Enterprise Knowledge Management Application Evaluation based on Cloud Gravity Center Model and Fuzzy Extended AHP

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***Abstract*—Enterprise knowledge management has important influence on an enterprise core competency, and enterprise knowledge management application evaluation plays an important role for the enterprise economic benefits, innovation ability and culture. The evaluation of the enterprise knowledge management application can guide the enterprise knowledge management implement better. In this paper, an enterprise knowledge management application evaluation index system is constructed and fuzzy extended analytic hierarchy process and cloud gravity center model are employed to evaluate the enterprise knowledge management application problem because it has the advantages of simple, less time taking and dealing with qualitative and quantitative indicators simultaneously. An implementation of the proposed model is used for a certain enterprise knowledge management application evaluation, and the results shows the proposed model is feasibility and effective for the evaluation.**

***Index Terms* — enterprise knowledge management, fuzzy extended analytic hierarchy process, cloud gravity center, evaluation.**

I. Introduction

Knowledge management presents the use of collective wisdom to improve adaptability and innovation for enterprises, it provides a new way to share explicit knowledge and tacit knowledge in enterprise members. According to mining and organizing the knowledge of enterprise's individuals, the whole object and the overall benefits of the enterprise can be also enhanced, and the workflow of the enterprise can be ordered clearly. The application of enterprise knowledge management needs to establish the enterprise's own knowledge base and promote the knowledge exchange between the employees. It need establish the internal knowledge environment of the enterprise, if employees can share information and knowledge in the environment and contribute their wisdom and ability, it will be transformed into knowledge productivity or creativity, and the generated benefit will be far superior to the generated benefit by capital, labor, land, machinery and so on.

The application of knowledge management in teamwork will increase the effectiveness of collective decision-making and it will become the most important contributor to business growth. Knowledge will become the most important asset of the enterprise. The role of the application of the knowledge management can be shown as a dynamic expression of knowledge production, knowledge sharing, knowledge application and innovation of the systematic process, it not only realize the knowledge-sharing, but also increase the core competency of the enterprise, at the same time, it make a great training of the enterprise staff skills and innovation capability, it enhances the response capacity of enterprises, the efficiency of enterprise and the insight of the enterprise[1-2].

Knowledge management has outstanding contributions of the enterprise's core competencies, many scholars have formed a consensus on this point and do some research in the evaluation problems of the knowledge management. Tiwana[3] studies the knowledge management performance assessment from the customer perspective. Andersen[4] present a KMAT method which can evaluate knowledge management from leadership, culture, technology, learning and assessment five aspects. Davenport[5] evaluates the knowledge management performance with the growth of related resources, knowledge content and efficiency of knowledge growth, the popularity of knowledge management projects, the concept of knowledge management staff acceptance, the possibility of financial recovery of the indicators. Dekker & Hoon [6] thinks that the value of intellectual capital is the enterprise knowledge product, and they divided intellectual capital into many independent parts, then measure each basic element to assessment the knowledge management. Kaplan[7] creates the Balanced Scorecard(BSC) method, and he assess knowledge management includes not only financial, but also customers, internal business processes, innovation, learning and growth. Base on BSC, Edivissninl[8] present a navigator model, he focus on five areas including customer, financial, process, human factors, renewal and development, which contains 30 indicators of an index system. Choi &Lee[9] also study the relationship between the knowledge management and the enterprise's performance base on BSC, they present a evaluation method from market share, growth rate, profitability, innovation and enterprise scale changes five aspects.

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The enterprise knowledge management application evaluation is an important part of the enterprise knowledge management; it is also one of the most important problems of the enterprise. However, enterprise knowledge management is a complex system, including management science, information technology, behavioral science, cognitive science and psychology. The application of the enterprise knowledge management relates to organizational structure, culture, institutional arrangements and incentive mechanisms of the enterprise. It involves lots of factors which contain quantitative and qualitative factors. It has brought great difficulties of enterprise knowledge management application evaluation. Currently it is lack of the study of the evaluation. Therefore, it is necessary to research the enterprise knowledge management application evaluation.

