Abstract: Engineering consulting (EC) firms in the construction industry are knowledge-intensive and experience-based organizations. As the knowledge accumulated from previous experiences is the essential asset for winning and managing future projects, many EC firms have developed diversified knowledge management systems (KMSs) to accumulate and retain this essential knowledge. However, evaluation methods and results regarding the benefit analysis of KMSs are rarely found in literature. To evaluate the performances of KMSs, most previous studies have adopted qualitative approaches. This paper, on the other hand, presents a ratio-based approach for evaluating the benefits of KMSs. The proposed approach is tested using one of the KMSs from a study EC firm: the proposal preparation assistant (PPA) system. Based on a test of two real cases, this study found that a 48.7% time reduction in data collection and 25.3% staff-hour savings can be achieved when using the PPA system to prepare service proposal drafts. The results revealed in this study not only prove the usability of the proposed ratio-based benefit analysis approach, but also provide convincing and inspiring information for knowledge management practitioners as they plan their future works. DOI: 10.1061/(ASCE)ME.1943-5479.0000221. © 2014 American Society of Civil Engineers.

Author keywords: Knowledge management system; Benefit analysis; Service proposal preparation; Engineering consulting firm.

Introduction

Knowledge is a justified personal belief that increases an individual’s capacity to take effective action (Nonaka 1994), while knowledge management (KM) is the process of creating value from an organization’s intangible assets (Davenport and Prusak 1998). In the innovative KM era, knowledge is an organizational asset that promotes a sustainable competitive advantage in hypercompetitive environments. Accordingly, KM is rapidly becoming a key organizational capability for creating a competitive advantage in the construction industry (Kale and Karaman 2011). Engineering consulting (EC) firms in the construction industry are knowledge-intensive and experience-based organizations. As such, they rely heavily on the knowledge and experiences accumulated from previous projects as they perform their work. In other words, EC firms require varied tools to retain their organizational assets for potential reuse.

Globally, over the past decade, many EC firms have developed their own knowledge management systems (KMSs), thereby enhancing their firms’ KM initiatives (Mezher et al. 2005, 2009; Anumba and Pulsifer 2010; Yu et al. 2010). Considerable organizational effort has been put into KM initiatives in recent years, and information and communication technologies (ICTs) have been central to many of these initiatives (Walsham 2001). Therefore, as the requirements and investments of ICT increase, so too do the ICT-related costs. It is easier to quantify the costs of ICT investments than to quantify the benefits, as the costs are measurable (Love and Irani 2001). Similar to the performance evaluations of the ICT-related investments and systems, to quantify the actual costs of developing a KMS is easy, but it is difficult to measure the real benefits of the KMS.

Initially, developing a KMS is usually regarded as a strategic weapon in industry competition. Consequently, the popular beneficial claims for implementing KMSs include the ability of organizations to be flexible and to respond more quickly to changing market conditions, the ability to be more innovative, and the ability to improve decision making and productivity (Alavi and Leidner 1999). However, the aforementioned identified benefits are not convincing to all stakeholders in an EC firm because the development of KMSs requires considerable costs as well as tremendous human-resource efforts, which are the core competence of the firm. Moreover, most KMSs play key roles in business operations. While the methodology for precisely measuring the quantitative and qualitative benefits becomes an essential challenge, it is that is usually considered confidential and is rarely found in literature. In this study, a quantitative measure is defined to evaluate the benefits of KMSs. This paper examines the proposed approach using a case study that evaluates the benefits of an existing KMS, namely, the proposal preparation assistant (PPA) system, which is used by engineers to prepare service proposals in a leading EC firm in Taiwan.

The rest of this paper is organized as follows. The next section reviews the literature on KMSs in the construction industry,
on benefit evaluations of information systems, on performance evaluations of KMSs and on identified benefits of KMSs in the construction industry. After that, the case KMS, the PPA system, is described in detail. Further, this study introduces the approach for the benefit evaluation and elaborates the details of system testing and evaluation design for the PPA system followed by discussing evaluation results with respect to the application of the developed approach. Finally, conclusions and recommendations are addressed.

