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Abstract

Purpose – The purpose of this paper is to develop a method for solving the multiple attribute decision-making (MADM) problem in which the decision maker can provide the five types of attribute aspirations, namely: benefit type with requirements; cost type with requirements; interval type; benefit type; and cost type.

Design/methodology/approach – First, for each type of attribute aspiration, the calculation formula of utility values of alternative concerning attributes is given. Then, using the calculation formulae, the attribute values are transformed into the corresponding utility values. On the basis of this, the overall ranking value of each alternative is calculated. Further, a ranking order of alternatives can be determined according to the obtained overall ranking values.

Findings – Research shows that it is necessary to develop the method for MADM with attribute aspirations. The example shows that the proposed method is applicable.

Practical implications – The proposed method can be applied to the selection of wastewater treatment technologies or other areas.

Originality/value – This paper proposes a new MADM method with multiple types of attribute aspirations. It develops and enriches the existing MADM methods.

Keywords Decision making, Management, Attribute aspiration, Multiple attribute decision making, Selection of wastewater treatment technologies

Paper type Research paper

1. Introduction

Multiple attribute decision making (MADM) refers to the problem of selecting alternatives associated with multiple attributes (Hwang and Yoon, 1981). It is a problem with wide backgrounds in practice (Cook and Kress, 1994; Ma *et al.*, 1999; Wang and Elhag, 2006; Onüt *et al.*, 2009; Krohling and de Souza, 2012; Liou, 2012; Li, 2013).

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In some practical MADM problems, the decision maker (DM) usually has the potential expectation or provides his/her aspiration-level with regard to each attribute (Matos, 1999; Prato, 1999; Kulak, 2005; Besharati *et al.*, 2006; Yan *et al.*, 2008; Liao, 2011; Fan *et al.*, 2013a). For example, the challenge in wastewater management is the selection of the most available wastewater treatment technology (Kalbar *et al.*, 2012). In the decision-making process for selection of an appropriate alternative among a finite set of available technologies for treating wastewater at a particular location, the DM may provide his/her aspiration-levels on the attributes (thereafter attribute aspirations) such as the life cycle costs, the manpower number requirement for operation and the flexibility of the system, etc. For example, the DM's aspirations on the life cycle costs would not be over $250,000 for one million liters per day (MLD), the manpower number requirement would better be in the range of 8-12, and the flexibility of the system would be the higher the better. Hence, in the situation that the DM provides the attribute aspirations, how to solve the MADM problem is a valuable research topic (Fan *et al.*, 2013a, b; Feng and Lai, 2014).

MADM problems with attribute aspirations have attracted the attentions of some scholars (Hwang and Yoon, 1981; Lotfi *et al.*, 1992; Nowak, 2004, 2006, 2007; Fan *et al.*, 2013a, b; Tan *et al.*, 2014; Liu *et al.*, 2014). Several methods for solving this kind of MADM problem have been found (Hwang and Yoon, 1981; Lotfi *et al.*, 1992; Nowak, 2007; Fan *et al.*, 2013a, b; Tan *et al.*, 2014; Liu *et al.*, 2014). The main thought of these methods is to find the desirable alternative(s) which can reach or be close to the DM's aspiration-levels as much as possible. For instance, Hwang and Yoon (1981) give the simple additive weighting (SAW) method and the TOPSIS method to solve the MADM problem, in which the benefit and cost type of attribute aspirations are considered, i.e., the DM expects the corresponding attribute values would be the larger the better for the benefit attributes, and the smaller the better for the cost attributes. Lotfi *et al.* (1992) develop an interactive method for finding the closest nondominated alternative, in which the benefit and cost type of attribute aspirations with requirements are considered, i.e., the DM expects each attribute value would better be over or under some certain number, and the aspiration-levels can be adjusted based on the feedback information. Nowak (2007) proposes an interactive method for solving the stochastic MADM problem, in which the benefit type of attribute aspirations with requirements is considered. In the method, some attribute aspirations can be adjusted to determine the desirable alternative(s) using stochastic dominance rules. Fan *et al.* (2013a, b) propose a method based on the prospect theory for solving the MADM problem, in which three types of attribute aspirations are considered, i.e., the benefit type with requirements, the cost type with requirements and the interval type. For the interval type, the DM expects that the attribute values would better be in the range of an interval. In the method, DM's attribute aspirations are viewed as the reference points according to the prospect theory. If an attribute value is over the reference point, the DM will be satisfied and the excess part can be regarded as his/her "gain"; if an attribute value is under the reference point, the DM will be disappointed and the lacking part can be regarded as his/her "loss." Tan *et al.* (2014) propose a method based on the prospect stochastic dominance for solving a discrete stochastic MADM problem, in which the benefit type of attribute aspirations with requirements is considered. Liu *et al.* (2014) propose a MADM method based on the DEMATEL-based ANP (DANP) and the modified VIKOR to solve the material selection problem, in which the benefit and cost type of attribute aspirations with requirements are considered and the attribute aspirations are interdependent.

The existing methods have made significant contributions to solving the MADM problems with attribute aspirations. Using these methods, the desirable alternative(s) can be determined to make one(s) reach or be close to the DM's aspiration-levels as much as possible. However, there are the strengths and weaknesses in the existing method, as shown in Table I. It is can be seen from Table I that in some existing methods, the computation processes are complicated (e.g. Lotfi *et al.*, 1992; Liu *et al.*, 2014), and the determinations of the parameters in the calculation formulae are difficult (e.g. Fan *et al.*, 2013a, b). Besides, the existing methods do not consider the DM's sensitivity that the attribute value exceeds or does not exceed the attribute aspiration. Also, the existing methods consider the situation of one, two or three types of attribute aspirations, but the situation of four or five types of attribute aspirations given by the DM often exists in some practical MADM problems. Therefore, it is necessary to further investigate the MADM problem with attribute aspirations, in which various types of attribute aspirations provided by the DM are considered. Simultaneously, it is also necessary to develop a simple method for solving the MADM problem.

