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Abstract

As the knowledge-based economy time comes, the core of business process is transforming financial intensive into technology intensive and knowledge intensive gradually. However, the value of knowledge itself can't be measured easily. We must evaluate and investigate the performance of knowledge management through activities of knowledge management process. During the performance evaluation process, many uncertain factors must be considered. It is also involved ambiguity occurred by human subjective judgment. Therefore, a performance evaluation model of knowledge management is proposed in this paper by combining Fuzzy Delphi with Fuzzy AHP. Finally, a numerical example is given to demonstrate the procedure for the proposed method at the end of this paper.

Keyword: Knowledge Management, Measuring Performance, Fuzzy Delphi, Fuzzy AHP

1. Introduction

When the knowledge becomes the key resource of the enterprise, how to apply knowledge appropriately to produce new knowledge and value is an important issue for business management.

Drucker[8] indicated that knowledge will become the most important sources for promoting business advantage. However, lacks of the effective measurement tool, knowledge cannot be exploited sufficiently. In recent years, many businesses have realized that knowledge management is the most important issue to increase their competitiveness. Therefore, the performance evaluation and measurement become a key point of promoting knowledge management plan successfully. However, the evaluation process of knowledge management must consider many uncertain factors such as attitude of employee, professional ability, and the subjective judgment of managers. Thus, it is difficult to evaluate the performance of knowledge management easily. Therefore, an evaluation model of knowledge management is proposed in this paper by combining fuzzy set theory with analytic hierarchy process (AHP).

2. Literature review

2.1 Knowledge Management

Liebowitz and Beckman[15] identified that knowledge management contains the following definitions.

(1) The knowledge management is a systematic process that creates knowledge clearly. Raise the relevant knowledge in business with applying avail knowledge.

(2) The knowledge management uses the experience, knowledge and expert knowledge to create new ability. It makes the business possesses the excellent performance, encourages innovation and increases the value of customers.

Papows[17] proposed seven reasons of implementing the knowledge management.

(1) Globalization. If Organizations all around world own an important competitive advantage, namely it can share experiences and resources effectively.

(2) Speed. As of the business shortens the lead time and obtain the valid business operations, we must get the information and the knowledge valuable quickly.

(3) Service orientation. If attaining quick response, all essential information and related operations must make the employee work on-line in any time and change the action procedure.

(4) Saturation of workers. Employees have higher turnover at knowledge age. We usually need a set of system to keep the knowledge of the worker and reuse them.

(5) More close relation of business. The WWW is also a resource that learns the new information. Each organization must integrate it in usual learning processes.

(6) Technique. Advanced information system, group software and WWW assembly together provide technique foundation of knowledge management for the company.

(7) Competition. The organization regards its intelligent capital as the force and promotes the competitive advantage of the organization systematically.

Sarvary[18] identified the knowledge management is the integration of the business flow via creation of business and using a process of collective knowledge. This process includes three flows as follows.

(1) Organization learning. The company acquires the process of the information or knowledge.

(2) Generalize knowledge. It is a process that information

is converted and integrated knowledge. The knowledge can resolve the problem of the commerce.

(3) Propagation knowledge. Making organization members can acquire and use the process of company community knowledge.

Synthesize above the viewpoints of the knowledge management, knowledge management is a process for business to increase the competitiveness by creation, transformation, diffusion and deposition of knowledge.

2.2Knowledge management activities

The knowledge management flow indicates the different attitudes of knowledge management in business management process. The definition of knowledge management flows includes knowledge creation, knowledge transformation, knowledge diffusion and knowledge storage. Some illustrations of knowledge management activities are shown in Table 1.

2.3Performance evaluation

The performance evaluation in nature is the control function in the business management activities. Being able to generate influences or take action in before the event or activities steering by the establishment of the performance evaluation system. The appraisal must depend on the reasonable and valid performance indicators and reach to the object of performance evaluation. Concretely, the performance evaluation has four objects[19]：

(1) The object of the fulfillment to weigh the extent of success.
(2) Providing the suggestion or correct amendments to the organization redevelopment.
(3) Providing the feedback mechanism to manager.
(4) Evaluating the internal input and output.