Literature Review

Knowledge Management in Construction Industry

KM has been recognized as a core business concern and an intellectual asset that plays a vital role in gaining competitive advantage. KM in the construction industry is essential for improving business performance because the construction industry is a knowledge-intensive and experience-based industry. Focused on safety knowledge in the construction industry, a case study was conducted and, it was reported that while construction organizations tend to acquire knowledge from a variety of internal and external sources, they have ineffective knowledge storage and transfer systems (Hallowell 2012). Therefore, developing suitable KMSs plays a vital role in the implementation of KM. When implementing KM, construction organizations may face some barriers, including the lack of standard processes, insufficient time, poor organizational culture, insufficient funding, employee resistance, and poor IT infrastructure (Whelton et al. 2002; Carrillo et al. 2004; Egbu and Robinson 2005; Al-Ghassani et al. 2006; Carrillo and Chinowsky 2006).

Based on a case study of four large United Kingdom construction organizations, a study concluded that construction organizations are likely to be successful in implementing KM if appropriate considerations are given to strategy formulation, implementation issues are addressed and the link between KM and business strategy is strengthened (Robinson et al. 2005). In the construction industry, the implementation of KMS has been widely considered, and an increasing number of companies have proposed KM initiatives. For example, a study proposed a conceptual framework for the contractors in the Turkish construction industry to formalize the knowledge-capturing process within construction companies and to demonstrate its implementation by way of a web-based system. The demonstrated system could be used to effectively manage both tacit and explicit knowledge in construction projects (Kivrak et al. 2008). In the Korean construction industry, a study suggested that three engineering and construction firms use KMSs to support necessary business cases (Park et al. 2010). Those firms received benefits after implementing successful KMSs.

A leading EC firm, the China Engineering Consultants, Inc., (CECI), in Taiwan, has developed an integrated KMS that combines the community-based systems with an emergency problem-solving system (SOS), namely, the knowledge management integrated problem-solver (KMiPS), to provide a platform for knowledge acquisition, sharing and utilization (Yu et al. 2007). The CECI has not only a traditional community-based KMS, but it has also developed the SOS system, which is a special system to extract knowledge from other KMSs. The SOS system provides a tentative forum for solving emergency problems encountered by engineers/managers (Yu et al. 2007). As a result, the CECI has received benefits from diversified KMS implementations.

Benefit Evaluation for Information System

Effective KM requires a combination of both mechanistic and organic approaches in an integrated way that incorporates both technological and organizational/cultural issues (Kamara et al. 2002). To facilitate the management tasks related to knowledge assets, the development of KMSs that integrate ICT tools and software systems have received global attention.

Traditionally, the cost-benefit analysis of computer-based information systems (ISs) is a major concern of managers in public and private organizations. The possible system benefits include those derived from calculating and printing tasks, record-keeping tasks, record-searching tasks, system restructuring capabilities, analyzing and simulating capabilities and process and resource control tasks (King and Schrems 1978). However, because economic and quantitative measures for the success of IS are difficult to obtain, researchers and practitioners often rely on subjective assessments and surrogate measures, such as user information satisfaction (UIS) instruments (Saarinen 1996). A KMS, usually regarded as an IS, has the same problem with benefit evaluation.

Performance Evaluation for KMS

Performance evaluations of KMSs have become increasingly important as the evaluations directly provide the reference for directing the strategic organizational learning and for identifying the capabilities of KMS that are generated to match the requirements to enhance enterprise competitiveness (Tseng 2008). Tseng (2008) proposed a set of indicators for evaluating a KMS performance that partitioned the activities of KMS into three types of processes: KM strategic, KM plan, and KM implementation. For most firms that have implemented KM, the economic and quantitative benefits derived from KM provide promising conclusions for maintaining existing KMS and developing new KMS.

Similar to the problem of evaluating the benefits of ISs, companies are not adequately able to assess the contributions of KMS. In selecting a suitable KMS, the study proposed a framework to identify the gaps and overlaps regarding extent to which the capabilities provided and utilized by their current KMS portfolio meet the KM needs of the organization (Nevo et al. 2008). For ex post evaluation of KMS, another study proposed a framework focused on the evaluation of KM components and their functionalities within an organization (Folkens and Spiliopoulos 2004). The identified items in the framework serve as good indicators for performance evaluations of KMSs.