This paper is to develop a new method for MADM with attribute aspirations. For simplicity, we only consider a general MADM problem, in which the five types of attribute aspirations are considered. The five types of attribute aspirations are: first, benefit type with requirements, i.e., "attribute value would better be over a number" (Mezias, 1988; Nowak, 2007; Yan *et al.*, 2008; Tan *et al.*, 2014); second, cost type with requirements, i.e., "attribute value would better not be over a number" (Nowak, 2004; Fan *et al.*, 2013a; Liu *et al.*, 2014); third, interval type, i.e., "attribute value would better be in the range of an interval" (Mezias, 1988; Yan *et al.*, 2008; Fan *et al.*, 2013a); fourth, benefit type, i.e., "attribute value would be the larger the better" (Hwang and Yoon, 1981); and fifth, cost type, i.e., "attribute value would be the smaller the better" (Hwang and Yoon, 1981). In the proposed method, first, for each type of attribute aspiration, the calculation formula of utility value of alternative concerning attributes is constructed. Then, the attribute values are transformed into the corresponding utility values using the calculation formulae. On the basis of this, the overall ranking value of each alternative is calculated. Further, a ranking of alternatives can be determined based on the obtained overall ranking values.

The remainder of this paper is organized as follows: Section 2 describes the MADM problem with multiple types of attribute aspirations. Section 3 gives the calculation formulae of the utility values of alternatives concerning attributes for the five types of attribute aspirations. Section 4 presents a method for ranking the alternatives. In Section 5, an example based on the background of wastewater treatment is given to illustrate the use of the proposed method. Finally, Section 6 summarizes and highlights the main contributions of the method proposed in the paper.

2. Description of the problem

The following assumptions or notations are used to represent the MADM problem with multiple types of attribute aspirations:

- $M = \{1, 2, \ldots, m\}$: a set of the number of alternatives, where m denotes the total number of alternatives.
- $N = \{1, 2, \ldots, n\}$: a set of the number of attributes, where n denotes the total number of attributes.
- $A = \{A_1, A_2, \ldots, A_m\}$: a set of m alternatives, where A_i denotes the ith alternative, $i \in M$.
- $C = \{C_1, C_2, \ldots, C_n\}$: a set of n attributes, where C_j denotes the jth attribute, $j \in N$.

Table I. The existing methods for MADM with attribute aspirations

The existing methods	Authors	Strengths	Weaknesses
The simple additive weighting (SAW) method	Hwang and Yoon (1981)	The attributes are classified into benefit and cost type, and the process of calculation of the method is simple	The benefit and cost attributes are not clearly regarded as the DM's aspiration-levels, and the other types of attribute aspirations are not considered
The TOPSIS method	Hwang and Yoon (1981)	The attributes are classified into benefit and cost type, and the positive and negative ideal points are introduced in the calculation process	The benefit and cost attributes are not clearly regarded as the DM's aspiration-levels, and the other types of attribute aspirations are not considered
The aspiration-level interactive method (AIM)	Lotfi *et al.* (1992)	The benefit and cost types of attribute aspirations with requirements are considered, and the DM's aspiration-levels can be adjusted based on the feedback information	The computation process is complicated and the other types of attribute aspirations are not considered
The interactive approach based on stochastic dominance	Nowak (2007)	The situation that attribute values are stochastic variables is considered and the aspiration-levels can be adjusted	Benefit type of attribute aspirations with requirements is only considered, but the other types are not considered
The method based on the prospect stochastic dominance	Tan *et al.* (2014)	The DM's attribute aspiration is viewed as the reference point, and the prospect stochastic dominance is used in MADM analysis	Benefit type of attribute aspirations with requirements is only considered, but the other types are not considered
The method based on the prospect theory	Fan *et al.* (2013a, b)	Benefit and cost type of attribute aspirations with requirements, and interval type are considered, and the prospect theory is used to solve the MADM problem with the attribute aspirations	It is difficult to determine the parameters in the calculation formulae, and the other types of attribute aspirations are not considered
The hybrid MCDM method combining DEMATEL-based ANP (DANP) and modified VIKOR	Liu *et al.* (2014)	The attributes are classified into the three types: benefit, cost and target. The benefit and cost type of attribute aspirations with requirements are considered, and the interdependences between the aspiration-levels are considered	The computation procedure of the method is complicated, and the other types of attribute aspirations are not considered

- $\boldsymbol{w} = (w_1, w_2, \ldots, w_n)^T$: a vector of attribute weights, where w_j denotes the weight of the jth attribute, $\sum_{j=1}^{n} w_j = 1$, $0 \leqslant w_j \leqslant 1$, $j \in N$. Usually, it can be obtained either directly by the assignment of the DM (Mulej, 2013) or indirectly using existing procedures such as AHP (Saaty, 1980).
- $\boldsymbol{D} = [d_{ij}]_{m \times n}$: a decision matrix, where d_{ij} denotes the consequence (attribute value) for alternative A_i concerning attribute C_j, $i \in M$, $j \in N$. To select the desirable alternative with DM's attribute aspirations, two types of decision attributes are considered in the decision process, i.e., quantitative and qualitative attributes. The values of quantitative attributes can be obtained from the quantitative data stored in the database, which are in the format of crisp number; while the values of qualitative attributes are obtained by the experts' evaluations such as scores or linguistic assessments, etc. (Feng and Lai, 2014).
- $E = \{E_I, E_{II}, E_{III}, E_{IV}, E_V\}$: a set of the types of attribute aspirations, where E_I, E_{II}, E_{III}, E_{IV} and E_V, respectively, represent the five types of attribute aspirations: benefit type with requirement, cost type with requirement, interval type, benefit type and cost type.
- $\overline{C} = \{C^I, C^{II}, C^{III}, C^{IV}, C^V\}$: a set of the attribute subsets, where C^I, C^{II}, C^{III}, C^{IV} and C^V represent the attribute subset with regard to E_I, E_{II}, E_{III}, E_{IV} and E_V, respectively, $C^I \cup C^{II} \cup C^{III} \cup C^{IV} \cup C^V = C$. Correspondingly, the subscripts sets of C^I, C^{II}, C^{III}, C^{IV} and C^V are N^I, N^{II}, N^{III}, N^{IV} and N^V, respectively, $N^I \cup N^{II} \cup N^{III} \cup N^{IV} \cup N^V = N$.