Because knowledge management flow of business and its performance evaluation have the subjective recognition, and is seen as problems of multi criteria, we can use many appraisable theories of multi criteria to reach reasonable performance evaluation. Therefore, this paper uses the linguistic variables to represent the subjective judgment of decision makers, and combine Fuzzy Delphi method with Fuzzy Analytic Hierarchy Process method (Fuzzy AHP) to propose a performance evaluation model of knowledge management.

3. Fuzzy Theory

3.1 Triangular fuzzy number and linguistic variable

The original concept of fuzzy sets in the pioneering paper of Zadeh was introduced as an extension of usual sets, by enlarging the truth value set of grade of membership from the two value set {0, 1} to the unit interval [0, 1] of real numbers[20].

3.1.1Triangular fuzzy number

Triangular fuzzy number can be defined by a triplet $\tilde{T} = (l, m, u)$ and $a \le b \le c$ (shown as Fig 1). The fuzzy number is the so-called triangular fuzzy number with its characteristic member function written as[1, 12]：

$$\mu_{\tilde{M}}(x) = \begin{cases} \dfrac{x-a}{b-a} & , a \le x \le b \\ \dfrac{c-x}{c-b} & , b \le x \le c \\ 0 & , otherwise \end{cases} \quad (1)$$

3.1.2 Linguistic variable

A linguistic variable is a variable whose values are linguistic terms [21]. The concept of linguistic variable is very useful in dealing with the situations are too complex to be reasonably described in quantitative expressions [21]. For example, the membership functions of the term set {Very Unimportant (VU), Unimportant (U), Medium (M), Important (I), Very Important (VI)} for representing weights of the importance of knowledge management. The linguistic values can also be represented via triangular fuzzy numbers.

3.1.3Distance measurement

Let $\tilde{M}_1 = (a_1, b_1, c_1)$ and $\tilde{M}_2 = (a_2, b_2, c_2)$ be two triangular fuzzy numbers, then the vertex method is defined to calculate the distance between them as[5]:

$$d(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (2)$$

3.2Fuzzy Delphi Method

This paper adopts Fuzzy Delphi Method to select the evaluation indicators. The Fuzzy Delphi Method is one of the specialist forecasts, its main object lies in obtaining the consensus of specialists, looking for to the opinion of the uniformity of the particular object [7].

The traditional Delphi method is one effective method, which enables forecasting by converge a possibility value through the feedback mechanism of the result of questionnaires, based on experts' judgments. However, the weakness of the traditional Delphi is that it requires repetitive surveys of the experts to allow the forecast values to converge. Therefore, Fuzzy Delphi Method uses Linguistic variable to express opinions of each expert, acquiring better integrative results [11, 13].

The Fuzzy Delphi Method is applied in this paper to find out the evaluation indicators. The steps are described as follows：

Step1. The expression of the specialist opinion

Each expert makes use of the Linguistic variable representing the importance weights of the decision criteria (shown as the Table 2).

Step2. Integrate fuzzy evaluative values of experts

Using Fuzzy Delphi Method to integrate fuzzy evaluative values of all experts in this step. If the *l*th expert judges the importance of the *k*th indicator is shown denoted by $\tilde{W}_{lk} = (a_{lk}, b_{lk}, c_{lk})$, the fuzzy weight $\tilde{W}_k$ of the *k*th indicator, then W_k can be calculated as:

$$\tilde{W}_k = (a_k, b_k, c_k) \quad , \quad k = 1,2,...,n \tag{3}$$

$$a_k = \min_l \{a_{lk}\}, b_k = \frac{1}{m}\sum_{l=1}^{m} b_{lk} \ , c_k = \max_l \{c_{lk}\}$$

Step3. Selecting evaluative indicators

Using Centroid Method to transform fuzzy weight of each indicator $\tilde{W}_k$ into single value. S_k [14]. It can be calculated as:

$$S_k = \frac{a_k + b_k + c_k}{3} \tag{4}$$

Set a threshold value as t and select a suitable evaluative indicator. The rule of selection is described as follows:

(a)If $S_k \geqq t$, then accept the kth initial indicator as evaluative indicator.

