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Measuring knowledge management performance using a competitive perspective: An empirical study

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ABSTRACT

This paper proposes an approach of measuring a technology university's knowledge management (KM) performance from competitive perspective. The approach integrates analytical network process (ANP), which is a theory of multiple criteria decision-making and is good at dealing with tangible and intangible information, with balanced scorecard (BSC) that contains four perspectives, including customer perspective, internal business perspective, innovation and learning perspective, and financial perspective, being adopted as the indicators of KM performance measurement (KMPM). This paper makes three important contributions: (1) it propose a methodology of comparing an organization's knowledge management performance with its major rivals to offer effective information for improving KM, increasing decision-making quality, and obtaining clear effort direction of attaining competitive advantage; (2) it explores the case involving a lot of findings that present the positions of the case organization against it major rivals and imply that the technology university has to reinforce knowledge creation and accumulation to catch up with its competitive rivals; and (3) it is generic in nature and applicable to benefit an organization. The results prove the proposed method can act as a measurement tool for the entire KM of an organization.

1. Introduction

Despite the various studies trying to develop metrics and methods to measure knowledge (Edvinsson, 1997; Lee, Lee, & Kang, 2005; Liebowitz & Wright, 1999), people think knowledge measurement is one of the most difficult parts of the knowledge management (KM) activities (Ruggles, 1997). Some studies argue that knowledge cannot be measured, but that activities or outcomes associated with applying knowledge can be measured (Ruggles, 1998). However, knowledge is a critical factor in an organization's competitiveness. It is also the future value of an organization. Nevertheless, knowledge is intangible and difficult to measure. Therefore, how to manage knowledge, becomes a critical issue, and KM becomes the key to success for an organization. To obtain effective knowledge management, it is necessary to be able to measure KM performance (Ahn & Chang, 2004). However, most of the metrics and methods of knowledge measurement that have been developed are concentrated on measuring the knowledge within the organization. In this hypercompetitive environment, the contributions of a KM performance measurement method will be seriously limited without comparing with major rivals from competitive perspective. Thus, its most important task is to compare the organization's KM performance with that of its major competitors, to find out what is required to attain the competitive edge.

To achieve this aim, this paper proposes an approach of measuring KM performance from competitive perspective. This approach integrates the analytical network process (ANP) with balanced scorecard (BSC) that contains four perspectives, including customer perspective, internal business perspective, innovation and learning perspective, and financial perspective, being adopted as the indicators of KM performance measurement. The ANP employed in this paper is a multi-attribute decision-making approach based on the reasoning, knowledge, experience, and perceptions of experts in the field. Even though it does not provide an optimal solution, it is valuable for MCDM involving intangible attributes that are associated with strategic factors (Joseph, 1999). One of the major advantages of using ANP is its capability to evaluate the consistency of the decision-maker while making pair-wise comparisons of the relevant importance of the environments.

The remainder of this paper is organized as follows. In Section 2, the relative literatures are reviewed. The details of the approach and a case study are illustrated in Section 3. Then, in Section 4, some important issues such as implications, limitations, and so forth are discussed. We conclude this paper in Section 5 with suggestions and future researches.

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2. Literature review

2.1. Knowledge management performance measurement

In recent years, the evaluation of KM performance has become increasingly important, since it promotes strategic organizational learning and so provides the capabilities required to meet customer needs (Marr, 2004; Smits & Moor, 2004). Some recent examples are as follows. Ahn and Chang (2004) developed the AP^3 methodology to assess the contribution of knowledge to business performances by employing product and process as intermediates between the two (Ahn & Chang, 2004). González, Giachetti, and Ramirez (2005) proposed a knowledge management system (KMS) called "a KM-centric help desk", which is designed to be incorporated into the daily operation of the help desk, to draw up diverse knowledge resources in the organization including databases, files, experts, knowledge bases, and group chats (González et al., 2005). The benefits of the KMS are evaluated using a simulation study with actual data from a help desk. Lee et al. (2005) provided a knowledge management performance index (KMPI) for assessing the performance of a firm in its KM at a point in time (Lee et al., 2005). For the purpose of the KMPI, they had defined a knowledge circulation process (KCP) as a logistics function having five components: knowledge creation, knowledge accumulation, knowledge sharing, knowledge utilization, and knowledge internalization. When the KCP efficiency increases, the KMPI expands as well, enabling firms to become knowledge-intensive.

KM performance measurement methods are broad categories of research issues. It may be said that the method developments are diversified due to researchers' backgrounds, expertise, and problem domains (Alavi & Leidner, 2001). In the prior research, we classified KM evaluation methods by using the following eight categories (Chen & Chen, 2005): qualitative analysis, quantitative analysis, financial indicator analysis, non-financial indicator analysis, internal performance analysis, external performance analysis, project-orientated analysis, and organizational-orientated analysis, together with their measurement matrices for different research and problem domains. These methods are summarized in Table 1.

Table 1
A review of KM performance evaluation perspectives.

Category	Sub-categories	Researchers
Qualitative analysis	Questionnaire	Changchit et al. (2001)
	Expert interviews	Longbottom and Chourides (2001)
	Critical success factors	Chourides et al. (2003)
Quantitative analysis		
Financial indicator analysis	Return on investment	Laitamaki and Kordupleski (1997)
	Net present value	Stein et al. (2001)
	Tobin's *q*	Lev (2001)
		Hall et al. (2000)
Non-financial indicator analysis	Communities of practice	Smits and Moor (2004)
	Individual, context, content and process knowledge assessment	Holt et al. (2004)
Internal performance analysis	Balanced scorecard	Kaplan and Norton (1996)
		Martinsons et al. (1999)
	Activity-based evaluation	Hasan and Gould (2001)
External performance analysis	Benchmarking	Marr (2004)
		Pemberton et al. (2001)
	Best practices	Asoh et al. (2002)
Project-orientated analysis	Social patterns	Bresnena et al. (2003)
	KM project management model	Kasvi et al. (2003)
Organizational-orientated analysis	Intellectual capital	Edvinsson (1997)
		Sveiby (1998)

2.1.1. Qualitative and quantitative approaches

A qualitative research approach was finalized by using the outcomes of a pilot study and the reviews by researchers of organizational learning. For example, the success of knowledge can be shared in an organizational culture, not only technological knowledge, but also the knowledge related to behavioral factors (Hertzum, 2002). In addition, expert interviews, critical success factors method (CSFs), and questionnaires are used to implement qualitative methods for exploring specific human problems.