In the following, the five types of DM's attribute aspirations are expounded, respectively.

(1) Benefit type with requirements (E_I): for attribute C_j ($C_j \in C^I$), the DM desires that attribute value d_{ij} would better be over e'_j, where e'_j is the DM's aspiration-level with regard to C_j. For example, when selecting an appropriate wastewater treatment technology, the DM desires that the technological life time would better be over 40 years.

(2) Cost type with requirements (E_{II}): for attribute C_j ($C_j \in C^{II}$), the DM desires that attribute value d_{ij} would better not be over e''_j, where e''_j is the DM's aspiration-level with regard to C_j. For example, the DM desires that the average capital cost would better not be over \$120,000 when treating one million liters wastewater per day.

(3) Interval type (E_{III}): for attribute C_j ($C_j \in C^{III}$), the DM desires that attribute value d_{ij} would better be in the range of e_j^L to e_j^U, i.e., interval $[e_j^L, e_j^U]$, $e_j^U > e_j^L$, and any value in the interval $[e_j^L, e_j^U]$ is equally acceptable to the DM (Bordley and Kirkwood, 2004). Here, $[e_j^L, e_j^U]$ is the DM's aspiration-level with regard to C_j. For instance, the DM desires that the number of staffs required for operating a medium scale wastewater treatment plant would better be in the range of 8-12.

(4) Benefit type (E_{IV}): for attribute C_j ($C_j \in C^{IV}$), the DM desires that attribute value d_{ij} would be the greater (or higher) the better, i.e., the greater d_{ij} is, the higher DM's satisfaction degree will be. For example, the DM may desire that the sustainability of a wastewater treatment system would be the higher the better.

(5) Cost type (E_V): for attribute C_j ($C_j \in C^V$), the DM desires that attribute value d_{ij} would be the smaller (or lower) the better, i.e., the smaller d_{ij} is, the higher DM's satisfaction degree will be. For example, the DM may desire that the probability of mechanical failures during the operation phase of wastewater treatment technology would be the lower the better.

In summary, in the situation of the attribute aspirations provided by the DM, the problem addressed in this paper is how to rank alternatives or to select the most desirable alternative(s) from the finite set A using decision matrix $\boldsymbol{D}$, attribute aspiration vector and attribute weight vector $\boldsymbol{w}$.

3. Calculation of the utility values for different types of attribute aspirations

When the DM provides his/her aspiration-level on an attribute, whether the attribute value reaches the aspiration-level is concerned. Thus, it is necessary to construct a utility function to measure the degree that the attribute value reaches the aspiration-level. Using the utility functions, attribute values can be transformed into the utility values concerning each attribute aspiration. Here, each utility value can be regarded as the satisfaction or disappointment degree with respect to the DM's aspiration-levels. Usually, the greater the utility value is, the higher the DM's satisfaction degree or the lower the DM's disappointment degree will be.

In the following, utility functions for the five types of attribute aspirations are described, respectively.

3.1 Calculation of utility value for the attribute aspiration type E_I

The attribute aspiration type E_I refers to that the attribute value d_{ij} would better be over the aspiration-level e'_j for the attribute C_j ($C_j \in C^I$). There are the three possible results for comparing d_{ij} with e'_j. If $d_{ij} < e'_j$, then the part that d_{ij} is over e'_j, i.e., $d_{ij}-e'_j$, can be regarded as DM's "elation." The larger the excess part is, the higher the DM's satisfaction degree will be. For this case, we may think that the corresponding utility value is greater than 0. If $d_{ij} = e'_j$, then the corresponding utility value is 0. If $d_{ij} < e'_j$, then e'_j-d_{ij} can be regarded as DM's "disappointment," and the corresponding utility value is less than 0.

Based on the above analysis, let x denote a variable for attribute value, then the utility function for the type E_I, $u^I(x)$, can be built, i.e.:

$$u^I(x) = \begin{cases} \left(\frac{x-e'_j}{d_j^{\max}-e'_j}\right)^{\alpha 1}, & x > e'_j, \\ 0, & x = e'_j, \quad j \in N^I, \\ -\left(\frac{e'_j-x}{e'_j-d_j^{\min}}\right)^{\beta 1}, & x < e'_j, \end{cases} \tag{1}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $\alpha_1 > 0$ and $\beta_1 > 0$. α_1 and β_1 are the coefficients determining the concavity and convexity of the utility function. The utility function $u^I(x)$ represented by Equation (1) is presented graphically in Figure 1. For the value range of α_1, there are the three situations, i.e., first, if $0 < \alpha_1 < 1$, $u^I(x)$ is a strictly increasing concave function. The smaller α_1 is, the greater the degree of concavity will be, i.e., the degree of utility value "amplification" will be greater. $0 < \alpha_1 < 1$ also implies that the DM is not sensitive to the excess part (i.e. attribute value is over the attribute aspiration) and the DM's sensitivity is diminishing with the increase of the excess part; second, if $\alpha_1 = 1$, $u^I(x)$ is a strictly increasing linear function; and third, if $\alpha_1 > 1$, u^I (x) is a strictly increasing convex function. The greater α_1 is, the greater the degree of convexity will be, i.e., the degree of utility value "minification" will be greater. $\alpha_1 > 1$ also implies that the DM is sensitive to the excess part and the DM's sensitivity is increasing with the increase of the excess part. The situations of β_1 are similar to those of α_1. α_1 and β_1 can be determined using the direct questioning method or the contrast questioning method in the utility theory (Fishburn and Kochenberger, 1979) by testing and analyzing the DM's perception or sensitivity degree that the attribute value exceeds or does not exceed the attribute aspiration.