For measuring the success of a KMS, a three-level model consisting of system and service (system quality, knowledge quality, and knowledge-specific service), use (system use and user satisfaction), and impact (impact on individuals and impact on collectives of people) was proposed and illustrated (Maier 2007). The cost-benefit analysis of a KMS can also be linked to organizational performance in the corresponding perspectives, such as customer satisfaction, business strategy development, product development and innovation, time-to-market, product promotion, market share, and competitive positioning (Alavi and Leidner 1999). Based on the techniques of the balanced scorecard (BSC), the analytic hierarchy process (AHP) and the fuzzy comprehensive evaluation method (FCEM), Yan (2008) evaluated the performance of enterprise knowledge management from four perspectives: financial perspective, customer perspective, internal process perspective and learning and growth perspective.
**Identified Benefits of KMSs in Construction Industry**

Through a real-world case study, Kale and Karaman (2011) proposed a model that incorporates benchmarking and KM concepts with fuzzy set theory to evaluate the KM performance of construction firms. The proposed model provided diagnostic information to the executives of construction firms by evaluating their firms’ KM performances, identifying their firms’ strengths and weaknesses with regard to each KM practice, and setting priorities for managerial actions related to KM practices that need improvement. The study indicated that the KMS can play a valuable role at the company level in the construction industry. Furthermore, based on the approach of active knowledge management, a study proposed a process model for effectual construction knowledge evaluation using the expert index, that is, the level that specialty workers achieve in a certain field after engaging in a knowledge activity (Park et al. 2010). The study determined that the KMS can be a useful tool at the workforce level in the construction industry.

For evaluating the benefits of a KMS, a study investigated quantitative models for measuring time, staff hours, and cost benefits resulting from a KMS implemented in a local leading engineering consulting firm in Taiwan. The KMS is the KMIPS mentioned previously, which was used to solve emergency problems proposed by engineers. The study found that the average time benefit is 63%, the average staff-hour benefit is 73.8%, and the average cost benefit is 86.6% (Yu et al. 2006). In sum, if the proper measure is developed, the benefits of KMSs are both measurable and achievable.

**Introduction to Proposal Preparation Assistant System**

This study used the PPA system in the CECI in Taiwan as a case study system. The PPA system provides knowledge corpuses to help engineers draft service proposals for a new project within a limited tendering period. In other words, the PPA system is developed to assist engineers to obtain useful documents from KMSs for performing proposal preparation work in a short period of time. Notably, the PPA system is designated as an assistant tool, not an automatic proposal generator. The PPA system is a subsystem of integrated KMSs in the CECI. Fig. 1 shows the framework of the PPA system, which consists of five modules: proposal decomposition, project information entry, proposal search, document extraction, and document integration. All modules are described as follows.

**Proposal Decomposition Module**

Based on the proposals of 24 projects obtained from a specific division of CECI, the proposal decomposition (PD) module is a unit that decomposes the proposals into individual chapters/sections and then stores the outcomes in a database. Currently, this module should be performed with knowledge engineers who are responsible for determining whether analyzed chapters/sections are analogous. The chapters or sections with high similarity in content will be regarded as similar and, accordingly, classified into the same category in the database. Before manipulating document decomposition, two questionnaires are used to collect and confirm the data structure of the proposal database. The first questionnaire is used to verify that the collected headings of chapters/sections are suitable for reuse in the future. With these preliminary chapters/section headings, the relevant cases from 24 projects with the same chapter/section headings are identified. The second questionnaire is used to confirm whether the identified headings of chapters/sections in the first should be retained. Through the questionnaires, the headings of the most frequently encountered chapters/sections or of potential for use in the future are identified and retained as the labels of attributes in the database. In sum, with the help of knowledge engineers, the PD module saves all available proposals into the database in the format of decomposed chapters/sections stored in their respective individual files.