In this paper, we employ the cloud gravity center model and FEAHP to evaluate the enterprise knowledge management application, the cloud gravity center model can deal with the quantitative value, fuzzy value and especially the language value, which are always in knowledge related evaluation. The FEAHP method will obtain the indexes weights in this study, because this method is also use the fuzzy number to compare the importance of the indexes, it more easily than using exact numbers 1-9 in AHP for the experts. These characteristic are more suitable for the enterprise knowledge management application evaluation. For the comparison with the Fuzzy AHP method, the proposed method can obtain the better performance, and the results shows the proposed model is feasibility and effective for the evaluation

The remainder of the paper is organized as follows: Section 2 gives the principle of the cloud gravity center model. In Section 3, the FEAHP method is used to determine the weight of the cloud gravity center model. Section 4 gives a complete implementation of a certain enterprise knowledge management application evaluation. Section 5 contains the conclusion of the paper.

II. Cloud Gravity Center Model

Cloud theory uses natural language concepts to change the qualitative concept into a quantitative value. It collects the fuzziness and randomness completely. Cloud gravity center model can achieve qualitative and quantitative properties rational conversion and it can evaluate multi-attribute index better. The basic idea is to use cloud to represent a concept of a qualitative and quantitative transformation model between the uncertainty, the number of the cloud features is expected value Ex, entropy En and deviation D, and the three values constitutes a qualitative and quantitative mapping. Ex is the cloud's center of gravity which expresses the corresponding central value of fuzzy concept. En is a measure of the concept of ambiguity and the value reflects the accepted number of elements by vague concept in a domain, which is a margin. D is a measure of cloud thickness and its value is the maximum value of the whole cloud thickness, which reflects the dispersion of the cloud. When the research question is pure randomness, En→ ∞, for the pure ambiguity problem, D = 0.

The cloud gravity center can be calculated by T=a×b , in which, a is the location of cloud gravity center, b is the height of the cloud gravity center. Generally speaking, a is the expectations which reflect the corresponding center value of fuzzy concept, and b is a constant value which is equal to 0.371. If two clouds have the same expectations, it can be distinguished the importance by comparing the height of the cloud gravity center, the height of the cloud gravity center reflects the importance of the cloud.

The steps of using cloud gravity center model to evaluate a problem are shown as follows[10]:

Step 1. Use cloud to express the index values.

Generally speaking, there are quantitative indicators and qualitative indicators in an index system. The treatment method is extracting a decision matrix composed of n states, then it can be expressed by cloud model by

$$E_x = \frac{E_{x1} + E_{x2} + \dots + E_{xn}}{n} \tag{1}$$

$$. E_n = \frac{\max(E_{X1}, E_{X2}, \dots, E_{xn}) - \min(E_{X1}, E_{X2}, \dots, E_{xn})}{6} .(2)$$

In which, E_x is the expected value and E_n is the entropy value of indicator *x*, E_{xi} is the value of indicator *x* in the state *i*.

Similarly, the value of each language type indicator can also be expresses as a cloud, when an indicator has n values, the cloud express method is as follows:

$$E_x = \frac{E_{x1}E_{n1} + E_{x2}E_{n2} + \dots + E_{xn}E_{nn}}{E_{n1} + E_{n2} + \dots + E_{nn}} \tag{3}$$

$$E_n = E_{n1} + E_{n2} + \dots + E_{nn} \tag{4}$$

Step 2. The representation of the system states

If *p* indicators describe an evaluation object, then a vector can express the system's state base on the cloud model. When the system changes state, the integrated cloud-dimensional shape will change, and its gravity has also changed. The gravity of a cloud can be present by the location *a* and the center of gravity height *b*. If the cloud gravity is the $T = (T_1, T_2, \dots, T_p)$ .then $T_i = a_i \times b_i \quad (i = 1, 2, \dots, p)$. When the system state changes, the focus accordingly changes to $T' = (T_1', T_2', \dots, T_p')$ ..

Step 3. Make sure the indicator's weight

In this step, a weight determine method can be used to select the indicator's weight, in this study, we will use FEAHP to determine the weight, the details are in section III.