From an organizational perspective, attention to an organization's internal controls has increased significantly since the 1990s. Changchit et al. used a questionnaire for an experimental examination to test how satisfactory the expert system was, to be able to facilitate the transfer of internal control knowledge to management (Changchit, Holsapple, & Viator, 2001). The results indicated that expert systems are viable aids for transferring internal control knowledge to managers. Longbottom and Chourides reported on interviews with key staff members of organizations, at various stages of approaching and deploying KM programs (Longbottom & Chourides, 2001). In a follow-up paper, the researcher investigated issues concerning the CSFs and measurements of KM, establishing practical and key factors likely to enhance the successful implementation of a KM system (Chourides, Longbottom, & Murphy, 2003).

The aim of quantitative analysis is to present the extent of the impact on both decision-making and task performance, using historical data that is easily available, relevant, accurate, and timely. This evaluation can avoid the drawbacks of qualitative analysis, especially in the subjective judgment of empirical results. Therefore, a quantitative research approach is designed to represent a tangible, visible and comparable 'ratio'. In other words, quantitative analysis can be used to measure the explicit knowledge of an organization or an individual, with both financial and non-financial indicators as discussed below.

2.1.2. Financial and non-financial approaches

Traditional quantitative methods focus on well-known financial measures, such as the analysis of financial statements, the payback period, the return on investment (ROI), the net present value (NPV), the return of knowledge (ROK), and the Tobin's *q*. These methods are best-suited to measure the value of daily transaction processing systems.

Laitamaki and Kordupleski used an ROI index to evaluate KM projects and performance in customer value added (CVA) products (Laitamaki & Kordupleski, 1997). From a managerial perspective, Stein et al. deployed a knowledge-based system which was designed to automate tasks previously performed manually, train new staff members, and capture knowledge, to enable a university organization to improve services (Stein, Manco, & Manco, 2001). Performance evaluation used NPV to diagnose the project outcome. Finally, the system could be viewed as an estimation tool, giving a competitive advantage to the organization (Stein et al., 2001). From an empirical point of view, it is well-known that Tobin's *q* ignores replacement costs for intangible assets because of the accounting treatment of intangibles (Lev, 2001). Therefore it is a fairly common practice, in studies using Tobin's *q* as a measure of corporate performance, to "correct" the denominator of q for the presence of such intangibles. Examples include knowledge capital (Hall et al., 2000), or customer assets.

In fact, the non-financial measures method is different from the traditional financial statement analysis. It uses non-financial indicators, such as: how often each employee logs into the knowledge bases; how many "times" each employee brings up a proposal, how many "topic numbers" there are on the discussion board, and how many communities of practice (CoP) are there in the company? All these indicators are related to behavioral factors and system usage situations.

CoP has begun to play an increasingly important role in modern and intensive-knowledge organizations. Smits and Moor presented a Knowledge Governance Framework, which is focused on how to define, measure, and use performance indicators for KM in a CoP. The results were successful and offer useful guidelines for KM procedures (Smits & Moor, 2004). To successfully manage knowledge it must be measured. Holt et al. used four metrics to access organizational knowledge, including individual, context, content and process knowledge measures (Holt, Bartczak, Clark, & Trent, 2004). These approaches enable people to relate knowledge to business performance in a more explicit manner, and they provide valuable insight on how knowledge may be strategically managed.

2.1.3. Internal and external performance approaches

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

Underlying Kaplan and Norton's concept of Balanced Scorecard (BSC) was the fact that all aspects of measurement have their drawbacks. However, if the companies offset some of the drawbacks of one measure, with the advantages of another, the net effect can lead to decisions resulting in both short term profitability and long term success (Kaplan & Norton, 1996). Many scholars have discussed the use of a BSC approach in determining a business-orientated relationship, between strategic KM usage and IT strategy and implementation (Laitamaki & Kordupleski, 1997). They applied an IT investment to KM by creating a KM scorecard that focused on both the current financial impact of intellectual capital on core processes, as well as future earnings capabilities in structural or human capital.

From an activity-based evaluation perspective, valuable knowledge resides within individual employees, and it is critical to an organization's ability to solve problems and create new knowledge. In a sense, KM can be viewed as an activity, which acts as a constituent of a community, performing one's task by using tools or technology (Hasan & Gould, 2001).

External performance measurement methods are always compared with benchmark companies, primary competitions, or the whole industry average. With benchmarking or best practices methodologies, technology universities are able to determine their own KM performance and compare themselves with their competition, and take appropriate action.

Benchmarking is also seen as a tool for identifying, understanding and adopting best practices in order to increase the operational performance of intellectual capital (IC) (Marr, 2004). From an organizational learning perspective, benchmarking is concerned with enhancing organizational performance, by establishing standards against which processes, products and performance can be compared and consequently improved (Pemberton, Stonehouse, & Yarrow, 2001).

The "Best Practice" approach is an essential component of KM. It provides an opportunity to retain and use knowledge, even when an expert has left the organization. Asoh et al. investigated how governments could deliver more innovative services to a demanding public (Asoh, Belardo, & Neilson, 2002). Governments were seen to be involved in the deployment of new services, such as e-Government and e-Commerce.

2.1.4. Project-orientated and organizational-orientated approaches

Recent studies of KM and organizational learning in environmental projects emphasized the difficulties of learning from projects—not only within individual projects, but also across and between projects (DeFillippi, 2001). Bresnen et al. reveals that processes of capturing, transferring, and learning of knowledge, in project settings, relies very heavily upon social patterns, practices, and processes, in ways that emphasizes the value and importance of adopting a community-based approach to knowledge management (Bresnena, Edelmanb, Newell, Scarbroug, & Swan, 2003).

Nevertheless, a project organization requires a particularly systematic and effective knowledge management, if it is to be used to avoid knowledge fragmentation and loss of organizational learning. Kasvi et al. dealt with knowledge management and knowledge competences in project organizations, particularly from a programmers' perspective (Kasvi, Vartiainen, & Hailikari, 2003). They made a contribution by presenting the Learning Programme Model. In order to systematically manage the knowledge created within a project, the project itself must be systematically managed by the model.

An organization-oriented analysis is focused on the whole organization, and on the multi-dimensions and multi-layers in the firm. A KM performance evaluation can be analyzed from intellectual capital, BSC, technology, and process perspectives. The primary objective is to estimate the level of KM performance in the whole organization.