**Project Information Entry Module**

The project information entry (PIE) module is a unit for users to input/select key project information (i.e., the characteristic attributes). The required project information contains two types:
(1) basic project information—including the attributes of project type, location and scope of service; and (2) required proposal chapter/section headings—including the chapter/section headings required by project clients or needed by users. The PIE module is implemented on a web-based platform; hence, the users can access and use the PPA system through a web browser.

**Proposal Search Module**

The proposal search (PS) module consists of three independent submodules (functions). Based on chapter/section headings selected by the user in the PIE module, the first submodule (function 1) is designed to search similar decomposed chapters or sections generated by the PD module in the database. This submodule calculates the similarity between the basic project information entered by the user and that stored in the proposal database. The second submodule (function 2) is used to search useful decomposed chapters or sections for a targeted topic. This submodule allows the user to enter the topic descriptions using natural language. The mechanism for similarity calculation using the vector space matrix (VSM) adopted from another research (Yu et al. 2010), which is programmed as a search engine. The third submodule (function 3) is designed to search useful intellectual assets, including lessons learned files (LLFs), knowledge cases (KCs), and knowledge corpuses, when preparing solutions to key issues that may be encountered by the in-tendering project. Similar to the second submodule, this submodule adopts the same search engine, but uses different knowledge sources.

**Document Extraction Module**

The document extraction (DE) module provides a platform for the user to select useful documents that are retrieved through the PS module. According to the submodules described in the PS module, this module provides three interfaces for the user to extract required documents, which include similar decomposed chapters/sections from function 1, specific decomposed chapters/sections related to a targeted topic from function 2, and some documents in the intellectual asset repository (IAR) of the KMS from function 3. The user can preview the documents on the web browser and then download the interested files for proposal preparation.

**Document Integration Module**

The document integration (DI) module is an independent program that allows the user to combine all downloaded files into one single Microsoft Word file in a prescribed directory. This module combines all files without modifying the content or the format of the original file. By so doing, the integrated file retains the original format and style for reuse. This module can be performed independently without other modules.

**Proposal Database and Intellectual Asset Repository**

The proposal database stores the decomposed files of previous service proposals through an index table in MS-SQL with separated Word files. This file treatment allows the PPA system to incorporate a high-speed file searching mechanism and maintain original Word file format for reuse.

The intellectual asset repository (IAR) database is a database that provides available knowledge corpuses from other KMSs. The IAR database consists of three major sources of knowledge: (1) lessons learned files (LLFs)—obtained from previous experiences of problem solving in the KMiPS; (2) knowledge cases (KCs)—a compilation of the reusable knowledge sharing cases from communities of practice (CoPs); (3) corpuses—the knowledge corpuses generated automatically from the completed project reports by another KMS.

**System Testing and Evaluation Design**

**Test Design**

To collect real data from proposal preparations using the traditional approach in the CECI and the approach supported by the PPA system, two testing teams from a specific division of the CECI are invited to join the study. Fig. 2 shows the design concept of system testing, an approach adopted from previous studies (Hwang 2002; Tseng et al. 2007). Although the adopted approach is not as robust as statistical tests; it is efficient and effective for a case study and has been widely adopted in many other fields.

Each testing team performs proposal preparation tasks using the traditional approach for the real project that the team is currently developing. On the other hand, each testing team performs proposal preparation tasks using the PPA system for the other project that the other team is currently developing. In sum, each testing team performs proposal preparation tasks for two testing projects; one incorporates the traditional approach and the other uses the PPA system. This testing arrangement requires each of the testing teams to perform proposal preparation tasks once for each testing project.

According to the testing approach, the two testing projects are executed independently by two testing project teams. For developing a consistent comparison baseline after testing runs, the leaders of the two testing teams discuss the outcomes of proposal preparation in their tests. The purpose of the discussion is to develop a consensus for the proposal drafts. Namely, the content and scope of the tasks required for proposal preparation are defined in advance. This arrangement results in the testing outcomes being as comparable as possible.

Based on the aforementioned arrangements, this study assumes that the draft proposals prepared by the testing teams are of the same quality. Consequently, the resource inputs (i.e., time and staff hours spent by the testing teams) for the tests are valuable for measurement and comparison. The tests were performed between September and November of 2010.