Step 4. Use the weight to calculate the changes of the cloud gravity

In an ideal state, a cloud gravity assumes $a = (E^0{}_{x1}, E^0{}_{x2}, \ldots, E^0{}_{xp})$,and the height of the cloud is $b = (b_1, b_2, \ldots, b_p)$, which is equal to the weight vector, then the cloud gravity vector can be shown as

$$T^0 = a * b^{\mathrm{T}} = (T_1^0, T_2^0, \cdots, T_p^0) \quad (5)$$

Similarly, to obtain a state of the cloud gravity vector $T = (T_1, T_2, \ldots, T_p)$,in which, the location of the cloud gravity is gotten by the expectations, then weighted degree of deviation θ can be used to measure the two kinds of state differences in the focus of the integrated cloud the situation. Firstly, the ideal state and the state of cloud center gravity vectors should be normalized, T^0 and T can be obtained as

$$T_i^G = \begin{cases} (T_i - T_i^0)/T_i^0 & T_i \le T_i^0 \\ (T_i - T_i^0)/T_i & T_i > T_i^0 \end{cases} \quad (6)$$

And the weighted degree of deviation θ is

$$\theta = \sum_{j=1}^{p} (W_j * T_i^G) \quad (7)$$

In which, W_j is the weight of the j indicator, and smaller value expresses the less difference.

Step 5. Determine the evaluation set of the indicators

The language set is commonly selected as (none, worst, worse, very poor, poor, ordinary, good, very good, better, best, excellent, perfect), and the language can change into a cloud gravity center which is called cloud generator is shown in Fig 1.

III. FEAHP METHOD

According to above introduction, a key problem for using cloud gravity center model is to give the reasonable weight at step 3. One of the well-known weight determined method is the analytic hierarchy process(AHP) method, which is proposed by Saaty[11-12], AHP is suitable for systematic multi-criterion decision making problems with complex hierarchy structure, and this method can deal with not only the quantitative factors but also the qualitative factors. It has the advantage of practicability, systemic and simplicity. However, it has been generally criticized because of the use of a discrete scale of one to nine which cannot handle the uncertainty and ambiguity present in deciding the priorities of different attributes, but the appearance of FEAHP[13-14] has provided a solution to this problem, because decision-makers usually find that it is more confident to give a fuzzy number than a precise number judgments. And the method has been applied successfully in many fields [15-19]. Therefore, We employed the FEAHP method to determine the weight of cloud gravity center model.

Triangular fuzzy numbers (TFN) are used in FEAHP, and a typical TFN is graphically depicted in Fig.2. If a, b and c, respectively denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event, then the TFN can be denoted as a triplet (a,b,c). Generally, $a \le b \le c$, And the relationship between x which can be any point between a, b and c, and its membership y conforms to

$$\begin{cases} x = a + (b-a)y & x \in [a,b] \\ x = c + (b-c)y & x \in [b,c] \\ 0 & otherwise \end{cases} \quad (8)$$

Then the one to nine scale used in deciding the priorities of different attributes in traditional AHP can be substituted by TFN according to Table 2.

And the weight can be calculated by the four steps as follows: (where all the $M_{g_i}^j$ are TFNs whose parameters are *a, b,* and *c*)