By Equation (1), the calculation formula of the utility value of alternative A_i concerning attribute C_j is given by:

$$u_{ij}^I(d_{ij}) = \begin{cases} \left(\frac{d_{ij}-e'_j}{d_j^{\max}-e'_j}\right)^{\alpha 1}, & d_{ij} > e'_j, \\ 0, & d_{ij} = e'_j, \qquad i \in M,\ j \in N^I, \\ -\left(\frac{e'_j-d_{ij}}{e'_j-d_j^{\min}}\right)^{\beta 1}, & d_{ij} < e'_j, \end{cases} \tag{2}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $j \in N^I$. By Equation (2), we know that $u_{ij}^I(d_{ij}) \in [-1,\ 1]$, $i \in M$, $j \in N^I$.

3.2 Calculation of utility value for the attribute aspiration type E_{II}

The attribute aspiration type E_{II} refers to that d_{ij} would better not be over the aspiration-level e''_j for the attribute C_j ($C_j \in C^{II}$). There are the three possible results for comparing d_{ij} with e''_j. If $d_{ij} < e''_j$, then the part that d_{ij} is under e''_j, i.e., $e''_j - d_{ij}$, can be regarded as DM's "elation." The larger the lacking part is, the higher the DM's satisfaction degree will be. For this case, we may think that the corresponding utility value is greater than 0. If $d_{ij} = e''_j$, then the corresponding utility value is 0. If $d_{ij} > e''_j$, then the part that d_{ij} is over e''_j, i.e., $d_{ij} - e''_j$, can be regarded as DM's "disappointment," and the corresponding utility value is less than 0.

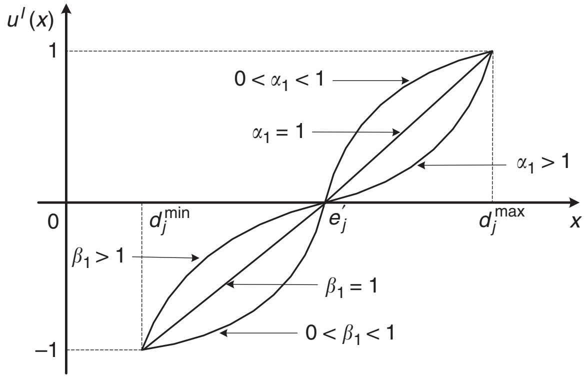

Figure 1.
The utility function for the attribute aspiration type E_I

Further, the utility function for the type E_{II}, $u^{II}(x)$, can be built, i.e.:

$$u^{II}(x)=\begin{cases}\left(\frac{e''_j-x}{e''_j-d_j^{\min}}\right)^{\alpha 2}, & x<e''_j,\\ 0, & x=e''_j, \quad j\in N^{II},\\ -\left(\frac{x-e''_j}{d_j^{\max}-e''_j}\right)^{\beta 2}, & x>e''_j,\end{cases} \tag{3}$$

where $d_j^{\min}=\min_{i\in M}\{d_{ij}\}$, $d_j^{\max}=\max_{i\in M}\{d_{ij}\}$, $\alpha_2>0$ and $\beta_2>0$. α_2 and β_2 are the coefficients determining the concavity and convexity of the utility function. The utility function $u^{II}(x)$ represented by Equation (3) is presented graphically in Figure 2.

By Equation (3), the calculation formula of the utility value of alternative A_i concerning attribute C_j is given by:

$$u_{ij}^{II}(d_{ij})=\begin{cases}\left(\frac{e''_j-d_{ij}}{e''_j-d_j^{\min}}\right)^{\alpha 2}, & d_{ij}<e''_j,\\ 0, & d_{ij}=e''_j, \quad i\in M,\ j\in N^{II},\\ -\left(\frac{d_{ij}-e''_j}{d_j^{\max}-e''_j}\right)^{\beta 2}, & d_{ij}>e''_j,\end{cases} \tag{4}$$

where $d_j^{\min}=\min_{i\in M}\{d_{ij}\}$, $d_j^{\max}=\max_{i\in M}\{d_{ij}\}$, $j\in N^{II}$. Obviously, $u_{ij}^{II}(d_{ij})\in[-1,\ 1]$, $i\in M$, $j\in N^{II}$.

3.3 Calculation of utility value for the attribute aspiration type E_{III}

The attribute aspiration type E_{III} refers to that d_{ij} would better be in the range of e_j^L to e_j^U for the attribute C_j ($C_j\in C^{III}$), $e_j^L<e_j^U$, $e_j^L\geqslant 0$. If $d_{ij}\in[e_j^L, e_j^U]$, then the attribute value reaches the DM's aspiration-level. For this case, the corresponding utility value is 0. If $d_{ij}<e_j^L$ (or $d_{ij}>e_j^U$), then the attribute value does not reach the DM's aspiration-level, and the corresponding utility value is less than 0.