**Benefit Evaluation Measure**

For quantifying the benefits of the PPA system, this study develops three indicators: a time performance indicator, staff-hour performance indicator, and cost performance indicator. Similar concepts

![Fig. 2. Testing approach executed in this study](image-url)
of all indicators are proposed by a previous study (Yu et al. 2006), and the definitions of the indicators are redefined and elaborated as follows:

- Time performance indicator: With respect to proposal preparation in EC firms, the time benefit related to a KMS, especially with respect to the PPA system, is expected because the tendering time period for proposal preparation is extremely tight. In general, the time period for tendering is less than twenty-eight days in Taiwan. For calculating the time performance indicator (TPI) for using a KMS, this study employed Eq. (1) to determine the ratio for time savings. In the equation, the time spent for proposal preparation under the traditional approach and T_{PPA} indicates the time spent for proposal preparation with a support by the PPA system.

\[
TPI(\%) = \frac{T_{TA} - T_{PPA}}{T_{TA}} \times 100\% \tag{1}
\]

- Staff-hour performance indicator: In an EC firm, the number of staff hours is usually regarded as an indicator for evaluating the performance of any type work. This study uses Eq. (2) to calculate the staff-hour performance (MHPI) for using a KMS where MHTA indicates the staff hours required for proposal preparation under the traditional approach and MH_{PPA} indicates the staff hours required for proposal preparation with support from the PPA system.

\[
MHPI(\%) = \frac{MHTA - MH_{PPA}}{MHTA} \times 100\% \tag{2}
\]

- Cost performance indicator: For an EC firm, the cost of work performed is another indicator for evaluating the potential benefit of work. The development of a KMS, the cost performance plays an important role in determining whether the system is a valuable investment. This study developed Eq. (3) to calculate the cost performance (CPI) when using a KMS where C_{TA} indicates the cost with respect to the staff hours required for proposal preparation under the traditional approach and C_{PPA} indicates the cost in staff hours required for proposal preparation with support from the PPA system. Furthermore, two variables, i.e., C_{TA} and C_{PPA} are calculated in Eqs. (4) and (5), respectively, where MHTA and MH_{PPA} indicate the staff hours required for proposal preparation under the traditional approach and the staff hours required with support from the PPA system. R_{MH} is the average hourly rate, which is provided by the study firm, for an engineer.

\[
CPI(\%) = \frac{C_{TA} - C_{PPA}}{C_{TA}} \times 100\% \tag{3}
\]

\[
C_{TA} = R_{MH} \times MHTA \tag{4}
\]

\[
C_{PPA} = R_{MH} \times MH_{PPA} \tag{5}
\]

**Evaluation Survey**

As previously mentioned, this study assumed that the results of two testing projects by two testing teams are equal; therefore, the resource inputs for the test are valuable for performance measurement and performance comparison. To collect the inputs for the system test, this study designed a questionnaire for the participants to record the essential information needed for benefit calculations. The questionnaire included several questions to prompt the participants to provide the necessary information, i.e., primarily time and staff hours. Furthermore, before the evaluation test was executed, a kickoff meeting was held to introduce the PPA system and a Q&A session was provided for the participants to avoid possible misunderstanding regarding the system and the evaluation process. All the recorded information during the system testing is discussed in the following section.

**Evaluation Results and Discussions**

**Data Source and Reusability**

For the two testing projects, this study asked two project teams to identify the data source and to provide an overall evaluation of the re-usability of the collected data. Table 1 indicates that both testing projects A and B can re-use data from previous projects. Accordingly, the ratio of reusability was approximately 37.5% on average. The information also reveals that the ratio (40%) of data reusability from the PPA system is higher than that (35%) from the traditional approach. In sum, the work of proposal preparation in the testing projects benefit moderately from the data collected from previous projects.

Table 2 shows the distribution of data sources for proposal preparation by the two testing teams for the two different projects. For testing project A, testing team 2 considers that 50% of the data used for preparing the proposal draft is available from the PPA system; for testing project B, testing team 1 considers that 40% of the data used for preparing the proposal draft is available from the PPA system. Therefore, approximately 45% of the data are computerized and retrievable through the PPA system.