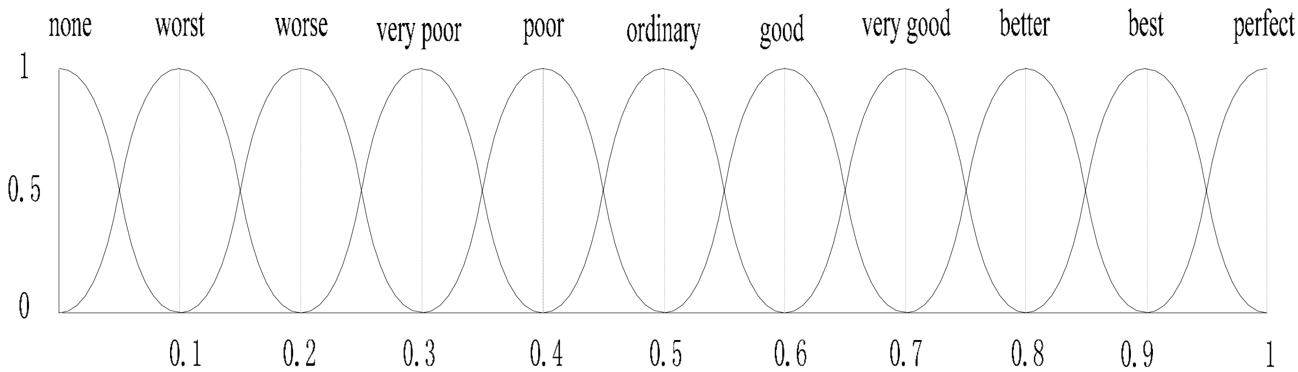

Figure.1. A cloud generator which can change the language value into a cloud gravity value

TABLE II FUZZY CONVERSION SCALE

Linguistic scale	TFN scale	TFN reciprocal scale
Just equal	(1,1,1)	(1,1,1)
Equally important	(1/2,1,3/2)	(2/3,1,2)
Weakly important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

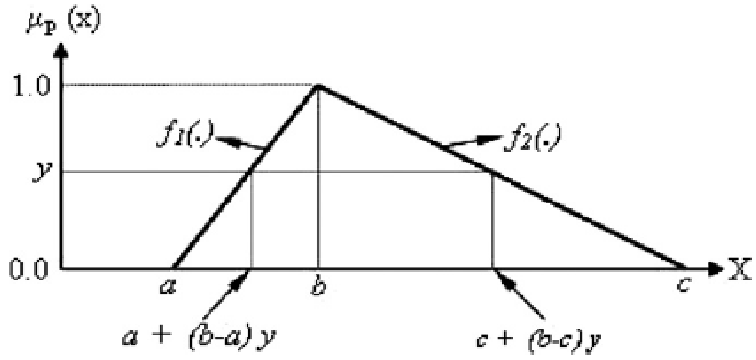

Figure 2. A triangular fuzzy number

And the weight can be calculated by the four steps as follows: (where all the $M_{g_i}^{j}$ are TFNs whose parameters are a, b, and c)

Step 1. The value of fuzzy synthetic extent with respect to the j th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \quad (9)$$

To obtain $\sum_{j=1}^{m} M_{g_i}^{j}$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} c_j \right), \ j = 1, 2, \ldots, m \quad (10)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1}$,perform the fuzzy addition operation of $M_{g_i}^{j}$ ($j=1,2,\ldots,m$)values such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} c_i}, \frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i} \right), \ i = 1, 2, \ldots, n \quad (11)$$

Step 2.The degree of possibility of $M_2 \geq M_1$ is defined as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)$$

$$= \begin{cases} 1 & b_2 \geq b_1 \\ 0 & a_1 \geq c_2 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)} & otherwise \end{cases} \quad (12)$$

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Where d is the ordinate of the highest intersection point d between μ_{M_2} and μ_{M_2} .

Step 3. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i=1,2,…,k) can be defined as follows:

$$V(M \geq M_1, M_2, \ldots, M_k) = \min V(M \geq M_i) \quad (14)$$

Step 4. Assume that $d'(A_i) = \sum V(M_i \geq M_k)$. Then the weight vector is given by

$$W' = \left(d'(A_1), d'(A_2), \ldots d'(A_n) \right)^T \quad (15)$$

where A_i $(i = 1, 2, \ldots, n)$ are n elements. Then normalize the vector to get the normalized weight vectors which are $W = \left(d(A_1), d(A_2), \ldots d(A_n) \right)^T$ where W is a non-fuzzy number.

IV. A NUMERIC EXAMPLE

An example of enterprise knowledge management evolution is presented in this section. Firstly, a three levels hierarchy structure enterprise knowledge management evolution index system is created. The first level is the object level, and it need to divide some sub indexes, with the survey of some experts, the second level contains three factors which are:

1. The economic revenue of knowledge application

Obviously, the enterprise managers are also pay attention to the enterprise's economic revenue. Only transferring to economic revenue can make the enterprise manager focus on the knowledge application.

