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What is This?

Integrating option model and knowledge management performance measures: an empirical study

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Abstract.

The knowledge-based economy is coming, and knowledge management (KM) has rapidly disseminated in academic circles as well as in the business world. While an increasing number of companies have launched into knowledge management initiatives, a large proportion of these initiatives are limited to a technical focus. The problem with this type of focus is that it excludes and neglects the true potential benefits that can be derived from knowledge management. This paper develops a new metric, knowledge management performance index (KMPI), for evaluating the performance of a firm in its KM at a point in time. We therefore suggest that a KMPI can be used to determine KM activities from the following perspectives: knowledge creation, knowledge conversion, knowledge circulation and knowledge completion. When KM activities efficiency is increased, KMPI will also be expanded, enabling firms to become knowledge intensive. This paper makes three important contributions: (1) it provides a formal theoretical grounding for the validity of

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the Black-Scholes model that might be applied to KM; (2) it proposes a measurement framework to enable knowledge assets to be leveraged effectively and efficiently; and (3) it presents the first application of the Black–Scholes model that uses a real-world business situation involving KM as its test bed. The results prove the option pricing model can act as a measurement guideline to the whole range of KM activities.

1. Introduction

In a knowledge economy where the only certainty is uncertainty, one source of lasting competitive advantage is knowledge and its manipulation [1]. Today, there is a growing recognition by researchers and practitioners of the importance of managing knowledge as a critical source of competitive advantage. As the resource commitments to knowledge management (KM) continue to escalate, the following types of question are asked more frequently: is that investment in KM worthwhile? Is that KM we implemented a success? Is our KM productive and effective?

Recent surveys indicate that issues such as 'measuring the value of KM' and 'evaluating KM performance' are of great importance to managers in Asia [2], the United States [3] and the United Kingdom [4]. Given the increasing role of KM in upgrading business competitiveness, the wide interest of managers in measuring and evaluating both KM performance and benefit is not surprising [5].

At another level of analysis, the productivity paradox has become a contentious issue among both economists and the information technology (IT) community [6, 7]. Indeed, many KM practitioners have used IT to practice KM through knowledge management systems (KMS). Unfortunately, several researchers indicate that, while the level of IT investment is correlated to corporate revenues, it is not correlated to either productivity or profitability [8, 9]. Managers have found it difficult to demonstrate tangible returns on the resources expended to plan, develop, implement and operate KM. For example, since effectiveness and innovation cannot be readily quantified in terms of traditional outputs, these improvements are not reflected in economic efficiency statistics. Certainly, the fundamental issue of measuring and evaluating KM investments and performance remains unresolved.

Therefore, there is an important research issue: how do most firms that have initiated KM develop appropriate metrics to measure the effectiveness of their initiative? In other words, there is a need for metrics to justify KM initiatives. Given that most KM benefits are intangible, one method of measurement is the balanced scorecard (BSC). This includes both financial and other perspectives; e.g. customer, internal business, growth and learning. However, linking KM initiatives to performance is not enough. We need a more rigorous metric to assess KM performance with the ability to explain it and suggest future strategic actions that the firms should take to improve KM performance.

Our research objective was therefore to propose a new metric approach to evaluate knowledge management performance. This paper aims to propose option pricing models in such a way that they become part of managerial practice when evaluating KM solutions. Its main contribution is the description of a real-life case study that demonstrates the use of option evaluation methods for analyzing KM. Regarding the organization of this paper, we start by giving an overview of prior research on KM evaluation in Section 2. We then describe the methodology of KM evaluation and with the role of BSC, in Section 3. Section 4 briefs on how the option models can serve as evaluation tools for KM managers. The above-mentioned case study is presented in Section 5. Finally, the conclusion and future work are discussed in Section 6.

2. Preliminaries

KPMG [10] reports that the reasons for the creation of knowledge management initiatives cited by most companies are to facilitate better decision making, increasing profit and reducing costs. However, KM suffers from the same challenges as many other management issues: it assumes that knowledge is a 'thing' that is amenable to being 'managed' by a 'manager'. First, which KM process is the key point to achieve competitive advantage? Second, which measurement method is the best viewpoint to appraise KM performance?

KM performance measurement methods are broad categories of research issues. We can see that the method developments are diversified due to researchers' backgrounds, expertise and problem domains [11]. In our research, we can classify KM evaluation methods according to three types: qualitative and quantitative, financial and non-financial, internal and external performance approaches.

2.1. Qualitative and quantitative approaches

A qualitative research approach was refined using the outcomes of a pilot study and reviews by researchers of organizational learning. For example, the successes of knowledge sharing in organizations' culture are not only technological but also related to behavior factors. Besides expert interviews, critical success factors method (CSFs) and questionnaires are used to implement qualitative methods for exploring specific human problems.

In contrast, a quantitative research approach was designed to represent a tangible, visible and comparable 'ratio.' It can be measured by a financial and non-financial index that we will discuss in the next section. Table 1 shows the KM benefits and indicates which index, qualitative or quantitative, each is measured with.