(b) If $S_k < t$, then delete kth initial indicator.

3.3 Fuzzy Analytic Hierarchy Process Method (Fuzzy AHP)

Buckley[2, 3] proposed that AHP method on the criteria's appraisal can't present appraisal subjective judgment and criterions in real situations. Therefore, Fuzzy AHP is proposed by combing fuzzy set theory with AHP to reflect true environment decision analysis suffers of subject. Making use of the Fuzzy AHP undertaking appraisal step justification as follows:

Step1. Based on features decomposed by each attribute to create the hierarchy levels.

Step2. Calculate fuzzy positive reciprocal matrix. Converting the linguistic evaluation into triangular fuzzy numbers to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion.

Step3. Calculate fuzzy weight. According to Lambda-Max method, we can calculate the fuzzy weight value [6].

4. Performance Evaluation Model

The knowledge management activities are divided into knowledge creation, knowledge diffusion, knowledge transformation, and knowledge storage in this paper. The performance evaluation framework of knowledge management is shown as Fig. 2.

The processes of knowledge management performance evaluation model is described as follows:

Step1. Calculate the fuzzy weight value of the evaluative dimension.

(1) Each expert use linguistic variable of the Table 3 to calculate the KM performance of each dimension. And give a linguistic variable to represent the relative importance in two dimensions [2]. Giving comparative and important evaluation of extent in pair-wise comparisons.

(2) Using Fuzzy AHP to calculate the fuzzy weight as $\tilde{W}_i^p$ of each expert.

(3) Using Average Method to integrate fuzzy weight value of each expert with regard to each dimension into $\tilde{\tilde{W}}_i$.

$$\tilde{\tilde{W}}_i = 1/P \left(\tilde{W}_i^1 \oplus \tilde{W}_i^2 \oplus \cdots \oplus \tilde{W}_i^p\right) \tag{5}$$

Step2. Calculating evaluative value of each dimension

(1) Each expert use linguistic variable of the Table 3 to calculate evaluative values and weight values of evaluative indicators within each evaluative dimension.

(2) Using Weighted Average Method to integrate all of fuzzy evaluative value of all experts within each evaluative dimension. It can be computed as:

$$\tilde{\tilde{X}}_{ij} = \frac{1}{p}\left\{\left(\tilde{X}_{ij1} \otimes \tilde{W}_{ij1}\right) \oplus \left(\tilde{X}_{ij2} \otimes \tilde{W}_{ij2}\right) \oplus \cdots \oplus \left(\tilde{X}_{ijp} \otimes \tilde{W}_{ijp}\right)\right\} \tag{6}$$

Where $\tilde{\tilde{X}}_{ij}$ is the jth indicator's fuzzy evaluative value within ith dimension after the integration of all experts. $\tilde{X}_{ijp}$ is the jth evaluative indicator's fuzzy evaluative value of the pth decision-maker within the ith dimension. $\tilde{W}_{ijp}$ is the jth indicator's fuzzy weight value of the pth expert within the ith dimension.

(3)Calculating fuzzy evaluative value in each dimension

as:

$$\tilde{X}_i = \frac{1}{n_i}\left\{\tilde{X}_{i1} \oplus \tilde{X}_{i2} \oplus \cdots \oplus \tilde{X}_{in_i}\right\}, i = 1,2,\cdots,m \qquad (7)$$

where $\tilde{X}_i$ is the fuzzy evaluative value of the ith dimension. n_i is the evaluative indicator's numbers of the ith dimension.