2. The workers quality increasing of knowledge application

Knowledge application transferring by each workers can make workers working effectually. When a enterprise forms a culture, the whole workers capacity would increase rapidly.

3. Knowledge management equipment

Good knowledge management equipment is helpful of the knowledge application. Nowadays, the most important equipment is knowledge information system, and the major part is the knowledge database.

The three factors can also be divided into several indexes, and the whole evaluation system is shown in Table 1

TABLE I. THE ENTERPRISE KNOWLEDGE MANAGEMENT APPLICATION EVALUATION INDEX SYSTEM

Level 1	Level 2	Level 3
Enterprise knowledge management application	The economic revenue of knowledge application(B1)	The revenue increasing rate of knowledge application(C1)
		The technique level increasing of knowledge application(C2)
		The contribution value of knowledge application(C3)
	The workers quality increasing of knowledge application(B2)	Cultural quality(C4)
		Ability to identify and internalization of knowledge(C5)
		The workers' capacity increasing through knowledge(C6)
	Knowledge management equipment(B3)	Knowledge database level(C7)
		Knowledge information system level(C8)
		Knowledge database update level(C9)

TABLE III. THE SCORE OF THE INDICATORS OF AN ENTERPRISE

index	C1	C2	C3	C4	C5	C6	C7	C8	C9
state 1	90	5	good	good	4	76	4	4	3
state 2	86	4	very good	very good	5	74	4	4	3
state 3	84	5	very good	good	4	72	4	4	4
ideal state	100	5	perfect	perfect	5	100	5	5	5

TABLE IV. EXPECTED VALUE E_X AND ENTROPY E_N OF EACH INDICATORS

index	C1	C2	C3	C4	C5	C6	C7	C8	C9
E_x	86.7	4.7	0.67	0.63	4.33	74	4	4	3.33
E_n	1	0.2	0.017	0.017	0.17	0.67	0	0	0.17

TABLE IV. THE FUZZY EVALUATION OF C_1,C_2,C_3

	C_1	C_2	C_3	W_1
C_1	(1,1,1)	(2/5,1/2,2/3)	(1,3/2,2)	0.335
C_2	(3/2,2,5/2)	(1,1,1)	(1,3/2,2)	0.397
C_3	(1/2,2/3,1)	(1/2,2/3,1)	(1,1,1)	0.268

TABLE V. THE FUZZY EVALUATION OF LEVEL TWO AND ITS FINAL WEIGHTS

	C_1	C_2	C_3	W_2
C_1	(1,1,1)	(1/2,1,3/2)	(1/2,2/3,1)	0.42
C_2	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	0.30
C_3	(1,3/2,2)	(1,3/2,2)	(1,1,1)	0.28

TABLE VI. THE FUZZY EVALUATION OF LEVEL TWO AND ITS FINAL WEIGHTS

	C_1	C_2	C_3	W_3
C_1	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.41
C_2	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	0.30
C_3	(2/5,1/2,2/3)	(2/3,1,2)	(1,1,1)	0.29

Based on the above knowledge management application comprehensive evaluation index system, Cloud gravity center model and FEAHP method, an enterprise knowledge management application evaluation can be evaluated as follows, select three time points of the enterprise's state and use the experts score method, the score of the indicators can be shown in Table 3.

According Fig.1 the language can be transferred as the quantitative values, and the decision matrix is gotten as

$$\begin{pmatrix} 90 & 5 & 0.6 & 0.6 & 4 & 76 & 4 & 4 & 3 \\ 86 & 4 & 0.7 & 0.7 & 5 & 74 & 4 & 4 & 3 \\ 84 & 5 & 0.7 & 0.6 & 4 & 72 & 4 & 4 & 4 \end{pmatrix}$$

The ideal state vector is $a_0 =$（100,5,1,1,5,100,5,5,5）. According to equation 1-4， expected value E_x and entropy E_n can be calculated, and the results is shown in table 4.