2.2. Financial and non-financial approaches

Traditional quantitative methods focus on well-known financial measures, such as the payback period, the return on investment (ROI), the net present value (NPV), the return of knowledge (ROK), and Tobin's q. These methods are best suited to measure the value of daily transaction processing systems. Unfortunately, evaluation methods that rely on financial measures are not so suitable for complicated IT applications. These systems typically seek to provide a wide range of benefits, including many that are intangible in nature. For example, it is difficult to quantify the full value of a point-of-sales (POS) system [12] or an enterprise resource planning (ERP) system [13].

Table 1
The benefits in the qualitative and quantitative index

Knowledge management benefits	
Qualitative index	Quantitative index
• Improving employees' skills	• Decreasing product cycle time
• Improving strategies' quality	• Decreasing operation costs
• Improving core business processes	• Increasing operation productivity
• Developing customer relationship	• Increasing market share
• Developing supplier relationship	• Increasing shareholder equities
• Developing innovative cultures	• Increasing patent income

The non-financial measures method is different from traditional financial statement analysis. It uses a non-financial index such as frequencies, times, counts and numbers. For example, the number of topics on discussion boards in KMS is related to behavior factors and system use.

2.3. Internal and external performance approaches

Internal performance measurement methods focus on process and goal achievement efficiency. These methods evaluate KM performance through the gap between target and current value. The well-known methods include ROI, NPV, BSC, and performance-based and activity-based evaluation.

External performance measurement methods always compare results with benchmark companies, primary competitions or whole industry average. For example, benchmarking is the process of determining who is the very best, who sets the standard, and what that standard is. When we apply the benchmarking concept in business, the following types of questions are asked: which company has the best manufacturing operation? How do we quantify that standard?

2.4. Option evaluation approach

A number of researchers have written on the use of option models in IT investment decision making. The pioneering work of Dos Santos [14] employs Margrabe's exchange option model [15] for valuing an IS project, using a novel technology for testing. He argues that the

option model would be better than NPV to evaluate new IT projects. Similarly, Kambil et al. [16] use the Cox–Rubinstein binomial option pricing model [17] to determine whether or not a pilot project should be undertaken.

For a software platform, several options are usually relevant. In a process analogous to Kester's 'growth options' for firms [18], Taudes investigates options for evaluating 'software growth options' [19] to value software platforms and benefits.

Benaroch and Kauffman [12] investigate the problem of investment timing using the Black–Scholes model in a real-world case study dealing with the development of point-of-sale (POS) debit service. Their contributions show not whether an investment should be undertaken, but when to exercise the option held, i.e. when to implement a particular IT solution. In a follow-up paper, Benaroch and Kauffman [20] use sensitivity analysis to probe the Black–Scholes evaluation for IT investment opportunities. Taudes et al. [13] also compare NPV with the Black–Scholes evaluation method for employing SAP R/2 or switching to SAP R/3. Their results also indicate that, in the absence of formal evaluation of the time option, traditional approaches for evaluating information technology investments would have produced wrong recommendations.

3. Method and evaluation design

A universally accepted definition of KM does not yet exist. While there is debate as to whether knowledge itself is a cognitive state, a process, or an object, the description of KM as a process is based on understanding an organization as a knowledge system [21]. This view examines the nature of individual knowledge and collective knowledge, and their interactions.

3.1. The methodology of KM evaluation

While authors differ in the terminology used in describing the KM process, in aggregate their works can be said to describe KM as a simple process, as depicted in Figure 1. We reached a general conclusion from a collection of related KM research and defined the '4C' process of KM activities: creation, conversion, circulation and completion.

Knowledge creation relates to knowledge addition and the correction of existing knowledge. Nonaka and Takeuchi [27] suggest four modes of knowledge creation: socialization, externalization, internalization
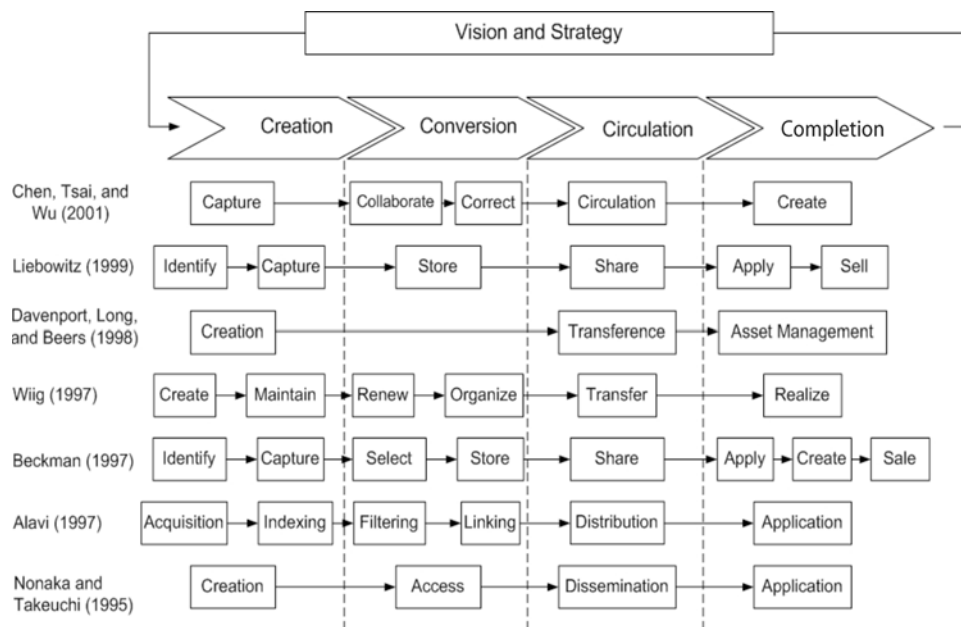
Fig. 1. KM process (see [22–28]).

and combination. The model emphasizes interactions between individuals and organizations.