(4)According to the fuzzy weight value and fuzzy evaluative value of each dimension, calculating comprehensive fuzzy evaluative value as:

$$\tilde{P} = \frac{1}{m}\sum_{i=1}^{m}\left(\tilde{X}_i \otimes W_i\right) \cong \left(P_1, P_2, P_3\right) \qquad (8)$$

where $\tilde{P}$ is the comprehensive fuzzy evaluative value, and m is the numbers of dimensions.

(5)Calculating the distance value of comprehensive fuzzy evaluative value $\tilde{P}$ and the linguistic variable L_i of each evaluative value (shown in Table 4). Distance measurement is computed as:

$$d(\tilde{P}, L_i) = \sqrt{\frac{1}{3}\left[(P_1 - l_{i1})^2 + (P_2 - l_{i2})^2 + (P_3 - l_{i3})^2\right]} \qquad (9)$$

where $\tilde{P} = (p_1, p_2, p_3)$ is the comprehensive fuzzy evaluative value. $L_i = (l_{i1}, l_{i2}, l_{i3}), i = 1,2,3,4,5$ is the linguistic variable of evaluative value.

(6)If the distance between comprehensive fuzzy evaluative value $\tilde{P}$ and the linguistic variable L_i is the minimum value, it represents that L_i is the integral evaluative value of KM activities.

5. Example Description

According to the business knowledge management performance evaluation framework (shown as Fig. 2) in this paper. Suppose there are three experts to evaluate the performance of KM. The step is described as follows:

Step1. The hypothesis makes the pair-wise comparison matrix by the three expert's important extent to each evaluative dimension as follows:

$$\tilde{T}_1 = \begin{bmatrix} (1,1,1) & (7,8,9) & (1,2,3) & (7,9,9) \\ (0.11,0.12,0.14) & (1,1,1) & (0.14,0.2,0.33) & (1,3,5) \\ (0.33,0.5,1) & (3,5,7) & (1,1,1) & (5,7,9) \\ (0.11,0.11,0.14) & (0.2,0.33,1) & (0.11,0.14,0.2) & (1,1,1) \end{bmatrix}$$

$$\tilde{T}_2 = \begin{bmatrix} (1,1,1) & (1,3,5) & (3,4,5) & (7,9,9) \\ (0.2,0.33,1) & (1,1,1) & (1,3,5) & (7,9,9) \\ (0.2,0.25,0.33) & (0.2,0.33,1) & (1,1,1) & (5,7,9) \\ (0.11,0.11,0.14) & (0.11,0.11,0.14) & (0.11,0.14,0.2) & (1,1,1) \end{bmatrix}$$

$$\tilde{T}_2 = \begin{bmatrix} (1,1,1) & (3,5,7) & (3,4,5) & (5,7,9) \\ (0.14,0.2,0.33) & (1,1,1) & (0.2,0.33,1) & (5,6,7) \\ (0.2,0.25,0.33) & (1,3,5) & (1,1,1) & (3,4,5) \\ (0.11,0.14,0.2) & (0.14,0.16,0.2) & (0.2,0.25,0.33) & (1,1,1) \end{bmatrix}$$

Step2. Calculating fuzzy weight value of each decision-maker within dimension via Fuzzy AHP as :

$$\tilde{W}_1^1 = (0.45,0.06,0.25,0.04)$$
$$\tilde{W}_1^2 = (0.3,0.16,0.11,0.03)$$
$$\tilde{W}_1^3 = (0.48,0.14,0.16,0.05)$$
$$\tilde{W}_2^1 = (0.55,0.09,0.32,0.04)$$
$$\tilde{W}_2^2 = (0.54,0.28,0.15,0.03)$$
$$\tilde{W}_2^3 = (0.58,0.14,0.23,0.05)$$
$$\tilde{W}_3^1 = (0.55,0.22,0.39,0.06)$$
$$\tilde{W}_3^2 = (0.54,0.33,0.16,0.13)$$
$$\tilde{W}_3^3 = (0.58,0.15,0.25,0.05)$$