Most organizations have only a vague understanding of how much they have invested in intellectual capital (IC) let alone what they may receive from those investments. Standard financial accounting systems are not geared for the easy estimation of intellectual capital investments. Among the approaches most widely used for IC management and reporting are the so-called Intangible Asset Monitor by Sveiby and the IC approach by Edvinsson and Van Buren, originally introduced by the insurance company Skandia (Edvinsson, 1997; Sveiby, 1998). These models are designed to measure human, innovation, process and customer capital, and represent a major step toward providing precisely the information that technology universities and their stakeholders need to foresee the future. Thus, these IC models can help to visualize the knowledge-producing process of research organizations.

2.2. Analytical network process (ANP)

The analytical hierarchical process (AHP) introduced by T.L. Thomas is a well-known and popular method of MCDM (Malcolm, 2002). The AHP is based on an organization theoretical foundation, as examples in the literature and the day-to-day operations of various governmental agencies, corporations and consulting technology universities illustrate. The AHP is a viable and usable decision-making tool (Kamal, 2001). The ANP is a more general form of the AHP. Whereas, the AHP models a decision-making framework using a unidirectional hierarchical relationship among decision levels, the ANP allows for the ability to model more complex and dynamic environments that are more evident at strategic planning levels influenced by ever changing external forces (Joseph & Sundarraj, 2002). The ANP approach has been defined as a nonlinear network relationship among various factors (Laura, 1998).

Like the AHP, the ANP is used to derive ratio scales from both discrete and continuous paired comparisons in multilevel network structures. These comparisons may be taken from actual measurements or from a fundamental scale that reflects the related strength of preferences and feelings (Thomas, 1996). The advantages include ease of use, over-specification of judgment, built-in consistency tests, use of proper measurement scales, and applicability in the elicitation of utility function (Joseph, 2003). In addition, the ANP approach is capable of handling interdependence among elements by obtaining the composite weights through the development of a 'supermatrix' (Madjid & Saehamay, 1995). Saaty (1996) explains the supermatrix concept as a parallel to the Markov chain process (Saaty, 1996).

Before we use ANP as a crucial tool, it is necessary to identify its advantages and disadvantages fitting this research. Ravi, Ravi, and Tiwari (2005) summarized the advantages and the disadvantages of ANP as follows (Ravi et al., 2005):

- *Advantages of the ANP*
  1. The ANP is a comprehensive technique that includes relevant tangible as well as intangible criteria, which have some bearing on the decision-making process.
  2. The ANP allows for a more complex relationship among the decision levels and attributes, as it does not require a strict hierarchical structure, whereas the AHP models a decision-making framework that assumes a uni-directional hierarchical relationship among the decision levels.
  3. The ANP allows for the consideration of interdependencies among and between levels of criteria and thus is an attractive multi-criteria decision-making tool. This feature makes it superior to AHP, which fails to capture interdependencies among different enablers, criteria, and sub-criteria.
  4. The ANP is beneficial in taking both qualitative as well as quantitative characteristics into consideration that need to be considered, as well as considering non-linear interdependent relationship among the attributes.
  5. The ANP provides synthetic scores which are considered a crucial indicator of the relative ranking of different alternatives available to the decision-maker.
- *Disadvantages of ANP*
  1. The ANP requires more calculations and formation of additional pair-wise comparison matrices as compared to the AHP process. Therefore, a careful track of matrices and pair-wise comparisons of attributes is necessary.
  2. Identifying the relevant attributes of the problem and determining their relative importance in the decision-making process requires brainstorming sessions and extensive discussion. Also, data acquisition is a very time intensive process for the ANP methodology.
  3. The pair-wise comparisons under consideration can only be performed subjectively, and hence the accuracy of their results depends on the expertise of the expert involved in the area concerned.

2.3. The balanced scorecard (BSC)

Kaplan and Norton (1992, 1996) developed a BSC using a combination of measure in four perspectives (financial performance, customer knowledge, internal business processes, and learning and growth) to align individual, organizational, and cross-departmental initiatives. The BSC was expected to help technology universities test and update their strategy and meet their customer's needs and the objectives of the shareholders. Kaplan and Norton argued that managers should not only concentrate on financial measures when taking decisions. Non-financial criteria also had to be taken account. When carefully integrated in a balanced manner "scorecard" it would provide managers with a brief but comprehensive and timely view of their business (Braam & Nijssen, 2004). BSC serves as a means for communicating long-term strategic initiatives to business-units and achieving long-term financial success. It combines important concepts and practices from various theories and disciplines into a single performance measurement system for the purpose of improving performance (Davis & Albright, 2004).

3. The research methodology and a case study

3.1. The research methodology

People usually only pay attention to an organization's internal KM performance measurement, but from competitive view systematic evaluation of whether an organization's KM performance is superior to each of its major rivals is more important. Thus, this paper integrates the ANP approach and BSC to judge and rank the performances of KM within an organization and among the organization and its major critical rivals. The rationale for choosing ANP is that the ANP approach is a theory of measurement for dealing with tangible and intangible criteria, is well suited to group decision-making, and offers numerous benefits as a synthesizing mechanism in group decisions.

While confirming the advantages of the ANP that fit the research in this paper, we must also respond to the disadvantages of the ANP. First, we have to organize an experienced expert team with appropriate expertise in the area concerned. Second, sufficient time and manpower for data collection must be allowed for. Third, we must adopt useful tools such as "Expert Choice" and "Mathematica" for the calculations and formation of pair-wise comparison matrices. The methodology for evaluating KM performance follows a series of steps:

Step 1: *Model construction and problem structuring:*

Step 2: *Pair-wise comparison matrices of interdependent levels:* eliciting preferences of various attributes and components requires a series of pair-wise comparisons where each member of the expert group will compare two components at a time with respect to an upper level 'control' criterion.

Step 3: *KM performance calculation:* It contains the supermatrix formation and the calculation of the "desirability index". The supermatrix is a partitioned matrix, where each submatrix is composed of a set of relationships between two levels in the graphical model.

Step 4: *Analyze the KM performance:* Using the results of the KM performance calculation, we analyze the KM performance within the case firm and among its major rivals.

3.2. A decision group

This paper has practiced the proposed methodology in a private technology university (the case organization) in Taiwan. A technology university, specially a private technology university in Taiwan, is facing two critical problems: (1) too many competitors, too many colleges and universities in Taiwan, and (2) the student resources decreasing (baby birth rate descending) year-by-year. For surviving, a private technology university has to retain competitive advantage in this hypercompetitive environment. As knowledge is a critical factor of business competitiveness, a private technology university with superior KM performance will increase its competitive advantage. Therefore, to measure KM performance from competitive perspective, comparing with major rivals, is a critical task for a private technology university, so the selected technology university, the case organization, is devoted to explore the KM performance measurement in this research.