Knowledge conversion relates to individual and organizational memory. While organizational memory reflects the shared interpretation of social interactions, individual memory depends on the individual's experiences and observations.

Knowledge circulation is the didactic exchange of knowledge between source and receiver. Transfer occurs at various levels: transfer of knowledge between individuals, from individuals to explicit sources, from individuals to groups, between groups, across groups, and from the groups to the organization.

An important aspect of the knowledge completion is that the source of competitive advantage resides in the knowledge itself. Here, a major challenge is how to integrate internal knowledge and the knowledge gained from the outside.

In order to present important research issues, the pursuit of which would lead to the enhancement of knowledge use in an organization, research questions related to each step of the KM process can be integrated into four perspectives with a BSC framework.

3.2. Integration with the BSC framework

Underlying Kaplan and Norton's [29,30,31] concept of the BSC is the idea that all aspects of measurement have their drawbacks; however, if companies offset some of the drawbacks with the advantages of others, the net measure can lead to decisions resulting in both short-term profitability and long-term success. As a result, they suggest that financial measures be supplemented with additional ones that reflect customer satisfaction, internal business processes, and the ability to learn and grow.

In a BSC framework, some metrics drive performance improvement and enable top management to make well-informed decisions that prepare their organization for the future. The major elements include:

(1) vision – an image of what the organization will look like and do in the future;
(2) strategy – giving a sense of purpose to their organization;
(3) objectives – the mission and vision are translated into objectives; and
(4) performance measures – the objectives can be measured through well-chosen indicators.

Table 2 outlines the four perspectives included in a balanced scorecard, and Figure 2 shows the relationships between them.

The BSC concept can also be used to measure, evaluate and guide activities that take place in specific functional areas of a business. For this reason, we integrated the concepts of BSC and the 4C process in KM.

Table 2
The four perspectives in a BSC

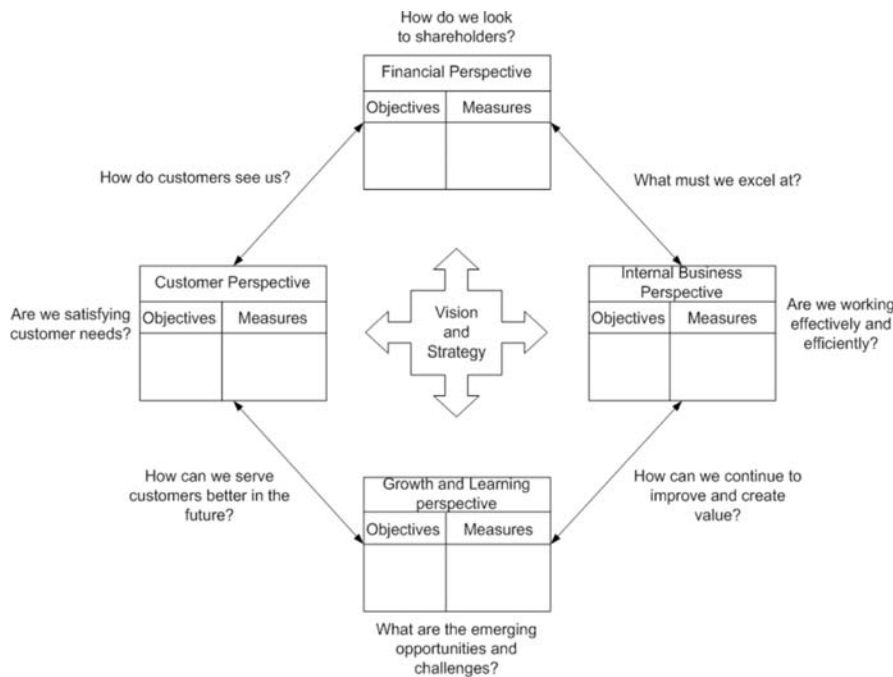| Perspective	Mission
Financial	To focus on the themes of (1) revenue growth and mix, (2) cost reduction and profitability, and (3) asset utilization and investment strategy.
Customer	To achieve desired overall performance, by improving customers' satisfaction, retention, and acquisition rate.
Internal business	To identify processes that are most critical for achieving customer and ownership objectives, i.e. quality, cycle time, and innovation.
Growth and learning	To identify needed developments within the organization to provide the infrastructure for future growth, i.e. employee capabilities, productivity, and empowerment.

Fig. 2. Relationship between the four perspectives in the BSC.

The following four perspectives have been suggested for a balanced KM scorecard: creation, conversion, circulation and completion. A framework based on these four new perspectives is shown in Table 3 and the relationships between them are illustrated in Figure 3.