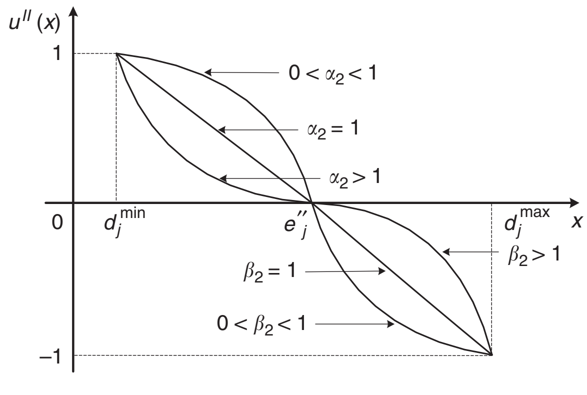

Figure 2.
The utility function for the attribute aspiration type E_{II}

Further, the utility function for the type E_{III}, $u^{III}(x)$, can be built, i.e.:

$$u^{III}(x) = \begin{cases} -\left(\frac{e_j^L - x}{e_j^L - d_j^{\min}}\right)^{\beta 3}, & x < e_j^L, \\ 0, & e_j^L \leqslant x \leqslant e_j^U, \qquad j \in N^{III}, \\ -\left(\frac{x - e_j^U}{d_j^{\max} - e_j^U}\right)^{\beta 3}, & x > e_j^U, \end{cases} \tag{5}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $\beta_3 > 0$. β_3 is the coefficient determining the concavity and convexity of the utility function. The utility function $u^{III}(x)$ represented by Equation (5) is presented graphically in Figure 3.

By Equation (5), the calculation formula of the utility value of alternative A_i concerning attribute C_j is given by:

$$u_{ij}^{III}(d_{ij}) = \begin{cases} -\left(\frac{e_j^L - d_{ij}}{e_j^L - d_j^{\min}}\right)^{\beta 3}, & d_{ij} < e_j^L, \\ 0, & e_j^L \leqslant d_{ij} \leqslant e_j^U, \quad i \in M,\ j \in N^{III}, \\ -\left(\frac{d_{ij} - e_j^U}{d_j^{\max} - e_j^U}\right)^{\beta 3}, & d_{ij} > e_j^U, \end{cases} \tag{6}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $j \in N^{III}$. Obviously, $u_{ij}^{III}(d_{ij}) \in [-1,\ 0]$, $i \in M$, $j \in N^{III}$.

3.4 Calculation of utility value for the attribute aspiration type E_{IV}

The attribute aspiration type E_{IV} refers to d_{ij} would be the larger the better for the attribute C_j ($C_j \in C^{IV}$). For this case, to construct the utility function of the alternative A_i concerning attribute C_j, we consider that there exists a virtual reference point, and the reference point can take the minimum value in the m attribute values ($d_{1j}, d_{2j}, \ldots, d_{mj}$), i.e., $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $j \in N^{IV}$. The part that the attribute value d_{ij} is over the reference point $d_j^{\min}$, i.e., $d_{ij} - d_j^{\min}$ can be regarded as DM's "elation." The larger the excess part is, the higher the DM's satisfaction degree will be. Specially, if $d_{ij} = d_j^{\min}$ (or $d_{ij} = d_j^{\max}$), $j \in N^{IV}$, then the corresponding utility value is 0 (or 1).

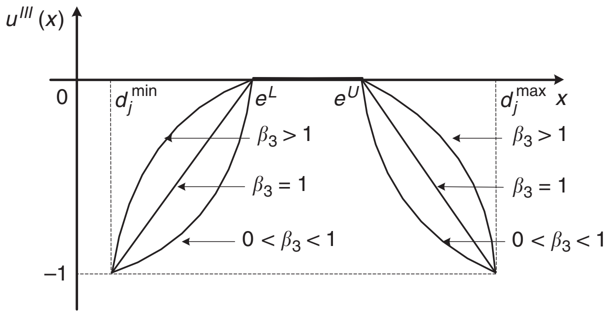

Figure 3.
The utility function for the attribute aspiration type E_{III}

Further, the utility function for the type E_{IV}, $u^{IV}(x)$, can be built, i.e.:

$$u^{IV}(x) = \begin{cases} 0, & x = d_j^{\min}, \\ \left(\frac{x - d_j^{\min}}{d_j^{\max} - d_j^{\min}}\right)^{\alpha 3}, & d_j^{\min} < x < d_j^{\max}, \quad j \in N^{IV}, \\ 1, & x = d_j^{\max}, \end{cases} \tag{7}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $\alpha_3 > 0$. α_3 is the coefficient determining the concavity and convexity of the utility function. The utility function $u^{IV}(x)$ represented by Equation (7) is presented graphically in Figure 4.

By Equation (7), the calculation formula of the utility value of alternative A_i concerning attribute C_j is given by:

$$u_{ij}^{IV}(d_{ij}) = \begin{cases} 0, & d_{ij} = d_j^{\min}, \\ \left(\frac{d_{ij} - d_j^{\min}}{d_j^{\max} - d_j^{\min}}\right)^{\alpha 3}, & d_j^{\min} < d_{ij} < d_j^{\max}, \quad i \in M, \quad j \in N^{IV}, \\ 1, & d_{ij} = d_j^{\max}, \end{cases} \tag{8}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}, j \in N^{IV}$. Obviously, $u_{ij}^{IV}(d_{ij}) \in [0, \ 1], i \in M, j \in N^{IV}$.

3.5 Calculation of utility value for the attribute aspiration type E_V

The attribute aspiration type E_V refers to that d_{ij} would be the smaller the better for the attribute C_j ($C_j \in C^V$). Similar to the analysis of the type E_{IV}, the utility function for the type E_V, $u^V(x)$, can be built, i.e.:

$$u^{V}(x) = \begin{cases} 1, & x = d_j^{\min}, \\ \left(\frac{d_j^{\max} - x}{d_j^{\max} - d_j^{\min}}\right)^{\beta 4}, & d_j^{\min} < x < d_j^{\max}, \quad j \in N^{V}, \\ 0, & x = d_j^{\max}, \end{cases} \tag{9}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}$, $\beta_4 > 0$. β_4 is the coefficient determining the concavity and convexity of the utility function. The utility function $u^V(x)$ represented by Equation (9) is presented graphically in Figure 5.