This case experience is expected to help us to understand the advantages and disadvantages of the methodology for KM performance measurement from a practical point of view. In the ANP approach, the accuracy of the results in pair-wise comparisons depends on the involving expert's expertise knowledge. Thus, organizing an experienced expert team with appropriate expertise knowledge in the area concerned is critical. There are about 10,000 students in the case organization that is a rapid growth technology university. The case organization pays much attention to the implementation and the performance of KM. A decision group was organized in the case organization with seven members: the president, the vice president, the dean of Management College, the direct of accounting office, and three professional consultants from industry and academia. The mission of the decision group is to measure the KM performance within the case organization and among the case organization and its major rivals to obtain effective information for supporting decision-making and strategic planning. The implementation and the analysis of the ANP approach in this case are presented in the following section.

3.3. The implementation and the analysis of the ANP approach

3.3.1. Step 1: Model construction and problem structuring

To structure a KM performance measurement into its basic components to be valuated is the first step. The relevant criteria and alternatives that are chosen on the basis of the review of literature and discussion with both industry and academia are structured in the form of a control hierarchy (see Fig. 1), where the overall objective is to evaluate the KM performance within the organization and amongst the organization and its major critical rivals.

The second-level criteria are customer perspective, internal business perspective, innovation and learning perspective, and financial perspective that are termed as the indicators of KM performance, which are the four perspectives of BSC. The mission of customer perspective (value-adding view) is to achieve an organization's vision by delivering value to its customers (Martinsons, Davison, & Tse, 1999). Providing an organization atmosphere with high quality customer service is the hallmark of an organization's strategy. An organization focuses on building relationships with its customers that increase its customer base (Davis & Albright, 2004). To measure the quality of customer services of an organization, periodic customer service surveys are necessary. Several core or generic measures of successful outcomes from the organization strategy such as customer satisfaction, customer retention, and market share in target segments can serve as outcome indicators for customer perspective (Abran & Buglione, 2003). The mission of internal business processes (process-based view) is to satisfy shareholders and customers through promoting efficiency and effectiveness in internal business processes that will have the great impact on customer satisfaction and achieving an organization's financial objectives. Lead-time, inventory, productivity, efficiency, and so forth can serve as the indicators to measure the outcomes of internal business process perspective. The mission of learning and growth processes (future view) is to achieve the organization vision by sustaining innovation and change capabilities, through continuous improvement and preparation for future challenges. To measure the outcomes of learning and growth processes perspective may concentrate on human capital such as employee turnover, information capital such as knowledge sharing, and organizational capital such as leadership efficiency. The mission of financial perspective is to success financially by delivering value to shareholders. Revenue growth, costs, margins, profitability, cash flow, return on investment (ROI), return on equity (ROE), and economic value added (EVA) usually serve as the outcome indicators of financial perspective. Possible measures of the four perspectives of BSC are shown in Table 2.

In the third level of the hierarchy there are five sub-criteria terms as dimensions of the model, supporting all the indicators at the second level relative to KM performance. These are knowledge creation (KC), knowledge accumulation (KA), knowledge sharing (KA), knowledge utilization (KU), and knowledge internalization (KI), and they were defined as the knowledge circulation process in Lee et al. (2005) (Lee et al., 2005). Knowledge creation is a continuous, self-transcending process through which one transcends the boundary of the old self into a new self by acquiring a new context and new knowledge (Nonaka & Takeuchi, 1995). The key to knowledge creation lies in the way it is mobilized and converted through technology (Awad & Ghaziri, 2004). To measure knowledge creation, two constructs are needed: task understanding and information understanding. The knowledge accumulated in firms play an important role in eliminating obstacles and insufficiencies and in improving management performance. However, if knowledge created through management activities is not accumulated systematically, then it cannot be beneficial for future decision-making needs. An instrument to assess knowledge accumulation uses three constructs: database utilization, systematic management of task knowledge, and individual capacity for accumulation. Knowledge

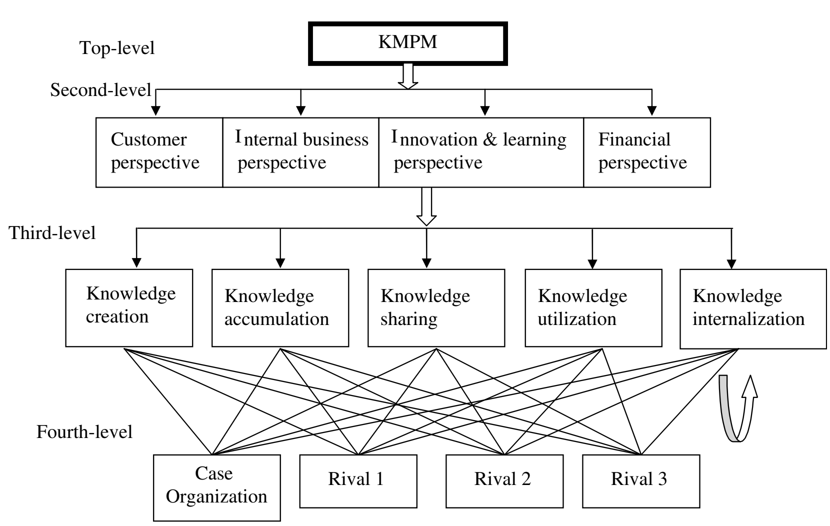

Fig. 1. The ANP model for KM Performance Measurement (KMPM).

Table 2
BSC measures (Papalexandris et al., 2005).