4. Applying the Black–Scholes model

The field of finance has developed a variety of option pricing models, with the fundamental one being the Black–Scholes model. Because these models were originally developed to evaluate options on securities traded in the financial markets, they make certain assumptions that more naturally apply to options on traded assets. Over time, these models and their extensions have also been used in a variety of evaluative settings involving capital, budgeting, investments, and embedding real options. This paper makes three important contributions in this context:

(1) it provides a formal theoretical grounding for the validity of the Black–Scholes model that might be applied to KM;

Table 3
The four perspectives in a balanced KM scorecard (see [4] and [32])

Knowledge conversion perspective (customers' view)	Knowledge completion perspective (financial/management's view)
Mission: deliver value-adding knowledge and services to end-users	Mission: contribute to the value of the business
Key question: are the knowledge and services provided by the KM project fulfilling the needs of the user community?	Key question: is the KM project accomplishing its goals and contributing value to the organization as a whole?

Objectives:
  Users' experiences
  Users' professional skills
  User satisfaction
  Users' information management ability
  The investment in new products or services
  The investment in employees
	Objectives:
	  Ensure the KM project provides business value
	  The quantities/qualities of the knowledge database
	  The numbers of patents
	  Sell appropriate KM products and services to third parties
	  Improve business brand
	  Improve business market value

Knowledge circulation perspective (internal business view)	Knowledge creation perspective (learning and growth view)
Mission: deliver knowledge and services in an efficient and effective manner	Mission: deliver continuous improvement and prepare for future challenges
Key question: does the KM project create, deliver and maintain its knowledge and services in an efficient manner?	Key question: is the KM project improving its knowledge and services, and preparing for potential changes and challenges?

Objectives:
  The average age of users
  The education level of users
  The incentive systems for users
  The sharing culture among users
	Objectives:
	  Continuously promote knowledge through training and development
	  Ensure executives' support and encourage KM projects
	  The innovation capability of the users
	  The average seniority of the users

(2) it proposes a measurement framework to enable leveraging knowledge assets effectively and efficiently; and

(3) it presents the first application of the Black–Scholes model using a real-world business situation involving KM as its test bed.

4.1. Fundamental option pricing model

In Section 2, we sought a range of issues for KM evaluation. Consequently, the key to understanding the KM performance evaluation in which option pricing is worth using relates to basic elements of the Black–Scholes model. For example:

(1) KM infrastructure investments are often made without any immediate expectation of payback. However, these can be converted investment opportunities into option's underlying asset. Some examples of these investments include intranet and internet environment, data ware-

housing and data mining technologies, and web service.

(2) It is often difficult to forecast value payoffs from KM embedded technologies in the face of the unpredictable, implementation, and maintenance costs. Some examples of these technologies include search engines, enterprise information portals, and automated workflow systems.

(3) Knowledge investments reveal that knowledge is a core part of a company's competition advantages. Therefore, knowledge can be viewed as a product and gain tangible or intangible profits. Nevertheless, knowledge has its 'product life cycle' through newborn, mature and abandoned phases. Here, the analyst can benefit from framing such choices in the context of option pricing by focusing on such elements as time remaining to exercise, when the option matures, and by tracking the value of the option to change the knowledge use situation. Therefore, the
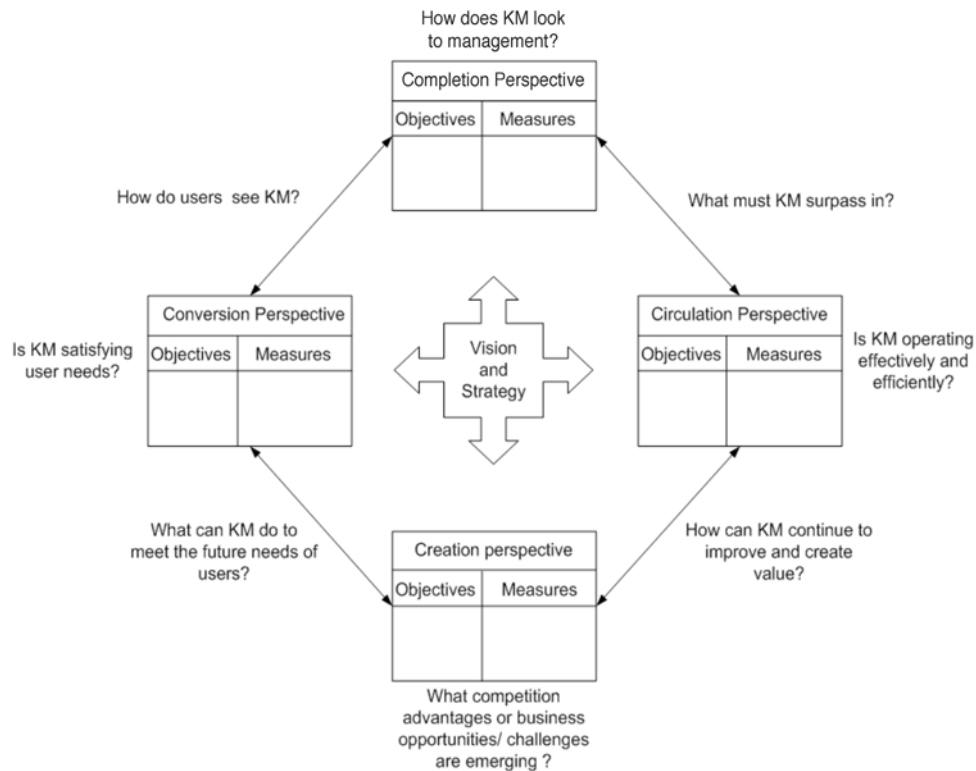
How does KM look
to management?