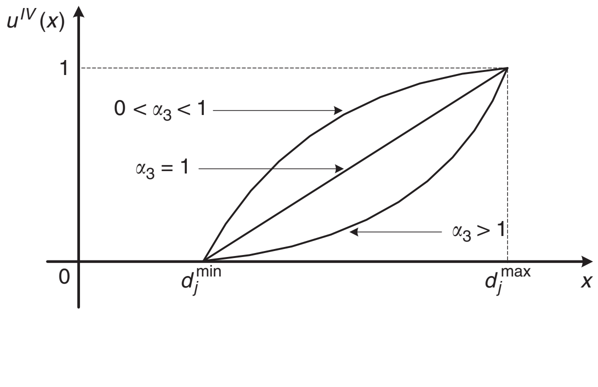

Figure 4.
The utility function for the attribute aspiration type E_{IV}

By Equation (9), the calculation formula of the utility value of alternative A_i concerning attribute C_j is given by:

$$u_{ij}^{V}(d_{ij}) = \begin{cases} 1, & d_{ij} = d_j^{\min}, \\ \left(\frac{d_j^{\max} - d_{ij}}{d_j^{\max} - d_j^{\min}}\right)^{\beta 4}, & d_j^{\min} < d_{ij} < d_j^{\max}, i \in M, \quad j \in N^V, \\ 0, & d_{ij} = d_j^{\max}, \end{cases} \tag{10}$$

where $d_j^{\min} = \min_{i \in M}\{d_{ij}\}$, $d_j^{\max} = \max_{i \in M}\{d_{ij}\}, j \in N^V$. Obviously, $u_{ij}^{V}(d_{ij}) \in [0, \ 1], i \in M, j \in N^V$.

4. The ranking method

In this section, we give the calculation formula of the overall ranking value of alternative based on Section 3. Then, the procedure for solving the MADM problem with the five types of attribute aspirations is given.

For the attribute value d_{ij} of the alternative A_i concerning the attribute C_j, the corresponding utility value $u_{ij}^{r}(d_{ij})$ can be calculated using Equations (2), (4), (6), (8) or (10), $r \in \Omega = \{I, II, III, IV, V\}$, $i \in M$. If $j \in N^I$ or $j \in N^{II}$, then $u_{ij}^{r}(d_{ij}) \in [-1, \ 1]$; if $j \in N^{III}$, then $u_{ij}^{r}(d_{ij}) \in [-1, \ 0]$; if $j \in N^{IV}$ or $j \in N^V$, then $u_{ij}^{r}(d_{ij}) \in [0, \ 1]$. Obviously, the meaning of each utility value is clear. If $u_{ij}^{r}(d_{ij}) > 0$, then it implies that the attribute value not only reaches but also exceeds the DM's attribute aspiration. If $u_{ij}^{r}(d_{ij}) = 0$, then it implies that the attribute value reaches the attribute aspiration. If $u_{ij}^{r}(d_{ij}) < 0$, then it implies that the attribute value does not reach the attribute aspiration. Therefore, the overall ranking value of alternative A_i can be calculated, i.e.:

$$U_i = \sum_{r \in \Omega} \sum_{j \in N^r} w_j u_{ij}^{r}(d_{ij}), \quad i \in M. \tag{11}$$

Obviously, the greater U_i is, the better the alternative A_i will be. Therefore, in accordance with a descending order of the overall ranking values of all the alternatives, we can determine the ranking of all the alternatives or select the desirable alternative(s).

In summary, the procedure for solving the MADM problem with the five types of attribute aspirations is given as follows:

- Step 1. Determine the types of attribute aspirations according to the aspiration-level on each attribute provided by the DM.

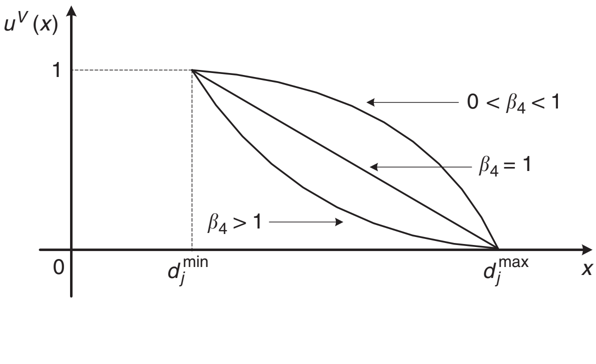

Figure 5. The utility function for the attribute aspiration type E_V

- Step 2. Calculate the utility value of the alternative A_i concerning the attribute C_j, $u_{ij}^r(d_{ij})$, using Equations (2), (4), (6), (8) and (10), $r \in \Omega$, $i \in M$ and $j \in N^r$.
- Step 3. Calculate the overall ranking value U_i of alternative A_i using Equation (11), $i \in M$.
- Step 4. Determine the ranking order of alternatives according to the obtained overall ranking values.