Perspectives	Possible measures
Customer	Customer satisfaction, retention, acquisition, profitability, market share, customer referrals, cross-selling, price relative to competition, brand recognition
Internal process	
Operation management	Quality, lead-time, inventory, productivity, efficiency, non-value adding activities, risk minimization, alternative distribution channels
Customer management	Customer complaints, complaint resolution, hours with customer, products per customer, segmentation
Innovation	Number of new products, R&D, patents, new opportunities, product and service diversification
Regulatory and social	Employee safety and health, environment, regulatory employee acquisition issues, donations, charities
Learning and growth	
Human capital	Employee turnover, acquisition, satisfaction, average workforce age, education, training
Information capital	Knowledge sharing, IT infrastructure, system response rate, down time
Organizational capital	Corporate value adoption, culture development, teamwork, leadership efficiency, organization alignment
Financial	Revenue growth, costs, margins, profitability, cash flow, return on investment (ROI), return on equity (ROE), Economic value added (EVA)

sharing promotes diffusion of knowledge and also contributes to making the work process astute and knowledge-intensive. An attempt at knowledge sharing is only valuable if one's views differ from that of the other parties, since one learns nothing from total homogeneity of view (Walsham, 2002). The degree of sharing knowledge depends on constructs such as core knowledge sharing. Knowledge utilization can occur at all levels of management activities in organizations. One of the popular forms of knowledge utilization is to adopt the best practice from other leading organizations, uncover relevant knowledge, and apply it. Knowledge utilization depends on two constructs: degree of knowledge utilization in the organization and the knowledge utilization culture. Knowledge internalization is the process of embodying explicit knowledge into tacit knowledge. Knowledge internalization may occur when individual workers discover relevant knowledge, obtain it and apply it. Thus, internalization may give rise to new knowledge. In this way, it provides a basis for active knowledge creation. Knowledge internalization can be measured by three constructs: capability to internalize task-related knowledge, education opportunity, and level of organizational learning (Lee et al., 2005).

The fourth-level of the hierarchy consists of the case organization and its major rivals. The most important task of KM performance measurement, comparing with major rivals, will be initiated here. The opinion of the expert team members will be sought in the comparisons of the relative importance of the criteria and the formation of pair-wise matrices to be used in the ANP model. The results of all four indicators and five KCP components will be used in the calculation of the KM performance measurement (KMPM) overall weighted index, which indicates the scores assigned to the case organization and its major rivals. The strength of the ANP model is the feedback function. We can compare the case organization with its major rivals through the overall KM performance and each component of the KCP. We can also rank the performance of each component of the KCP within the case organization or for each of its major rivals.

In this research, we identified the relevant attributes of the problem and determined their relative importance in the decision-making process, several brainstorming sessions and extensive discussions were held in the decision group. In the initial meetings, the group had identified the motivation, the objective, the framework, and the method of the KM performance measurement. The decision group adopts BSC four perspectives (customer, internal business, innovation and learning, and financial) as the KM performance indicators relative to the KM performance measurement and the KCP components (knowledge creation, knowledge accumulation, knowledge sharing, knowledge utilization, and knowledge internalization) as the KM sub-criteria. Three key rivals of the case firm were determined for constructing the ANP model (see Fig. 1). After seven weeks' data (including the tangible and the intangible) collection and classification, the pair-wise comparisons relevant meetings were held for measuring the KM performance using the ANP approach. In the following steps, each member of the decision group was asked to respond to a series of pair-wise comparisons where two elements at a time are compared with respect to an upper level 'control' criterion. These comparisons are made so as to establish the relative importance of the criteria in achieving the objectives of the case firm's KM performance measurement.

3.3.2. Step 2: Pair-wise comparison matrices of interdependent levels

In the ANP, like the AHP, pair-wise comparisons of the elements in each level are conducted with respect to their relevant importance regarding the control criterion. In this step, the members of the expert team are asked to respond to a series of pair-wise comparisons where at a time two components are compared with respect to an upper level 'control criterion'. These comparisons are made so as to establish the relative importance of the determinants in achieving the overall objective. In such pair-wise comparisons, a one-to-nine (1–9) scale (please see Appendix A) is used to compare two options. The numerical values representing the judgments of the comparisons are arranged in a matrix for further calculations. Notationally, the comparison matrix A for comparing n elements is $A = [aij]$ (where $aij = 1/aji$, $aii = 1$, $1 \leqq i \leqq n$, and $1 \leqq j \leqq n$). Once the pair-wise comparisons are completed, the local priority vector w is computed as follows (Laura, 1998):

$$AW = \lambda_{\max} W, \tag{1}$$

$$\left(A = \begin{bmatrix} a_{11} \dots a_{12} \dots & \dots & \dots a_{1n} \\ \vdots & \dots & \vdots \\ a_{i1} \dots a_{i2} \dots & \dots & \dots a_{in} \\ \vdots & \dots & \vdots \\ a_{n1} \dots a_{n2} \dots & \dots & \dots a_{nn} \end{bmatrix} \quad \text{and} \quad W = \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix} \right),$$

where A is the matrix of the pair-wise comparisons, W is the matrix of the weights, and $\lambda_{\max}$ is the largest eigenvalue of A. This is a two-stage algorithm that involves forming a new $n \times n$ matrix by dividing each element in a column by the sum of the column elements and then summing the elements in each row of the resultant matrix and dividing them by the n elements in that row. This is the process of averaging over normalized columns (Khalid, YanBing, & Nalia, 2002), and is represented as w_i,

$$w_i = \frac{\sum_{i=1}^{I} \left(\frac{a_{ij}}{\sum_{j=1}^{J} a_{ij}} \right)}{J}, \tag{2}$$

where w_i is the weighted priority for component i, I the index number of rows (components), J the index number of columns (components).

In the evaluating process there may occur a problem in the consistency of the pair-wise comparisons. To check the consistency, we may calculate the consistency ratio, CR, as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{3}$$

Table 3
Pair-wise comparisons of KM Performance indicators.

KMPM	CP	IBP	I& LP	FP	e-vector
CP	1	1/2	1/3	2	0.160
IBP	3	1	1/2	3	0.277
I& LP	5	2	1	4	0.467
FP	1/2	1/3	1/4	1	0.096

Inconsistency = 0.01(CP, customer perspective; IBP, internal business perspective; I&LP, innovation and learning perspective; FP, financial perspective).

where

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{4}$$

RI is random consistency. Selecting appropriate value of random consistency ratio for a matrix size uses the values in Table B1 (see Appendix B). As the value of CR is less than 0.1 the judgments are acceptable. There are four sub-steps described as following paragraphs, respectively.

(1) Pair-wise comparisons of four KM performance indicators
In the beginning, the pair-wise comparisons between four KM performance indicators were made. Table 3 presents the KM performance indicators pair-wise comparison matrix for the KMPM by integrating the responses from the members of the decision group. For the pair-wise comparison, the question asked to the members of the decision group was: "what is the relative impact on the KM performance measurement by KM performance indicator *a* compared to indicator *b*? " From Table 3, it can be seen that the L&P respective is viewed as being much more important than customer perspective. The e-vectors (also referred to as the local priority vector) are the weighted priorities of the KM performance indicators and are shown in the last column of the matrix. The L&P respective is the most important KM performance indicator (e-vector = 0.467). These e-vectors are used in Table 11 for the calculation of the KMPM overall weighted indexed for the case organization and its major rivals. From Table 3, the results of the comparisons (e-vectors) of the KM performance indicators for the KMPM are shown as P_j in Table 11.