Completion Perspective

| Objectives | Measures |

How do users see KM?

What must KM surpass in?

Conversion Perspective

| Objectives | Measures |

Is KM satisfying
user needs?

Vision
and
Strategy

Circulation Perspective

| Objectives | Measures |

Is KM operating
effectively and
efficiently?

What can KM do to
meet the future needs of
users?

Creation perspective

| Objectives | Measures |

How can KM continue to
improve and create
value?

What competition
advantages or business
opportunities/ challenges
are emerging ?

Fig. 3. Relationship between the four perspectives in the balanced KM scorecard.

knowledge investments are similar to option pricing model.

4.2. Assumptions in the Black–Scholes model

The Black–Scholes option pricing formula [33] prices European call or put options on a stock that does not pay a dividend or make other distributions. The formula assumes the underlying stock price follows a geometric Brownian motion with constant volatility.

4.2.1. Definition of the Black–Scholes formula. Equation (1) can be explained in that perfect financial markets are arbitrage-free in the sense that no investor can make a profit without taking some risk or expending some capital. Such gains could be made if an option were priced differently from a portfolio consisting of the underlying asset and a risk-less security with the amounts continuously adjusted so that the value of the portfolio replicates the value of the option. In equation (1), the value of a company or an asset based on an underlying perception of the value is called intrinsic

value. For call options, this is the difference between the underlying stock price and the strike price; and further, time value represents the portion of the option premium that is attributable to the amount of time remaining until the expiration of the option contract. Basically, time value is the value the option has in addition to its intrinsic value.

$$\text{Option pricing formula} = \text{intrinsic value} + \text{time value} \quad (1)$$

4.2.2. Applying the Black–Scholes formula. In the Black–Scholes model [34], the value of a call option is its discounted expected terminal value, $E[C_T]$. The current value of a call option is given by $C = E[C_T] (1 + r)^{-1}$, where $(1 + r)^{-1}$ is the present value factor for risk-neutral investors. For a risk-neutral investor there is no difference between an investment with a certain rate of return and an investment with an uncertain rate if the return expected value matches that of the investment's rate of return. Given that $C_T = \max [0, S_T - K]$, and assuming that S_T is log–normally distributed, it can be shown that:

Black–Scholes formula

$$C = S \cdot \Phi(d_1) - K(1 + r)^{-t}\Phi(d_2) \qquad (2)$$

where

$$d_1 = \frac{\ln\frac{S}{K} + (r + 0.5\sigma^2)t}{\sigma\sqrt{t}}$$

$$d_2 = \frac{\ln\frac{S}{K} + (r - 0.5\sigma^2)t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t}$$

As shown in equation (2), the Black–Scholes formula contains fewer parameters, making it easier to determine. In addition to the 'ease of use' issue, applying option-pricing concepts is attractive because of the conceptual clarity it brings to the analysis. Many knowledge management initiatives indicate that the high potential variance of expected revenues from KM would be the key element in making the right decision. In this sense, option pricing seems just right. We assume the parameters of the Black–Scholes model to be applied to KM. We employ the notation shown in Table 4.

5. Case study

In this paper, we used a case study methodology to evaluate the performance of option pricing models. To demonstrate how the test was executed, one high-technology company was selected. The research process is shown in Figure 4.

The whole KM evaluation process can be roughly divided into four phases. Each phase is described as follows:

- Preparation phase. In principle, it is impossible to design a perfect experiment to start off with. In the preparation phase all we have to do is simply set up and understand our experiment for that particular case study. After some adjustments we then construct an evaluation model for KM, as shown in Figure 3.
  Step 1: Set up
  Step 2: Related work
  Step 3: Establish the evaluation model

- General KM evaluation phase. Once the evaluation model has been constructed in step 3, we use a questionnaire and interview methodology to verify that we have a balanced KM scorecard. In addition, we use fuzzy linguistic analysis to calculate each perspective value in the balanced KM scorecard. The details are described in Section 5.1.
  Step 4: Questionnaire/interview
  Step 5: Choose interviewer
  Step 6: Fuzzy linguistic analysis
  Step 7: Calculate the index

- Option phase. In this phase, we use the Black–Scholes model to estimate four perspectives in KM. With that result we can then calculate the appropriate value to represent the total knowledge management performance index (KMPI). We also use a sensitivity analysis to show how the result of an analysis changes as its underlying assumption changes. The details are described in Sections 5.2 and 5.3.
  Step 8: Apply the Black–Scholes option model
  Step 9: Sensitivity analysis

- Revision phase. Finally, we will ask experts to verify the evaluation model under construction. If necessary, we will modify the formula and the model according to their suggestions.
  Step 10: Review the evaluation model
  Step 11: Modify the evaluation formula
  Step 12: Modify the evaluation model