5. An application to wastewater treatment

The wastewater treatment is an important problem for a city. When selecting a wastewater treatment alternative, some factors usually are considered, such as technology requirements, cost, land constraint and human resource, etc. (Singhirunnusorn and Stenstrom, 2009; Kalbar *et al.*, 2012). In this section a problem of wastewater treatment technology selection is considered. Some attributes and candidate alternatives involved in the problem come from the literature (Kalbar *et al.*, 2012). Here, seven attributes are considered, and their definitions and measures are listed in Table II, where C_1, C_2, C_3, C_4 and C_5 are quantitative attributes, and C_6 and C_7 are qualitative ones. The attribute weight vector provided by the DM is $\boldsymbol{w} = (0.21, 0.19, 0.15, 0.07, 0.11, 0.13, 0.14)^T$. The four alternatives are the activated sludge process (A_1), the sequential batch reactor (A_2), the up flow anaerobic sludge blanket reactor followed by a facultative aerated lagoon (A_3) and the constructed wetlands (A_4), respectively. The decision matrix is shown in Table III, where the attribute values of attributes C_6 and C_7 concerning each alternative are evaluations given by the experts using the

Table II. Definitions and measures of the attributes

Attributes	Definitions	Measures
C_1: global warming	Energy consumption during the operational phase of the plant over its life cycle	The relative contributions of different gases to climate change compared in terms of carbon dioxide equivalents (unit: kg CO_2-Eq/year)
C_2: eutrophication	Performance of the plant based on release of organics and nutrients in treated wastewater	The relative contributions of pollutants to water bodies compared in terms of phosphorus equivalents (unit: kg PO_4^{3-}-Eq/year)
C_3: life cycle costs	The costs of civil works, electromechanical equipment, land, operation and maintenance of the plant	The net present worth of all future cash flow incurred for treating a million liters wastewater per day (unit: \$1,000/MLD)
C_4: manpower requirement for operation	The number of staffs required for operation of the plant	The actual manpower requirement is estimated by studying field-scale wastewater treatment plant (WWTPs)
C_5: durability	The technological life time with minimal maintenance and spare part requirements	The minimal years of the wastewater treatment technology
C_6: flexibility	The easiness of upgrade of the existing treatment plant	The candidates are assessed by the experts through their subjective judgments and prediction
C_7: mechanical failures	The possibility of mechanical failures during a period, which is an important indicator to characterize mechanical reliability	The candidates are assessed by the experts through their subjective judgments and prediction

scores from 1 to 10 (1: the lowest; 10: the highest). Furthermore, the DM gives his/her aspiration-level on each attribute according to the field investigation and survey of the experts, as shown in Table IV. To select the desirable wastewater treatment alternative, the method proposed in this paper is used. According to the procedure of the method given in Section 4, the computation processes and some results are presented below:

- Step 1. The types of the seven attribute aspirations are determined. According to Table IV, we know that the aspirations on C_1, C_2 and C_3 are of cost type with requirements, the aspiration on C_4 is of interval type, the aspiration on C_5 is of benefit type with requirement, the aspiration on C_6 is of benefit type and the aspiration on C_7 is of cost type, i.e., $C_1, C_2, C_3 \in C^{II}$, $C_4 \in C^{III}$, $C_5 \in C^{I}$, $C_6 \in C^{IV}$ and $C_7 \in C^{V}$.
- Step 2. Using Equations (2), (4), (6), (8) and (10), the attribute values in Table III are transformed into the corresponding utility values, as shown in Table V, where $\alpha_1 = 0.5$, $\alpha_2 = 0.8$, $\alpha_3 = 0.4$, $\beta_1 = 2$, $\beta_2 = 1$, $\beta_3 = 2.5$ and $\beta_4 = 1.5$.
- Step 3. Using Equation (11), the overall ranking value of each alternative can be obtained, i.e., $U_1 = 0.217$, $U_2 = 0.260$, $U_3 = 0.129$, $U_4 = 0.062$.
- Step 4. According to the obtained overall ranking values, we know that the ranking order of the alternatives is $A_2 \succ A_1 \succ A_3 \succ A_4$.

Therefore, A_2 is the most desirable alternative toward treating wastewater.

Alternatives	Attributes C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	18.5	3.76	227.42	10	80	8	8
A_2	31.97	1.38	210.82	6	75	6	8
A_3	7.67	5.85	170.98	14	60	4	6
A_4	−3.86	3.40	400.06	4	40	3	4

Table III. The decision matrix

Attributes	Aspiration-levels
C_1	Global warming would better not be over 10.5 kg CO_2-Eq/year
C_2	Eutrophication would better not be over 3.76 kg PO_4^{3-}-Eq/year
C_3	Life cycle costs would better not be over $250,000/MLD
C_4	Manpower requirement for operation would better be in the range of 8-12
C_5	Durability would better be over 50 years
C_6	Flexibility would be the higher the better
C_7	Mechanical failures would be the lower the better

Table IV. The DM's aspiration-level on each attribute

Alternatives	Attributes C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	−0.373	0	0.367	0	1	1	0
A_2	−1	1	0.571	−0.177	0.913	0.815	0
A_3	0.273	−1	1	−1	0.577	0.525	0.354
A_4	1	0.221	−1	−1	−1	0	1

Table V. The utility values of alternatives concerning attributes

Further, when different coefficient values are chosen in Equations (2), (4), (6), (8) and (10), the corresponding overall ranking values are calculated. Through extensive numerical experiments, we find that the different coefficient values would influence the ranking results of alternatives. To demonstrate this, two groups of coefficient values are taken and the corresponding calculation results are shown in Table VI. It can be seen that the two results are different.

Next, the comparison analysis of the proposed method and the existing methods is conducted based on the decision matrix in Table III and the attribute weight vector mentioned above. Here, the three existing methods are selected, i.e., the SAW method (Hwang and Yoon, 1981), the TOPSIS method (Hwang and Yoon, 1981) and the method based on the prospect theory (Fan *et al.*, 2013a). In the situation of the same types of attribute aspirations, the comparative results of the proposed method and each existing method are presented in Tables VII and VIII. According to the comparative results, the followings can be obtained:

- First, in the situation that the DM's sensitivity that the attribute value exceeds or does not exceed the attribute aspirations is not considered (e.g. $\alpha_3 = \beta_4 = 1$ in Table VII), the ranking of alternatives obtained by the proposed method is the same with those by the existing methods. This implies that the proposed method is feasible.
- Second, in the situation that the DM's sensitivity that the attribute value exceeds or does not exceed the attribute aspiration is considered (e.g. $\alpha_3 = \beta_4 = 0.3$ or $\alpha_3 = \beta_4 = 2$ in Table VII), the ranking of alternatives obtained by the proposed method is different from those by the existing methods. This implies that the DM's sensitivities (coefficients in the calculation formulae of utility values) have impact on the ranking of alternatives.