Using FEAHP to calculate the weight of the indicators. At first, the fuzzy evaluation matrix of the second level is constructed by the pairwise comparison of the different indicators using triangular fuzzy numbers, which is shown in Table 4-6.

The different values of fuzzy synthetic extent with the three indicators are denoted by S_1, S_2, S_3 respectively, According to Eq.(12) the weight of the three indicators(W_1) can be calculated as follows:

$$S_1 = (2.4, 3, 3.67) \otimes (1/12.17, 1/9.83, 1/7.9)$$
$$= (0.197, 0.305, 0.464)$$

$$S_2 = (3.5, 4.5, 5.5) \otimes (1/12.17, 1/9.83, 1/7.9)$$
$$= (0.288, 0.458, 0.696)$$

$$S_3 = (2, 2.33, 3) \otimes (1/12.17, 1/9.83, 1/7.9)$$
$$= (0.164, 0.237, 0.379)$$

Using Eq.(14) to compare with S_1, S_2, S_3, $V(S_1 \geq S_2) = 0.536$; $V(S_1 \geq S_3) = 1$; $V(S_2 \geq S_3) = 1$; $V(S_3 \geq S_1) = 0.729$， $V(S_3 \geq S_2) = 0.295$. Then $d'(S_1) = \sum V(S_1 \geq S_2, S_3, S_4) = 2.536$; $d'(S_2) = 3$; $d'(S_3) = 2.024$.

The weight is $W_1 = (0.335, 0.397, 0.268)^T$ .Similarly, $W_2 = (0.42, 0.30, 0.28)^T$ and $W_3 = (0.29, 0.30, 0.41)^T$ can be obtained, and the final weight vector is $w = (0.16, 0.11, 0.14, 0.13, 0.09, 0.08, 0.08, 0.08, 0.11)^T$.

And the height of the cloud gravity center vector b is equal to w

$$b = (0.16, 0.11, 0.14, 0.13, 0.09, 0.08, 0.08, 0.08, 0.11)^T$$

according equation 5, the ideal cloud gravity vector is $a = (16.34, 0.57, 0.14, 0.13, 0.46, 8.26, 0.41, 0.42, 0.57)^T$

and the enterprise cloud gravity vector is

$$a = (14.17, 0.53, 0.10, 0.08, 0.40, 6.11, 0.33, 0.34, 0.38)^T .$$

According to equation 6 and equation 7, the weighted degree of deviation θ is 0.71. In cloud generator, it will activate the "good" and "very good" two properties, but more emphasis on "good" state. Therefore, the enterprise knowledge management application result is good.

In order to prove the proposed method, we employ several experts for scoring the state of the enterprise's knowledge management application, each indexes' score is between 0 and 100. And the average value is used as the final score of the enterprise's knowledge management application, the average is $s = (86.67, 93.33, 66.67, 66.67, 86.67, 74, 80, 80, 67.67)^T$, and the weight is used the same weight w which is gotten by FEAHP, the final score is 75.99 obtained by $w \cdot b$. It express state of the enterprise's knowledge application is between "good" and "very good" state. However, it more emphasis on " very good " state.

For comparing the two method, it is easily seen that two method are also evaluate the state of the enterprise's knowledge application is between "good" and "very good" state. The difference is the proposed method is emphasis "good" side, and the other method emphasis the other side. The reason is that the proposed method can more easily deal with the different values of different attribute, especially the language values. When we use the score instead the language values, it would have some deviation as the other method.

V. CONCLUSIONS

Knowledge management application can bring to the enterprise continuously upgrade the comprehensive performance, and it also bring to the enterprises' overall competitiveness. Knowledge management application can improve the economic efficiency, staff quality, innovation and technology ability of the enterprise. It will make the business more stable by the positive effects.

In this study, a cloud gravity model and a fuzzy extended AHP (FEAHP) approach has been presented to evaluate an enterprise knowledge management application. A three levels hierarchy index system are also presented, which is evaluating from the economic revenue of knowledge application, the workers quality increasing of knowledge application and knowledge management equipment three aspects, and the results obtained in the example reflect the situation of the enterprise knowledge management application. It also can be used for any other enterprise.

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