Table 4
The notations for Black–Scholes option pricing model and its application to KM

| Notation	Black–Scholes option pricing model	Apply to KM
C	The theoretical call premium	Value of investment
S	The value of the option's underlying stock price	Value of expected revenues
K	The option's exercise price	Actual costs/expenses
σ	The standard deviation of the expected rate of return on S	Uncertain factors
$\Phi(d_1)$	The exposure of the option price with respect to the stock price	Measurement of KM investment and output
$\Phi(d_2)$	The cumulative standard normal distribution evaluated at $(S > K)$ or $(S < K)$	Probability of KM success or failure
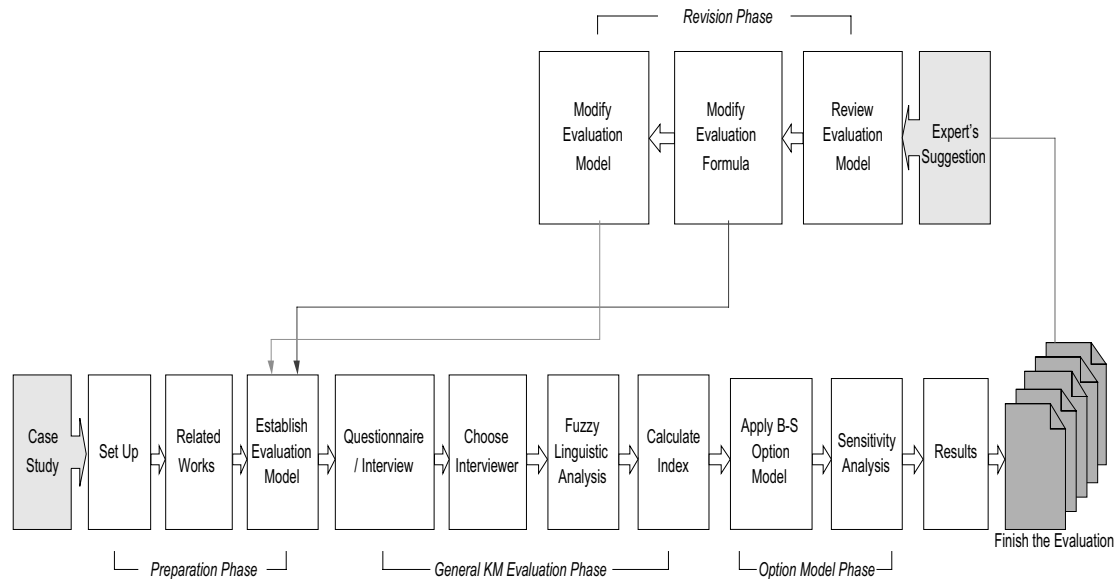
Fig. 4. Case study research process.

5.1. General KM evaluation

In order to judge the importance of each measure in the proposed four perspectives balanced KM scorecard, we designed a questionnaire and interviewed end-users. Additionally, we used fuzzy linguistic analysis to decide the default value for importance in each measure.

5.1.1. The questionnaire analysis. We sent out 74 questionnaires and 60 valid questionnaires were retrieved, so the ratio of valid retrievals was 81%.

 Reliability. In our study, we evaluated KM activities from the following perspectives: knowledge creation, knowledge conversion, knowledge circulation and knowledge application. Reliability was evaluated by assessing the internal consistency of the items representing each factor, using Cronbach's α. The 20-item instrument has a reliability of 0.86, exceeding the minimum standard of 0.80 suggested for basic research. Furthermore, each of these 20 items has a corrected item-to-total correlation of above 0.612.

 Content validity. The instrument meets the requirements of reliability and consistent factor structure. However, while high reliability and internal consistency are necessary conditions for a scale's construct validity (the extent to which a scale fully and unambiguously captures the underlying, unobservable, construct it is intended to measure) they are not sufficient. The basic qualitative criterion concerning construct

validity is content validity. Content validity implies that the instrument considers all aspects of the construct being measured. In our study, we use the fuzzy Delphi method to adjust the fuzzy weight value for each measure in the questionnaire, as shown in Appendix A. Then, we calculate the triangular fuzzy number for each measure. After the above step, we average each fuzzy weight value, and obtain the mean value. It is our aim to find the critical objective measures in our questionnaire.

5.1.2. Setting up the triangular fuzzy number. We used fuzzy Delphi method to adjust the fuzzy weight value for each measure. For example, the final measure of 'innovation ability' in the knowledge creation perspective was described as follows.

$$\widetilde{W}_{\text{innovation}} = (0.2, 0.61, 0.9)$$

$$a_{\text{innovation}} = 0.2$$

$$b_{\text{innovation}} = \tfrac{1}{60}[(14*0.8) + (9*0.3) + (11*0.75) + (22*0.5) + (4*0.9)] = 0.6125$$

$$c_{\text{innovation}} = 0.9$$

where $\widetilde{W} = (a_k, b_k, c_k)$, $k = 1, 2, \ldots, n$

$$a_k = \operatorname*{Min}_l\{a_{lk}\}, \quad b_k = \frac{1}{m}\sum_{l=1}^{m} b_{lk}, \quad c_k = \operatorname*{Max}_l\{c_{lk}\} \qquad (3)$$