Table VI.
Impact of the coefficient values on the ranking of alternatives

Coefficient values	Overall ranking values of alternatives U_1	U_2	U_3	U_4	Rankings of alternatives
$\alpha_1 = 1.5$, $\beta_1 = 0.3$, $\alpha_2 = 0.1$, $\beta_2 = 0.7$, $\beta_3 = 1.4$, $\alpha_3 = 0.6$, $\beta_4 = 3$	0.267	0.273	0.157	0.177	$A_2 \succ A_1 \succ A_4 \succ A_3$
$\alpha_1 = 0.3$, $\beta_1 = 2.2$, $\alpha_2 = 1$, $\beta_2 = 0.4$, $\beta_3 = 0.2$, $\alpha_3 = 0.5$, $\beta_4 = 0.1$	0.141	0.198	0.199	0.049	$A_3 \succ A_2 \succ A_1 \succ A_4$

Table VII.
The comparison of the proposed method with the SAW and TOPSIS method

Methods	Rankings of alternatives	Coefficients
The simple additive weighting (SAW) method (Hwang and Yoon, 1981)	$A_1 \succ A_2 \succ A_4 \succ A_3$	
The TOPSIS method (Hwang and Yoon, 1981)	$A_1 \succ A_2 \succ A_4 \succ A_3$	
The proposed method	$A_1 \succ A_2 \succ A_4 \succ A_3$	$\alpha_3 = 1$, $\beta_4 = 1$
	$A_4 \succ A_2 \succ A_1 \succ A_3$	$\alpha_3 = 2$, $\beta_4 = 2$
	$A_1 \succ A_3 \succ A_2 \succ A_4$	$\alpha_3 = 0.3$, $\beta_4 = 0.3$

Note: In the comparison among the methods, the benefit and cost type of attribute aspirations are considered, i.e., aspirations on the attributes C_1, C_2, C_3, C_4 and C_7 are of the cost type, and C_5 and C_6 are of the benefit type

6. Conclusions

This paper proposes a method for solving the MADM problem with the five types of attribute aspirations: "benefit type with requirements," "cost type with requirements," "interval type," "benefit type" and "cost type." For each type of the attribute aspiration, the calculation formula of the utility value of alternative concerning attribute is given, and the attribute values can be transformed into the corresponding utility values using the calculation formulae. On the basis of this, a ranking result of the alternatives can be determined by calculating the overall ranking value of each alternative. An example on the wastewater treatment technology selection is used to illustrate the feasibility and validity of the proposed method. The contributions of this paper are summarized as follows.

In this paper, the MADM problem with multiple types of attribute aspirations is systematically studied. According to the DM's requirements in some practical MADM problems, the five types of attribute aspirations provided by the DM are considered. It is valuable to study the problem. To solve the problem, the method proposed in this paper overcomes the shortages of the existing methods only considering the one, two or three types of attribute aspirations.

This paper proposes a new method for solving the MADM problem with the five types of attribute aspirations. The key of the method is that the utility function for each type of attribute aspiration is constructed to depict the DM's satisfaction or disappointment degree. In the utility functions, the coefficients are introduced to present the DM's sensitivity that the attribute value exceeds or does not exceed the attribute aspiration. Using the utility functions, attribute values can be transformed into utility values for each type of attribute aspiration. The greater the utility value is, the higher the DM's satisfaction degree or the lower the DM's disappointment degree will be. In the proposed method, the overall ranking value of each alternative is calculated based on the utility values, and the desirable alternative can be determined according to the largest overall ranking value. Compared with the existing methods, the proposed method has a clear logic and a simple computation procedure, and it is also applicable to the situation that the DM provides less than the five types of attribute aspirations.

It is important to highlight that since the method presented in this paper is new and different from the existing methods, it gives the DM one more choice in methods for solving the MADM problem with multiple types of attribute aspirations. The proposed

Methods	Rankings of alternatives	Coefficients
The method based on the prospect theory (Fan *et al.*, 2013a)[a]	$A_1 \succ A_2 \succ A_3 \succ A_4$	
The proposed method	$A_1 \succ A_2 \succ A_3 \succ A_4$	$\alpha_1 = \alpha_2 = 1$, $\beta_1 = \beta_2 = \beta_3 = 1$
	$A_1 \succ A_2 \succ A_4 \succ A_3$	$\alpha_1 = \alpha_2 = 2$, $\beta_1 = \beta_2 = \beta_3 = 2$
	$A_2 \succ A_3 \succ A_1 \succ A_4$	$\alpha_1 = \alpha_2 = 0.5$, $\beta_1 = \beta_2 = \beta_3 = 0.5$

Notes: [a]We take $\alpha = \beta = 0.88$ and $\lambda = 2.25$ in the method based on prospect theory (Fan *et al.*, 2013a). In the comparison among the methods, the benefit and cost type of attribute aspirations with requirements, and the interval type are considered, i.e., aspirations on the attributes C_1, C_2, C_3 and C_7 are of the cost type with requirements (we assume that they would better not be over 10.5, 3.76, 250 and 8, respectively), C_5 and C_6 are of the benefit type with requirements (they would better be over 50 and 3, respectively), and C_4 is of the interval type (it would better be in [8,12])

Table VIII. The comparison of the proposed method with the method based on the prospect theory method is applied to solve the problem of the wastewater treatment technology selection. The application has a demonstrative role. Apparently, the method can also be applied to the other areas.

In terms of future research, the proposed method can be embedded into the decision support system. It can be also extended to support MADM problems in which the attribute values are in other forms, such as interval or fuzzy numbers.

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