**Time Used to Collect Documents**

When preparing proposal drafts, collecting the required documents is an essential step. Table 3 shows the timesheet provided by the

**Table 1. Data Reusability for Testing Projects**

<table>
<thead>
<tr>
<th>Testing project</th>
<th>Traditional approach (%)</th>
<th>PPA (%)</th>
<th>Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project A</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Project B</td>
<td>30</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Average</td>
<td>35</td>
<td>40</td>
<td>37.5</td>
</tr>
</tbody>
</table>

**Table 2. Distribution of Data Source for Proposal Preparations in Testing Projects**

<table>
<thead>
<tr>
<th>Testing project</th>
<th>Data source</th>
<th>Team 1 (%)</th>
<th>Team 2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project A</td>
<td>Internet</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Hardcopy</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Electronic files in PPA system</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Electronic files not in PPA system</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Discussion by meeting</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Discussion by telephone</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Discussion by face-to-face</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Project B</td>
<td>Internet</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Hardcopy</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Electronic files in PPA system</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Electronic files not in PPA system</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Discussion by meeting</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Discussion by telephone</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Discussion by face-to-face</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
two testing teams. From Table 3, it is determined that using the PPA system to collect required documents can save 235 hours for project A and 12 hours for project B. In other words, using the PPA system has a time-saving benefit of 123.5 hour, on average. Based on the proposed time performance indicator (TPI), the test shows that a ratio of 48.7% time-saving benefit is achieved. Eq. (6) shows the calculation results. Thus, it is obvious that the PPA system provides high TPI value (approximately 50%)

\[
TPI(\%) = \frac{T_{TA} - T_{PPA}}{T_{TA}} \times 100\% = \frac{253.5 - 130}{253.5} \times 100\% \approx 48.7\% 
\]  

(6)

For testing project B, the time saved for collecting required documents is only 12 hours, which is relatively low compared to testing project A. After discussing this difference with the participants, it was determined that testing project B has a very different scope of service tasks compared to former projects that are stored in the proposal database. Namely, testing project B is a relatively new type of project compared to those encountered by the testing division. This information suggests that the scope of cases in the proposal database plays an essential role in whether a new project can benefit directly from the PPA system.

Staff-Hour Input for Proposal Preparation

For testing system performance, the project teams identified all the staff hours spent by the team members on proposal preparations. According to the tasks for proposal preparation, the staff hours needed to prepare the proposal draft included the following four types: (1) the staff hours used to collect data, (2) the staff hours spent in meetings, (3) the staff hours spent on editing and cosmetic work, and (4) the staff hours spent on other support tasks (for example, communicating with client representatives to clarify project information). Table 4 reflects all of the staff hours needed to prepare the proposal drafts. According to the defined staff-hour performance indicator (MHPI), this study found that using the PPA system achieved a staff-hour savings of 25.3%. Eq. (7) shows the calculation result. Similarly, the work related to collecting data, meeting for discussion, editing and other tasks related to proposal draft preparation achieved staff-hour savings of 48.7, −233.3, 24.9 and 12.9%, respectively

\[
MHPI(\%) = \frac{M_{H_{TA}} - M_{H_{PPA}}}{M_{H_{TA}}} \times 100\% = \frac{1010.5 - 755}{1010.5} \times 100\% 
\]  

\[
\approx 25.3\% 
\]  

(7)

It is interesting that the work related to meeting for discussion has a negative value for MHPI. This information implies that the PPA system requires more staff hours for discussion and proposal finalization. Based on a discussion with project team members, this study attempted to determine the underlying reason for this negative value. The discussion result revealed that the negative value was because the PPA system provides more raw materials to the project teams than those obtained by the traditional approach, i.e., from a single historical proposal document in which all sections are relevant. As a result, the team members need more time to determine what materials should be included in the proposal and what should be modified. Furthermore, collecting data using the PPA system reaps the greatest benefits when compared to the other tasks assessed in the draft preparation.

Based on the experience of preparing a draft proposal, the staff hours used to modify a proposal draft into a final version for proposal submission are also estimated by the project teams. Table 5 shows the estimated staff hours for required for content modification, discussion time, additional data collection and final editing. Accordingly, the staff-hour savings are 18.4, 22.6, 22.2 and −35.6%, respectively. Although there is still a negative value, the estimates show that the PPA system achieves, overall, a staff-hour savings of 20.1%.