Therefore, integrates the fuzzy weight value of each decision-maker within evaluative dimension as:

$$\tilde{\tilde{W}}_1 = (1.23,0.36,0.52,0.12)$$
$$\tilde{\tilde{W}}_2 = (1.67,0.51,0.7,0.12)$$
$$\tilde{\tilde{W}}_3 = (1.67,0.7,0.8,0.24)$$

$$W_1 = 0.52\ ,\quad W_2 = 0.18\ ,\quad W_3 = 0.22\ ,\quad W_4 = 0.08$$

Step3. Decision-makers use linguistic variable (shown as Table 5 and 6) to give their assessment value. According to data of Table 4. The first dimension value can be computed as:

$$\tilde{x}_{11} = \frac{1}{3}(\cdot)\left\{\begin{bmatrix}[(0.5,0.6,0.7)\otimes(0.7,0.8,0.9)]\oplus \\ [(0.5,0.6,0.7)\otimes(0.3,0.5,0.7)]\oplus \\ [(0.5,0.6,0.7)\otimes(0.7,0.8,0.9)]\end{bmatrix}\right\}$$
$$= (0.28,0.42,0.58)$$

Step4. Calculating evaluative value of each dimension as:

$$\tilde{x}_1 = (0.16,0.25,0.35)$$
$$\tilde{x}_2 = (0.07,0.14,0.25)$$
$$\tilde{x}_3 = (0.18,0.28,0.36)$$

Step5. Calculating fuzzy evaluative value of comprehensive effects according to the weight value of each dimension is $\tilde{P} = (0.28,0.46,0.63)$。

Step6. Calculating the distance value of comprehensive fuzzy evaluative value and the linguistic variable of each evaluative value via distance measurement as:

$$d(\tilde{P},\tilde{R}_1)=\sqrt{\frac{1}{3}[(0.28-0.7)^2+(0.46-0.9)^2+(0.63-0.9)^2]}=0.38(\mathrm{VG})$$

$$d(\tilde{P},\tilde{R}_2)=0.35(\mathrm{G})$$

$$d(\tilde{P},\tilde{R}_3)=0.25(\mathrm{MG})$$

$$d(\tilde{P},\tilde{R}_4)=0.15(\mathrm{F})$$

$$d(\tilde{P},\tilde{R}_5)=0.01(\mathrm{MP})$$

$$d(\tilde{P},\tilde{R}_6)=0.08(\mathrm{P})$$

$$d(\tilde{P},\tilde{R}_7)=0.16(\mathrm{VP})$$

$$d(\tilde{P},\tilde{R}_8)=0.26(\mathrm{CP})$$

$$d(\tilde{P},\tilde{R}_9)=0.95(\mathrm{CG})$$

Step7. If the distance value is the minimal, it's represented the whole performance evaluative value as namely the corresponding linguistic variables is [Medium poor].

According to the foregoing results, the knowledge management performance of this business belongs to "Medium Poor".

6. Conclusion

From the viewpoint of the business, knowledge management is based on the knowledge embedded in the process and allowed that business to operate profitably in providing attractive products and services to customers. The knowledge has become the most important practical factor. To demonstrate a business benefit, knowledge must be measured.

In general, business must reach a balance between intangible and tangible assets. The proposed model provides business systematic processes to measure the business performances evaluation in knowledge management. Using the linguistic variable and fuzzy Delphi method, managers can evaluate and understand the overall performance in knowledge management easily and effectively.