(2) Pair-wise comparisons of the KCP components
For a KM performance indicator, a pair-wise comparison matrix is made between the components of the KCP. For example, Table 4 shows the pair-wise comparison matrix for customer perspective under KM PM. In Table 4, the relative importance of the KC when compared to the KA with respect to customer perspective, in achieving the KMPM, is three. It is also observed that each of the component KC and the component KU has the maximum influence (e-vector = 0.326) on the customer perspective in evaluating the performance of KM. Similarly, KI has the least influence (e-vector = 0.061). The number of such pair-wise comparison matrices depends on the number of KM performance indicators. Thus, four pair-wise comparison matrices for four KM performance indicators are formed, and each matrix involves 10 pair-wise comparisons. The e-vectors obtained from these matrices are imported as A_{kj} in Table 11.

(3) Pair-wise comparisons of organizations
Pair-wise comparisons are made for the relative impact of each of the organizations on the KCP components influencing the knowledge indicators and KMPM. One such comparison matrix is shown in Table 5. It represents the result of the KMPM-customer perspective cluster with knowledge creation as the control KCP component on the organizations. The questions are asked to the members of the decision group for evaluating the organizations were: 'when considering knowledge creation with regards to the increasing the impact of the customer perspective, what is the relative impact of technology university *a* compared to that of technology university *b*?' and, "For example, when considering knowledge creation and the increasing the impact of it on the customer perspective, what is the relative impact of it on the case organization when compared to that on the rival 1?' From Table 5, it is observed that the rival 1 (e-vector = 0.477) has a maximum impact on the KMPM-customer perspective cluster with knowledge creation as the control KCP component over case organization and the other rivals. It is also observed that the impact of the rival 3 is minimal (e-vector = 0.081). Therefore, the rival 1 is the strongest competitor for knowledge creation in the KMPM-customer perspective cluster for the case organization. For a KM performance indicator there will be 5 such matrices and 30 pair-wise comparisons at this level of relationship. For a KCP component such as knowledge creation, there will be 3 such matrices from four clusters: the KMPM-CP cluster, the KMPM-IBP cluster, the KMPM-I & LP cluster, and the KMPM-FP cluster. Table 6 shows the e-vector matrix A for the KCP component under customer perspective over the organizations.

(4) Pair-wise comparisons of the KCP components among the organizations
The local priority weights for the relative impact of the KCP components for each organization are now determined. An example of the impact on the case organization of various KCP components is shown in Table 7. Notice that knowledge utilization (e-vector = 0.412) will influence the case organization more than any of the other components. It must also be observed that the impact of the knowledge creation on

Table 4
Pair-wise comparisons of the KCP components under customer perspective.

Customer perspective	KC	KA	KS	KU	KI	e-vector
KC	1	3	2	1	5	0.326
KA	1/3	1	1/2	1/3	2	0.107
KS	1/2	2	1	1/2	3	0.180
KU	1	3	2	1	5	0.326
KI	1/5	1/2	1/3	1/5	1	0.061

Inconsistency = 0.00.

Table 5
Pair-wise comparison matrix for case organization under KMPM, CP, and KC cluster.

Knowledge creation	Case organization	Rival 1	Rival 2	Rival 3	e-vector
Case organization	1	1/2	2	4	0.288
Rival 1	2	1	3	5	0.477
Rival 2	1/2	1/3	1	2	0.154
Rival 3	1/4	1/5	1/2	1	0.081

Inconsistency = 0.09.

Table 6
Matrix *A* for the KCP components under CP over the case organization.

Matrix *A*	KC	KA	KS	KU	KI
Case organization	0.288	0.253	0.581	0.582	0.455
Rival 1	0.477	0.108	0.092	0.163	0.141
Rival 2	0.154	0.547	0.149	0.163	0.263
Rival 3	0.081	0.065	0.178	0.092	0.141

Table 7
Pair-wise comparisons of the KCP components under the case organization.

Case organization	KC	KA	KS	KU	KI	e-vector
KC	1	1/2	1/3	1/4	1/2	0.077
KA	2	1	1/2	1/3	2	0.152
KS	3	2	1	1/2	3	0.256
KU	4	3	2	1	4	0.412
KI	2	1/2	1/3	1/4	1	0.102

Inconsistency = 0.10.

Table 8
E-vector matrix *B* for the case organization over the KCP components under CP.

Matrix *B*	Case organization	Rival 1	Rival 2	Rival 3
KC	0.077	0.400	0.141	0.097
KA	0.152	0.246	0.415	0.366
KS	0.256	0.104	0.056	0.216
KU	0.412	0.058	0.141	0.237
KI	0.103	0.192	0.247	0.084

the case organization is minimal (e-vector = 0.077). Each of the four organizations will have as a result an e-vector of priority weights, and together these vectors form a matrix *B*, as shown in Table 8.

3.3.3. Step 3: KM performance calculation

The KM performance calculation is composed of the supermatrix formation and the calculation of the "desirability index". The supermatrix is a partitioned matrix, in which each submatrix consists of a set of relationships between two levels in the graphic model. Raising the supermatrix to the power $2k + l$, where k is an arbitrarily large number, allows convergence of the interdependent relationships between two levels. In this step, we focus on how to calculate the supermatrix value. The details are discussed as follows.

In this model, there are four supermatrices for four indicators of the KM performance hierarchy network, which need to be evaluated. One such supermatrix X-CP, shown in Table 9, displays the results of the relative importance measures for each of the organizations for each component of the KCP under the CP indicator of KMPM.

The matrix *A* in Table 6 and the matrix *B* in Table 8 are combined to form the supermatrix X-CP shown in Table 9. Raising the supermatrix to the power $2k + l$, where k is an arbitrarily large number, allows the convergence of the interdependent relationships between two levels (Meade & Sarkis, 1999). The long-term stable weighted values are shown in Table 10. According to Table 10, relative importance weights for the various KCP components for the organizations are 0.1557, 0.2662, 0.1684, 0.2527, and 0.1570, respectively. The relative performance scores for various organizations on the KCP components are 0.4277, 0.1818, 0.2772, and 0.1133, respectively.