Table 5
The value of four perspectives in a balanced KM scorecard

KM process	Objective	Measure	Value
Creation	Continuous training and development	0.64	
	The innovation abilities for users	0.57	0.65
	The average seniority for users	0.73	
Conversion	Users' experiences	0.62	
	Users' professional skills	0.48	0.54
	User satisfaction	0.52	
Circulation	The incentive systems for users	0.55	
	The sharing culture among users	0.57	0.54
	The standardization of documents	0.51	
Completion	Ensure the KM project provides business value	0.62	
	The quantities/qualities of the knowledge database	0.42	0.51
	The numbers of patents	0.50	

In Equation (3), $\tilde{W}$ represents the kth measure's importance of the lth participation's evaluation.

5.1.3. Averaging the evaluation measures. After the above step, we average each fuzzy weight value $\tilde{W}_k$, and obtain the mean value S_k. For example, the mean value S_k of 'innovation ability' in the knowledge creation perspective was described as follows. Table 5 shows an example of measures and values for the four perspectives.

$$S_{\text{innovation}} = \frac{0.2 + 0.61 + 0.9}{3} = 0.57 \qquad (3a)$$

According to the results, we understand the KM performance in each perspective. However, we cannot gather significant discoveries because there are no differentiable measure values in Table 5. Therefore, we will use our proposed option pricing model to estimate KM performance for each perspective.

5.2. Using the Black–Scholes option pricing model

In this section, we use the Black–Scholes model to estimate the knowledge creation perspective. In equations (4)–(6), we use parameters of the model to calculate the appropriate value that can represent the total knowledge management performance index (KMPI). In equation (7), we can determine which KM process or perspective must be improved by KMPI. As shown in Table 6, the knowledge completion process is the weakest in the whole range of KM activities (KMPI = 0.0014). Therefore, the manager will enhance related objectives in this perspective according to the above statement.

(1) Calculating the investment costs of KM (S)

$$S_{\text{KM}} = \sum_{1}^{t} C_{\text{KM}} = (\text{equipment cost + labour cost} + \text{time cost + operation cost}) \qquad (4)$$

(2) Calculating the expected revenues of KM (K)

$$K_{\text{KM}} = \sum_{1}^{t} R_{\text{KM}} = (\text{physical revenues} + \text{invisible revenues}) \qquad (5)$$

(3) Calculating the uncertain factors (σ)

$$\sqrt{\sum_{i=1}^{n} \frac{(S_i - \overline{S_{\text{KM}}})^2}{n}}, \, S_i = S_{\text{KM}}(t) - S_{\text{KM}}(t-1) \qquad (6)$$

(4) Calculating the knowledge management performance index (KMPI)

$$BS_{\text{KM}} \text{ value} = \text{KMPI}$$
$$\text{KMPI} = C = S \cdot \Phi(d_1) - K(1+r)^{-t}\Phi(d_2) \qquad (7)$$

Table 6
KMPI of Black–Scholes model

KM process	Intrinsic value ($S - K$)		Time value		Black-Scholes option value
	S	K	σ	t	
Creation	2400	3215	12%	2	35.8174
Conversion	2150	3000	12%	2	20.2288
Circulation	2000	3400	12%	2	1.0652
Completion	2000	4600	12%	2	0.0014

5.3. Sensitivity analysis using Black–Scholes model derivatives

Sensitivity analysis aims to show how the results of an analysis change as its underlying assumptions change. The derivative analysis is used in the investment arena for analyzing the sensitivity of the value of a financial option to changes in the variables. As shown in Table 7, we can evaluate the benefits or costs in the KM project with derivative analysis.

5.3.1. Option sensitivity analysis. Sensitivity analysis is a set of factor sensitivities used extensively by traders to quantify the exposures of portfolios that contain options. Each measures how the portfolio's market value should respond to a change in some variable example, implied volatility, interest rate or time. Option sensitivity analysis is called 'the Greeks' because four out of the five are named after letters of the Greek alphabet.

$$Delta = \Delta = \frac{\partial C}{\partial S} = N(d_1), \;\; Gamma = \Gamma = \frac{\partial^2 C}{\partial S^2}$$

$$Vega = v = \frac{\partial C}{\partial \sigma}, \;\; Rho = \rho = \frac{\partial C}{\partial r}, \; Theta = \theta = \frac{\partial C}{\partial t} \qquad (8)$$

As shown in Equation (8), the derivatives are computed with respect to the value of the call option, for the value of the underlying project asset, the cost to exercise the option, the implied volatility, the changes in the risk-free rate, and the time decay of the option as expiration nears, respectively. In addition to providing the analyst with a reading on the sensitivity of an option position to these parameters, option derivative analysis is also used to devise heading strategies that ensure a position is immunized against movements or changes in the parameters that create market or instrument risk.

5.3.2. KM performance sensitivity analysis. As shown in Table 7, we find that the delta and gamma values are higher in the stage of knowledge creation, which means the stage of knowledge creation affects knowledge management performance. In addition, we can understand the vega and rho values are influenced by time and uncertain factors. However, we generalize about the fourth stage – KM completion is not sufficient to support the whole KM project successfully. Due to the lowest performance value in the KM completion stage, the enterprise can make appropriate decisions to improve KM performance. Furthermore, when the Black–Scholes option pricing model is adopted, the enterprise can use sensitivity analysis to supervise KM performance at any time, without having to re-estimate any variables or recompute any models.