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Table 1 Activities and contents of knowledge management

Knowledge management activities	Contents
Knowledge creation [16]	Organizational knowledge creation involves five main steps：(1) Sharing tacit knowledge (2) Creating concepts (3) Justifying concepts (4) Building a prototype (5) Cross-leveling knowledge.
Knowledge transformation [16]	Knowledge Spiral brings up knowledge creation having four paths included from tacit to tacit(Originating-sharing tacit knowledge between individuals)、from tacit to explicit(Conversing-having group conversations to form concepts)、from explicit to explicit(Documenting-converting knowledge into explicit forms)、from explicit to tacit(Internalizing-making explicit knowledge tacit once more). It is mainly aimed at the interaction of tacit and explicit knowledge to show the path of the knowledge management removal at the same time, by the criterion knowledge oneself whether be easy to be explicit, and then aimed at the knowledge to be easy to be explicit or not, depend on the different path to design the more likely knowledge removal mechanism.
Knowledge diffusion [9]	Knowledge diffusion suffers the impact of common knowledge in employee easily, containing common language, common symbol, collective expertise, consciousness that share, know the individual knowledge realm.
Knowledge storage[4]	The business is considering how to store knowledge resource. It can adopt the knowledge to extract, the knowledge diffusion, structured etc.

Table 2 Linguistic variables for the importance weight

Linguistic variables	Triangular fuzzy number
Very Important	(0.7,0.9,0.9)
Important	(0.5,0.7,0.9)
Medium	(0.3,0.5,0.7)
Unimportant	(0.1,0.3,0.5)
Very Unimportant	(0.1,0.1,0.3)

Table 3 Linguistic variables for the ratings

Linguistic variables	Triangular fuzzy number
Equal importance	(1,1,1)
Equal importance	(1,1,3)
Both of them	(1,2,3)
Rather importance	(1,3,5)
Both of them	(3,4,5)
Very importance	(3,5,7)
Both of them	(5,6,7)
Extreme importance	(5,7,9)
Both of them	(7,8,9)
Absolute importance	(7,9,9)

Table 4 Fuzzy evaluative value of Decision-maker

Dimension		Knowledge Creation		Knowledge Transformation		Knowledge Diffusion		Knowledge Storage		The linguistic ratings of KM
Evaluative indicator		Workers with innovative ability	Knowledge Documentation	Worker's experience	Investment of professional employee	Authorization of employees	Professional knowledge techniques	Emphasis on intellectual property rights management	Information resource	
Expert 1	Evaluative value	C	MG	C	MP	MG	MP	MG	F	MP
	Weight value	I	I	I	MI	VI	VI	VI	VI	
Expert 2	Evaluative value	C	MG	MP	P	MG	C	MG	MP	F
	Weight value	MI	I	MI	MI	I	I	I	I	
Expert 3	Evaluative value	C	MG	MP	MP	G	C	MG	MP	MP
	Weight value	I	VI	MI	MI	I	VI	I	I	

Table 5 Linguistic variables of weight value

Linguistic variables	Triangular fuzzy number
Considerably unimportant (CUI)	(0.1,0.2,0.3)
Very unimportant (VUI)	(0.1,0.3,0.5)
Unimportant (UI)	(0.3,0.4,0.5)
Medium unimportant (MUI)	(0.3,0.5,0.7)
Common(C)	(0.5,0.6,0.7)
Medium important (MI)	(0.5,0.7,0.9)
Important (I)	(0.7,0.8,0.9)
Very important (VI)	(0.7,0.9,0.9)
Considerably important (CI)	(1, 1, 1)

Table 6 Linguistic variables of evaluative value

Linguistic variables	Triangular fuzzy number
Considerably poor (CP)	(0.1,0.2,0.3)
Very poor (VP)	(0.1,0.3,0.5)
Poor (P)	(0.3,0.4,0.5)
Medium poor (MP)	(0.3,0.5,0.7)
Fair (F)	(0.5,0.6,0.7)
Medium good (MG)	(0.5,0.7,0.9)
Good (G)	(0.7,0.8,0.9)
Very good (VG)	(0.7,0.9,0.9)
Considerably good (CG)	(1, 1, 1)