3.3.4. Step 4: Analyzing the KM performance

The calculation of the "desirability index" is the final calculation. Using the results of the KM performance calculation, we can analyze the KM performance within the case organization and compared to its major rivals. The implications of the results will be useful for the case organization's KM and its decision-making. The overall KM performance analysis depends on the calculation of the "desirability index" for an organization *i* (*Di*). The equation for *Di* is defined by Eq. (5) (Thomas, 1999):

$$Di = \sum_{j=1}^{J} \sum_{k=1}^{K} P_j A_{kj} B_{kj} S_{ikj}, \quad (5)$$

where P_j is the relative importance weight of KM performance indicator j, A_{kj} is the relative importance weight of the component k of KCP on the KM performance indicator j, B_{kj} is the stabilized relative importance weight of the component k of KCP on the KM performance indicator j, S_{ikj} is the relative performance score of organization i on the component k of KCP for the KM performance indicator j, K is the index set of component k of KCP, and J is the index set of KM performance indicator j.

Table 11 shows the desirability indices for the organizations' KM performance measurement. This is based on the KMPM hierar-

Table 9
Supermatrix X-CP.

Matrix *X*	KC	KA	KS	KU	KI	Case organization	Rival 1	Rival 2	Rival 3
KC	0	0	0	0	0	0.077	0.400	0.141	0.097
KA	0	0	0	0	0	0.152	0.246	0.415	0.366
KS	0	0	0	0	0	0.256	0.104	0.056	0.216
KU	0	0	0	0	0	0.412	0.058	0.141	0.237
KI	0	0	0	0	0	0.103	0.192	0.247	0.084
Case organization	0.288	0.253	0.581	0.582	0.455	0	0	0	0
Rival 1	0.477	0.108	0.092	0.163	0.141	0	0	0	0
Rival 2	0.154	0.547	0.149	0.163	0.263	0	0	0	0
Rival 3	0.081	0.065	0.178	0.092	0.141	0	0	0	0

Table 10
Supermatrix convergence to long-term weights from supermatrix *X*.

Matrix Y	KC	KA	KS	KU	KI	Case organization	Rival 1	Rival 2	Rival 3
KC	0	0	0	0	0	0.1557	0.1557	0.1557	0.1557
KA	0	0	0	0	0	0.2662	0.2662	0.2662	0.2662
KS	0	0	0	0	0	0.1684	0.1684	0.1684	0.1684
KU	0	0	0	0	0	0.2527	0.2527	0.2527	0.2527
KI	0	0	0	0	0	0.1570	0.1570	0.1570	0.1570
Case organization	0.4277	0.4277	0.4277	0.4277	0.4277	0	0	0	0
Rival 1	0.1818	0.1818	0.1818	0.1818	0.1818	0	0	0	0
Rival 2	0.2772	0.2772	0.2772	0.2772	0.2772	0	0	0	0
Rival 3	0.1133	0.1133	0.1133	0.1133	0.1133	0	0	0	0

Table 11
Desirability index calculation for KMPM.

Indicators	P_j	Components	A_{kj}	B_{kj}	S_{ik1}	S_{ik2}	S_{ik3}	S_{ik4}	Case organization	Rival 1	Rival 2	Rival 3
CP	0.16	KC	0.326	0.1557	0.288	0.477	0.154	0.081	0.002339	0.003874	0.001251	0.000658
	0.16	KA	0.107	0.2662	0.25	0.108	0.547	0.092	0.001139	0.000492	0.002493	0.000419
	0.16	KS	0.18	0.1684	0.581	0.092	0.149	0.178	0.002818	0.000446	0.000723	0.000863
	0.16	KU	0.326	0.2527	0.582	0.163	0.163	0.092	0.007671	0.002148	0.002148	0.001213
	0.16	KI	0.061	0.157	0.455	0.141	0.263	0.141	0.000697	0.000216	0.000403	0.000216
IBP	0.277	KC	0.041	0.0873	0.245	0.508	0.154	0.093	0.000243	0.000504	0.000153	9.22E−05
	0.277	KA	0.146	0.2901	0.301	0.103	0.462	0.134	0.003531	0.001208	0.00542	0.001572
	0.277	KS	0.464	0.1925	0.577	0.111	0.179	0.133	0.014276	0.002746	0.004429	0.003291
	0.277	KU	0.092	0.254	0.558	0.168	0.16	0.114	0.003612	0.001087	0.001036	0.000738
	0.277	KI	0.257	0.1761	0.516	0.106	0.189	0.189	0.006469	0.001329	0.002369	0.002369
I&LP	0.467	KC	0.076	0.0753	0.318	0.487	0.122	0.073	0.00085	0.001302	0.000326	0.000195
	0.467	KA	0.288	0.3414	0.265	0.118	0.547	0.07	0.012168	0.005418	0.025117	0.003214
	0.467	KS	0.484	0.3482	0.649	0.177	0.107	0.067	0.051078	0.01393	0.008421	0.005273
	0.467	KU	0.076	0.1378	0.688	0.123	0.123	0.066	0.003365	0.000602	0.000602	0.000323
	0.467	KI	0.076	0.0973	0.615	0.126	0.126	0.101	0.002124	0.000435	0.000435	0.000349
FP	0.096	KC	0.34	0.0676	0.271	0.51	0.152	0.067	0.000598	0.001125	0.000335	0.000148
	0.096	KA	0.123	0.3656	0.264	0.143	0.507	0.086	0.00114	0.000617	0.002189	0.000371
	0.096	KS	0.123	0.3406	0.691	0.083	0.146	0.08	0.002779	0.000334	0.000587	0.000322
	0.096	KU	0.34	0.0738	0.651	0.179	0.091	0.079	0.001568	0.000431	0.000219	0.00019
	0.096	KI	0.074	0.1524	0.546	0.232	0.232	0.138	0.000591	0.000251	0.000251	0.000149
									0.119056	0.038497	0.058907	0.021966

chy using the relative weights obtained from the pair-wise comparison of organizations, KCP components, indicators, and weights of KCP components from the converged supermatrix. These weights are used to calculate a score for the KM overall weighted index (KMOWI) for each of the organizations being compared. In Table 11, the values of the second column are imported from Table 3, which are obtained by comparing the relative impact of the indicators on the KMPM. The values of the fourth column are from the pair-wise comparisons of the KCP components for the knowledge indicators and the KMPM. We also put the stable independent weights of the KCP components obtained through the converged supermatrix (Table 10) in the fifth column of Table 11. The next four columns are from the pair-wise comparison matrices showing the relative impact of each of the organizations on the components. The final four columns represent the weighted values of the organizations ($P_j \times A_{kj} \times B_{kj} \times S_{ikj}$). For illustration, the value corresponding to the case organization for KC under CP is 0.002339 ($0.160 \times 0.326 \times 0.1557 \times 0.288 = 0.002339$). The summations of these results are shown in the final row of Table 11. These results indicate that the case organization with a value of 0.119056 has the maximum score and that competitor 2 with a value of 0.058907 is in the second place in KMPM. Therefore, from the overall KM performance analysis, competitor 2 is the first competitor for the case organization in KM and the rivals 1 and 3 are the second and third competitor, respectively.