Cost Benefit by Using PPA System

To calculate the cost benefit from the PPA system, this study employs Eqs. (3)–(5) described previously. Through an interview with the staff of CECI, this study obtained the average salary and working hours per month for calculations. In general, an engineer who has an opportunity to participate in proposal preparation earned a salary of NT$55,000 (approximately US$1,833) per month with

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**Table 3. Time Used to Collect Required Documents**

<table>
<thead>
<tr>
<th>Testing project</th>
<th>Traditional approach</th>
<th>PPA</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project A</td>
<td>315</td>
<td>80</td>
<td>235</td>
</tr>
<tr>
<td>Project B</td>
<td>192</td>
<td>180</td>
<td>12</td>
</tr>
<tr>
<td>Average</td>
<td>253.5</td>
<td>130</td>
<td>123.5</td>
</tr>
</tbody>
</table>

**Table 4. Staff Hours Used to Proposal Draft Preparation**

<table>
<thead>
<tr>
<th>Testing project</th>
<th>Collecting data</th>
<th>Meeting for discussion</th>
<th>Cosmetic works</th>
<th>Others</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project A</td>
<td>315</td>
<td>6</td>
<td>320</td>
<td>368</td>
<td>1,009</td>
</tr>
<tr>
<td>Project B</td>
<td>192</td>
<td>6</td>
<td>420</td>
<td>394</td>
<td>1,012</td>
</tr>
<tr>
<td>Average</td>
<td>253.5</td>
<td>6</td>
<td>370</td>
<td>381</td>
<td>1,010.5</td>
</tr>
<tr>
<td>PPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project A</td>
<td>80</td>
<td>20</td>
<td>300</td>
<td>344</td>
<td>744</td>
</tr>
<tr>
<td>Project B</td>
<td>180</td>
<td>20</td>
<td>256</td>
<td>320</td>
<td>776</td>
</tr>
<tr>
<td>Average</td>
<td>130</td>
<td>20</td>
<td>278</td>
<td>332</td>
<td>755</td>
</tr>
</tbody>
</table>

**Table 5. Estimated Staff Hours Used to Modify Proposal Draft into Proposal Submission**

<table>
<thead>
<tr>
<th>Testing project</th>
<th>Content modification</th>
<th>Meeting for discussion</th>
<th>Collecting more data</th>
<th>Cosmetic works</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project A</td>
<td>150</td>
<td>60</td>
<td>10</td>
<td>100</td>
<td>320</td>
</tr>
<tr>
<td>Project B</td>
<td>56</td>
<td>64</td>
<td>8</td>
<td>80</td>
<td>208</td>
</tr>
<tr>
<td>Average</td>
<td>103</td>
<td>62</td>
<td>9</td>
<td>90</td>
<td>264</td>
</tr>
<tr>
<td>PPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project A</td>
<td>48</td>
<td>48</td>
<td>8</td>
<td>180</td>
<td>184</td>
</tr>
<tr>
<td>Project B</td>
<td>120</td>
<td>48</td>
<td>6</td>
<td>64</td>
<td>238</td>
</tr>
<tr>
<td>Average</td>
<td>84</td>
<td>48</td>
<td>7</td>
<td>122</td>
<td>211</td>
</tr>
</tbody>
</table>
180 working hours. This study used the hourly rate of US$10 (roughly obtained by dividing monthly salary by working hours) for further calculations.

Through the information shown in Table 4, on average, the project teams spent 1,010.5 staff hours and 755 staff hours using the traditional approach and the PPA system, respectively. Therefore, the cost benefit was US$2,555 = (1010.5 − 755) × 10 and the cost performance (CPI) was 25.3% [see Eq. (8)]

\[
\text{CPI} = \frac{C_{\text{TA}} - C_{\text{PPA}}}{C_{\text{TA}}} \times 100\%
\]

\[
\approx \frac{(10 \times 1010.5) - (10 \times 755)}{10 \times 1010.5} \times 100% \approx 25.3\%
\]

Notably, the cost benefit provided above is a comparative value, not an absolute value. In other words, the cost benefit of US$2,555 is not the whole investment benefit of the PPA system. Although the cost benefit of US$2,555 (roughly equal to 1.4 man-month payments for an engineer) is low, this information provides the management of the EC firm an index for labor resource allocation.