Delta (Δ) is a by-product of the Black–Scholes model; it measures an option price that will move given a small change in the underlying stock price. We can use delta degree to measure the change in expected revenues underlying change in the value of investment in KM projects. The delta of KM value can control the efficiency of KM.

Gamma (Γ) measures how fast the delta changes for small changes in the underlying stock price. In KM performance evaluation, we can use gamma degree to evaluate the value of KM practice for enterprise.

Vega (v). The change in option price given a one percentage point change in volatility. Like delta and gamma, vega is also used for hedging. In KM performance evaluation, we can use vega degree to evaluate uncertain factors that influence KM performance.

Rho (ρ). The change in option price given a one percentage point change in the risk-free interest rate. In KM performance evaluation, we can use rho degree to evaluate the risk-free interest influence for KM performance. So, we can use the index to evaluate KM practice cost efficiency, because of the interest influence in factor cost.

Theta (θ). The change in option price given a one day decrease in time to expiration. It is a basic measure of time decay. Unless the portfolio is travelling at close to the speed of light, the passage of time is constant and

Table 7
Sensitivity analysis

KM process	(Delta)	(Gamma)	(Vega)	(Theta)	(Rho)
Creation	0.176	0.0006	878.0326	−49.5336	773.0867
Conversion	0.1208	0.0006	611.0055	−32.6966	478.8825
Circulation	0.0098	0.0001	73.9137	−3.3267	36.9776
Completion	0.0	0.0	0.2634	−0.0093	0.0744

inexorable. In KM performance evaluation, we can use theta degree to evaluate the passage of time's influence on KM performance.

A major challenge for KM research lies in making models and theories to evaluate KM performance and values. However, traditional methodologies have long relied on NPV, simple cost–benefit analysis, critical success factors and other less-structured techniques to perform their assessments. Thus, our experiment has been to review critically the case for using option pricing as a basis for KM performance analysis and to evaluate its merits in an actual real-world business setting.

6. Conclusions

In this paper, we have put forward the argument that the option pricing model can be applied to KM performance evaluation. In the initial stage, we reached a general conclusion from a collection of related KM research and defined the 4C process of KM activities: creation, conversion, circulation and completion. In the next stage, we sought to identify which process would lead to the enhancement of KM performance in a firm; hence we integrated the KM process with the BSC framework in four interrelated main research streams. Finally, we illustrated how the Black–Scholes model can be applied in the case of a real-world KM performance option, where significant uncertainties that are not appropriately handled using traditional financial analysis were present. The results have proved that the option pricing model can act as a measurement guideline for KM activities.

The power of KMPI to represent the 4C performance of firms was tested. When KMPI increases, KM performance likewise improves. Therefore, KM project managers should invest their related resources in the weakest KM process. KM project managers can improve the objectives of weak KM processes with a balanced KM scorecard, and thus lead to higher performance. Accordingly, KM project managers can recognize the value of 4C as it relates to organizational performance, and develop a more accurate model of their KM. KMPI provides some preliminary insights on how corporate knowledge activities should be organized to contribute maximally to KM performance.

Future research will focus on several issues. First, we will investigate other firms using our approach to KM performance evaluation. Second, we will gage the risk associated with the KM project in a firm. Finally, we will improve the parameter estimation methods. In particular, more general guidelines could make the option evaluation of KM performance less time-consuming and more reliable.

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Appendix A. Questionnaire

	1	2	3	4	5
I *Knowledge creation*					
Continuously promote knowledge through training and development	☐	☐	☐	☐	☐
Ensure executives support and encourage KM projects	☐	☐	☐	☐	☐
The innovation capability of the users	☐	☐	☐	☐	☐
The average seniority of the users	☐	☐	☐	☐	☐
II *Knowledge conversion*					
Users' experience	☐	☐	☐	☐	☐
Users' professional skills	☐	☐	☐	☐	☐
Users' satisfaction	☐	☐	☐	☐	☐
Users' information management ability	☐	☐	☐	☐	☐
The investment of new products or services	☐	☐	☐	☐	☐
The investment of employees	☐	☐	☐	☐	☐
III *Knowledge circulation*					
The average age of users	☐	☐	☐	☐	☐
The education level of users	☐	☐	☐	☐	☐
The incentive systems for users	☐	☐	☐	☐	☐
The sharing culture among users	☐	☐	☐	☐	☐
IV *Knowledge application*					
Ensure the KM project provides business value	☐	☐	☐	☐	☐
The quantities/qualities of the knowledge database	☐	☐	☐	☐	☐
The numbers of patents	☐	☐	☐	☐	☐
Sell appropriate KM products and services to third parties	☐	☐	☐	☐	☐
Improve business brand	☐	☐	☐	☐	☐
Improve business market value	☐	☐	☐	☐	☐

Note: 1 → Strongly Disagree   2 → Disagree   3 → Average
4 → Agree   5 → Strongly Agree