Table 12, which is extracted from Table 11 provides the summation information for the KMPM analysis through five KCP components for the organizations. Although the case organization's ranking in KMOWI is the best, from Table 12 it is evident that rival 2 is superior to the case organization at KA and rival 1 is superior to the case organization at KC. Thus, it is suggested that the case organization should reinforce the databaseutilization, its systematic management of task knowledge, and its individual capacity for accumulation in the KM process and improve its tasks understandings and information understandings for knowledge creation. The case organization has a better performance than its major rivals in knowledge sharing and knowledge utilization which can occur at all levels of management activities in organizations. In particular, the case organization is outstanding at knowledge sharing because the case organization has the best practice for knowledge sharing in a positive knowledge sharing culture.

Table 12
KMPM analysis through five KCP components.

	Case organization	Rival 1	Rival 2	Rival 3
Knowledge creation	0.00403	0.006804	0.002065	0.001093
Knowledge accumulation	0.017978	0.007736	0.035218	0.005577
Knowledge sharing	0.070951	0.017457	0.01416	0.009749
Knowledge utilization	0.016216	0.004269	0.004005	0.002464
Knowledge internalization	0.009881	0.002231	0.003459	0.003084
KMOWI	0.119056	0.038497	0.058907	0.021966
Normalized values for KMOWI	0.499343	0.161464	0.247065	0.092129
Rank	1	3	2	4

4. Discussion and implications

The main contribution of this paper lies in the development of a comprehensive model, which incorporates diversified issues for conducting KMPM from competitive perspective. As a result, the main findings can be described as follows:

(1) It considers four indicators namely customer perspective, internal business perspective, innovation and learning perspective, and financial perspective for conducting the KM performance measurement. The proposed ANP model in this paper, not only guides the decision group for the efficient conduct of the KMPM, but also enables them to visualize the impact of various criteria when arriving at the final results. In addition, the interdependencies among the various criteria can be effectively captured using the ANP technique, something which has rarely been applied in the context of KMPM for comparing with major competitors.

(2) The results indicate that the competitor 2 is the first competitor of the case organization and that competitors 1 and 3 are the 2nd and the 3rd, respectively. The KM performance comparisons may be attributed to the KCP components: knowledge creation, knowledge accumulation, knowledge sharing, knowledge utilization, and knowledge internalization. From Table 10, in which the values are stable weighted, KA (e-vector = 0.2662) is the most important component for the KM performance measurement following by KU

(0.2527), KS (0.1684), KI (0.1579), and KC (01557). Combined, KA and KU has almost determined the KMPM. These implications are straightforward as in hypercompetitive private technology universities where the effective accumulation and utiliziation of knowledge are the most important components for enhancing KM performance. This result shows that knowledge accumulation (storing) and knowledge utilization (application) are the crucial characteristics of private technology universities.

(3) Table 12 shows the KMOWI for the organizations. From this table, it can be seen that the case organization has the highest score in KMOWI, which means that from an overall point of view the case company is superior to each of its major rivals from the overall KM performance measurement. It is also evident that the rival 2 is superior to the case organization at KA and that even rival 1 is also superior to the case organization in KC. Thus, it can be said that the case organization's weakest component is knowledge creation and knowledge accumulation, and consequently it will be necessary for the case organization to promote its capacity of knowledge creation and knowledge accumulation in the KM process is necessary.

(4) During the implementation of the proposed approach, the decision group had difficulties in making pair-wise comparisons because of data incompleteness. Usually the data are impossible to be collected completely. Under this condition, the members of the decision group have to answer the pair-wise questions based on their experiences and judgments. However, ANP is a multi-attribute decision-making approach based on reasoning, knowledge, experience, and perceptions of experts in the field. The case organization managers fully agreed with the proposed ANP approach as a systematic decision-making tool and they were satisfied with the results.

(5) In this paper, we adopted the four perspectives as the indicators of KM performance. In different situations, other terms such as marketing share, return on investment, and so forth may be considered as the indicators. Certainty, the approach that proposed by this paper can be also applied to other cases such as a firm, a hospital, and so forth.

5. Conclusion

As the era of knowledge economy is emerging, the importance of KM performance is gradually increasing. The question of how to measure a firm's KM performance is becoming increasingly important as time goes by. However, most of the metrics and methods of knowledge measurement that have been developed are focused on measuring the knowledge within the organization, which in practice limits their effectiveness because the most important task of the KM performance measurement is the comparison of a firm with its main competitors.

Summarily, this paper makes four important contributions: (1) it proposed a methodology of comparing an organization's knowledge management performance with its major rivals using the Analytical Network Process (ANP) for obtaining clear direction of how to obtain a competitive advantage; (2) it designed to provide a detailed comparison of an organization's KM performance against its major rivals, and then provide effective information for improving the KM and increase its quality of decision-making; (3) it explored the case organization involved a lot of findings that showed the competitive position of the case organization compared to its major rivals and implied that the case organization needed to upgrade its knowledge creation and knowledge accumulation to catch up with its major competitor.; and (4) conclusively, it is generic in nature and is applicable to benefit any organization.

Table A1
The pair-wise comparison judgments and values.

Judgment	Value
Equal importance	1
Weak importance	2
Moderate importance	3
Moderate plus	4
Strong importance	5
Strong plus	6
Very strong	7
Very, very strong	8
Extreme importance	9

Table B1
Average random consistency (RI).

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

For long term observation and analysis of the KM performance among the case organization and its major competitors, a successive KM performance measurement analysis will be necessary. In the future, using several forecasting techniques, such as the integration of the methodology used in this study with the Time Series may predict and analyze the future trends for comparing each of the components of the organization' KM performance with its major rivals.

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Appendix A

The judgment of the importance (or strength) of one alternative (or organization) over another can be made subjectively and converted to numerical value using a scale of 1–9 where 1 denotes equal importance (or strength) and 9 denotes the highest degree of favor-item. Table A1 lists the possible judgments and their respective numerical values.

Appendix B

Table B1 shows each value of random consistency ratio for each matrix size (from 1 to 10).

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