**Differences between the Two Test Teams**

For testing team 1, who examined testing project A using the traditional approach and testing project B with the help of the PPA system, this study found that testing team 1 spent more time (see Table 3) preparing proposals than did testing team 2. Through an in-depth interview with the participants, this study found that the leader of testing team 1 tended to involve more team members in the discussion during a meeting. Therefore, the time spent in both of the two methods by testing team 1 is greater than that spent by the testing team 2.

This study did not investigate further the difference between the outcomes by the two testing teams. It would be interesting to determine whether different project leaders or different proposal preparation approaches resulted in obviously different outcomes. That is, what management style and proposal preparation approach achieved the higher performance outcome?

**Potential Benefits of the PPA System**

Initially, the purpose of the PPA system was to reuse the computerized intellectual assets from other KMSs. The PPA system has obviously accomplished this goal. Namely, the PPA system provides the considerable value-adding of other KMSs. As mentioned previously, while the cost benefit of the PPA system is low, the PPA system produces an apparent time-saving benefit. This saved time offers the project team a precious opportunity to refine their proposal before submission. Such a refinement may be a determining factor for the winning the project. As a result, by using the PPA system, project team members have more time to prepare their proposals within an already short window of time.

**Indicator Usability and Significance**

To evaluate the benefits of using a KMS, this study developed three evaluation measures, the time performance indicator (TPI), the staff-hour performance indicator (MHPI) and the cost performance indicator (CPI). By implementing KMS in two real projects as discussed previously, this study has proven that the proposed evaluation measures can be used to evaluate KMS benefits.

Notably, those indicators play different roles in benefit evaluations in the study KMS. In EC firms, the number of worker-hours is regarded as an important indicator for evaluating work performance; therefore, achieving a higher MHPI outcome suggests that EC firms achieve greater satisfaction benefits. The MHPI can be a general benefit evaluation measure for EC firms. In the study KMS, the TPI is another essential indicator because a limited time period is allowed for proposal preparation. Compared to other indicators, CPI is less important in this study when using a KMS because the saved costs would be low compared to the KMS investments. However, recoding cost-saving measurements over a period of time would reflect considerable benefits.

**Conclusions**

Engineering consulting firms (EC firms) in the construction industry are knowledge-intensive and experience-based firms. Increasingly more EC firms have adopted KMSs as initiatives to enhance their professional services. However, though a quantitative benefit analysis of using KMSs is important to all stakeholders, it is rarely reported in the literature. To evaluate the performances of KMSs, most previous studies have adopted qualitative approaches, which give the stakeholders less useful information for adopting KMSs. This study proposes a simple ratio-based approach to calculate the benefits of using a KMS, the PPA system, in a case study EC firm in Taiwan. Based on a test of two real projects by two testing teams, this study concluded that the case KMS achieves the following quantitative benefits:

- With respect to proposal preparation work, approximately 45% of the data from previous projects can be retrieved from the study system;
- With respect to data collection, a 48.7% time-saving performance is achieved;
- With respect to total staff hours spent preparing proposal drafts, a 25.3% staff-hour saving is obtained; and
- With respect to cost benefit and based on a salary of US$1,833 per month for an engineer, the cost benefit of using the system is US$2,555 per project.

The benefits revealed in this study provide convincing and inspiring information to the industrial KM practitioners as they plan their future works. Based on the results of this study, the following two research directions are suggested for the future:

- The proposed approach considers only the inputs (for example, time and staff hours) of a KMS. To integrate the outputs (for example, the quality of knowledge output) of a KMS with the proposed approach provides a complete evaluation of KMSs; and
- The development of an automated program to decompose documents, for example, proposals and reports, will enrich the content of the database. Such an improvement will help the PPA system to provide quicker and higher quality information for users.

**Acknowledgments**

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