure 1.

Table 1: Numbers and percentage of the aggregation methods.

Aggregation Methods	No. of Authors	Percentage (%)
Arithmetic Mean	15	14.56
Geometric Mean	10	9.71
Harmonic Mean	5	4.85
Bonferroni Mean (BM)	8	7.77
Power	10	9.71
Choquet Integral	18	17.48
Sugeno Integral	4	3.88
Hybrid	8	7.77
Prioritized	9	8.74
Linguistic	16	15.53
Total	103	100

Based on the Table 1 and Figure 1, the Choquet integral have attracted more attention because it is usually known in the literature as a flexible aggregation operator and it is a generalization of the weighted average (WA) or simple additive weighting method, the ordered weighted average, and the max-min operator [130].

In addition, the Choquet integral is the appropriate tool to solve the interactions among the criteria in decision making problem as the traditional multi-criteria decision making (MCDM) methods are based on the additive concept along with the independence assumption where, in fact, each individual criterion is not completely independent [95].

Furthermore, the aggregation operator based on the linguistic variable has received considerable attention too. The linguistic information is used when the information available is vague or imprecise, but unable to analyze it using numerical values [131].

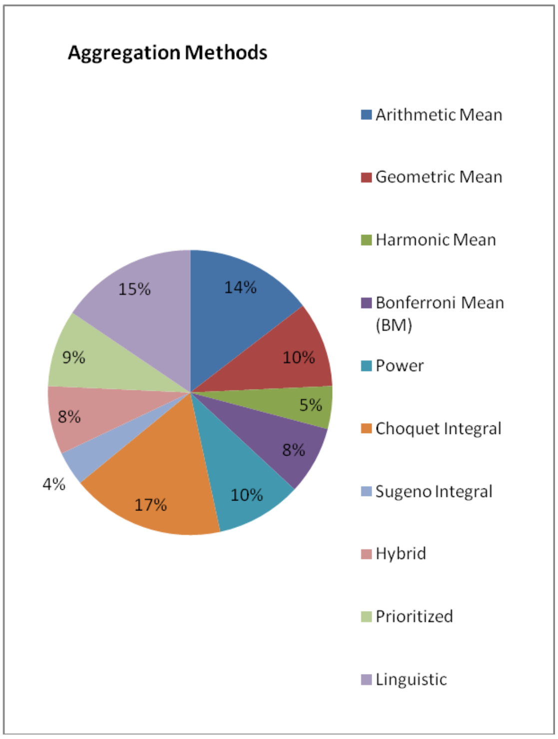

Figure 1: Percentage of aggregation methods.

Other than that, one of the conventional aggregation operators which is arithmetic mean also received attention from many scholars. They have been widely used because the first aggregation operator which introduced by Yager in 1988 is OWA which provide parameterized the arithmetic mean. Then, it is easy to compute. Since then, many researchers have developed aggregation operator that based on the arithmetic since because it is practical in the decision making problem.

Besides that, there are many aggregation operators used in the decision making problem depending on various kinds of factors investigated. For example, most of these operators, however, can only be used in situations where the input arguments are the exact values, and few of them can be used to aggregate the linguistic preference information.

4 Future work

From the observations, there are many types of aggregation operator that have been used by the researchers. Recently, the most appealing and great attention of researchers is Choquet integral because this method can represent the interaction between criteria, ranging from negative interaction to positive interaction. Even the classical of aggregation operator, power operator and linguistic variables have attracted numbers of researchers to apply to this field. It is suggested that the Choquet integral in order to build a more robust method and can be improved or extended by taking into account a weighted combination of both experts' knowledge and data. This suggestion is based on the only expert opinion can be overly subjective and may not result in desired performance.

The Choquet integral derives from the large numbers of coefficients $\left(2^{n}-2\right)$ associated with a fuzzy measure, however, this flexibility can drive to be a serious drawback, especially when assigning real values to the importance of all possible combinations.

Further research could be further in selecting the fuzzy measure to the Choquet integral. It is because different fuzzy measure will be impacted to the Choquet integral.

Since the linguistic aggregation operator shows more than fifty percent of overall, it is possible to further to the next phase. In the future, it may extend this approach to other situations that can be assessed with other linguistic approaches and introducing the new aspects in the formulation by integrating them with other types of aggregation operators.

The arithmetic aggregation operator also shows the highest percentage among other aggregation operator. It is expected to expand in the future by using a generalized aggregation operator, distance measures and unified aggregation operators. Moreover, it can be represented in the uncertain environment using fuzzy numbers and linguistic variables.

5 Conclusion

The main purpose of this study is to find the appropriate aggregation operator that is able to present aggregation by taking account the importance of the data that being fused.

In this paper, we have analyzed the method used based on the journals and conference proceedings that are collected from selected popular academic databases.

From the collected journal, we have separated them according to the method that being used by the authors. Each of the aggregation method has been presented in the percentage. See Table 1 and Figure 1 in section 3.

From the observation, most of the criteria of the classical and linguistic aggregation operator in decision-making methods mentioned above are assumed to be independent of one another, but in reality, the criteria of the problems are often interdependent or interactive. For real decision making problems, it does not need the assumption that criteria or preferences are independent of one another and was used to show as a powerful tool for modeling interaction phenomena in decision making [100]. Usually, there is interaction among preference of decision makers. This phenomenon is called correlated criteria.

In the real world of decision making problems, most criteria have interdependent, interactive or correlative characteristics. The interaction phenomena among criteria or the preference of experts is considered which is making it more feasible and practical than other traditional aggregation operator. In addition, it is not suitable for us to aggregate them by classical weighted arithmetic mean or geometric mean method which based on the additive measure. On the contrary, to approximate the human subjective decision making process, it would be more suitable to apply fuzzy measures, where it is not assuming additivity and independence among decision making criteria

To tackle this problem, Choquet integral is a powerful tool to solve the MCDM problems with correlated criteria. In the Choquet integral model, criteria can be interdependent, a fuzzy measure is used to define a weight on each combination of criteria, thus making it possible to model the interaction existing among the criteria. Besides that, Choquet integral which taking into account for correlated inputs may give a more accurate prediction of the users' rating. Furthermore, it is a very useful tool to measure the expected utility of an uncertain environment.

6 References

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