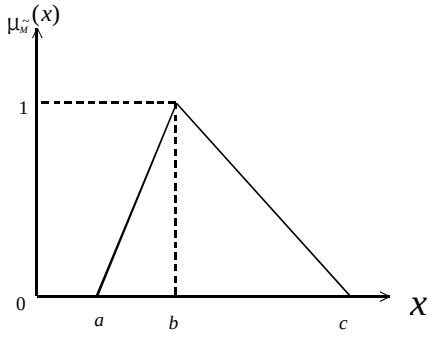

Fig. 1 Triangle fuzzy number $\mu_{\tilde{M}}(x)$.

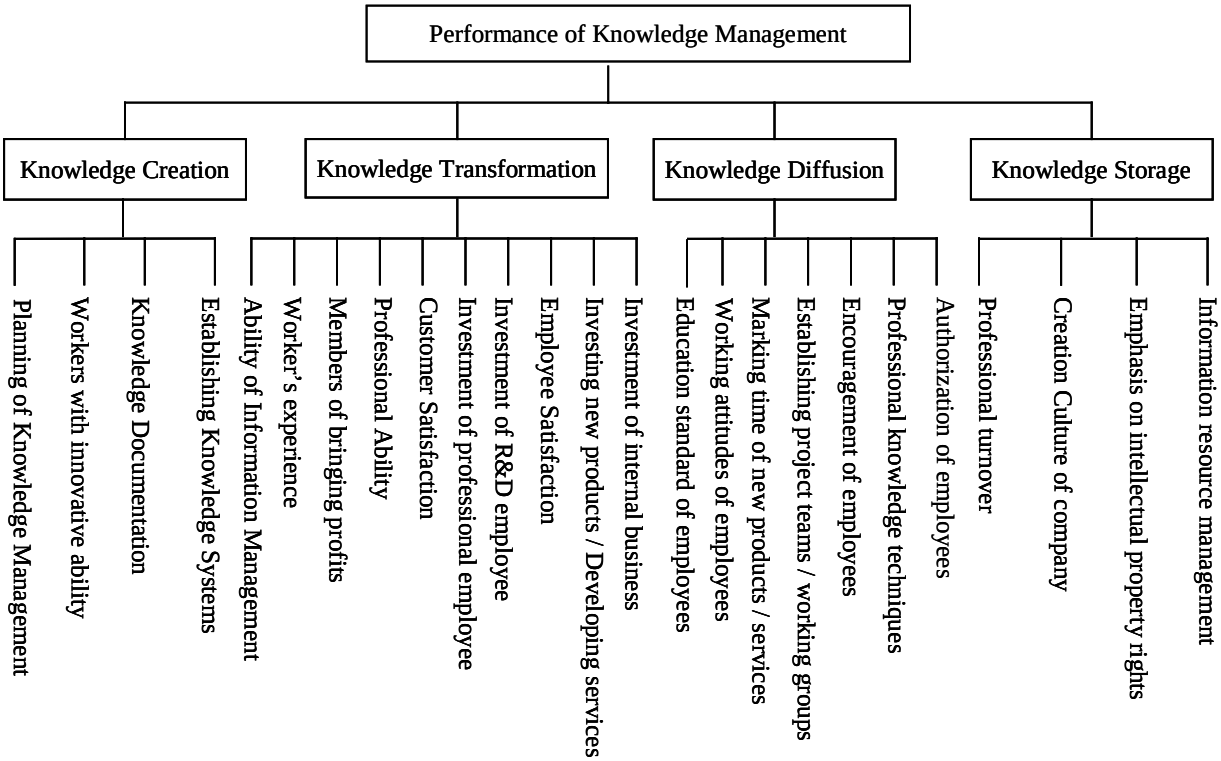

Fig. 2 Evaluative framework