



## STRUCTURE DEVELOPMENT AND PERFORMANCE EVALUATION OF CONSTRUCTION KNOWLEDGE MANAGEMENT SYSTEM

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**Abstract.** Construction or civil engineering is a kind of basic necessary industry for each citizen's livelihood. Due to its characteristic of participants and tasks variety, this industry becomes highly requirement for collaboration and professional knowledge. Applying knowledge management in construction industry can improve its' operation with positive help. To illustrate the application effect and correct suitable management system, an appropriate evaluation model of performance result with constructional knowledge management system should be built. So this research uses Windows 2003 Server IIS Ver. 5.0 as the platform to develop a constructional knowledge management sharing system. Both end user and systematic function were integrated in this system. Meanwhile, this system applied three-tier structure and FrontPage to edit Web Server pages.

This research also develops a performance evaluation model to check the application result of constructional knowledge management system. With the result of this research, the competition capability of construction industry could be increased. According to the main concept of this essay, the reference about performance evaluation will be collected at first. Then the current situation of internal construction knowledge management will be described. After that, scientific analysis including fuzzy Delphi method, fuzzy analytic hierarchy process (FAHP) and fuzzy theory will be used to develop an evaluation system of knowledge management performance. This model includes four levels: knowledge creation, knowledge transportation, knowledge spreading and knowledge accumulating.

After developing and testing, the proof of knowledge manage the feasibility duct into the construction industry, organization decision ability and competitiveness in construction industry could be promoted through this system and to echo an objective of knowledge economy.

**Keywords:** knowledge management, performance evaluation, knowledge sharing, Fuzzy Delphi Method, Fuzzy Analytic Hierarchy Process.

### 1. Introduction

Construction projects use the professional technology in civil engineering and relevant facilities to change land renovation and prevent calamity. This technique has not only close relation to the people's life, but also one of the key indexes in influencing the nation's public construction and economic development. Construction or civil engineering is a kind of basic necessary industry for each citizen's livelihood. Due to the characteristic of participants and tasks variety, this industry becomes highly requirement for collaboration and professional knowledge, especially in computer technology (Lin *et al.* 2004). Therefore, the enhancement of the competitiveness of a construction company is one of the most important strategic tasks in construction industry (Šiškina *et al.* 2009). For example, Fig. 1 shows the construction simulation of a high raise steel structure building with computer, Fig. 2 illustrates the scenario simulation of a dynamic fire disaster within a shopping mall, and Fig. 3 shows the calculation result of a simulation analysis. Up to today, it might because this industrial engineers' conventionalism trait, professional knowledge transferring and sharing did not work appropriately (Nonaka and Teece 2001; Bonner 2000; Park *et al.*

2009). Such situation makes the competitive ability of construction industry getting lower. Therefore, applying knowledge management in construction industry can improve its' operation with positive help. To illustrate the application effect and correct suitable management system, an appropriate evaluation model of performance result with constructional knowledge management system should be built.

This research illustrates how to use Windows 2003 Server IIS Ver. 5.0 to develop a prototype constructional knowledge management system. In this system, text, picture and image were edited by HTML schema. On the other hand, this system also applied ASP language to establish interactive web page. By applying of computer software and information technology, three-tier structural prototype of constructional knowledge management system was done. Because many researches focus on applying and conferring the guidance of structure system about knowledge management, only a little is aimed with performance evaluation of constructional knowledge management system (Chang *et al.* 2008; Lin and Shi 2004; Lin and Lin 2007; O'Leary 2002; Sayed *et al.* 2009). Therefore, this research develops a performance evaluation model to investigate the application result of constructional knowledge management system.

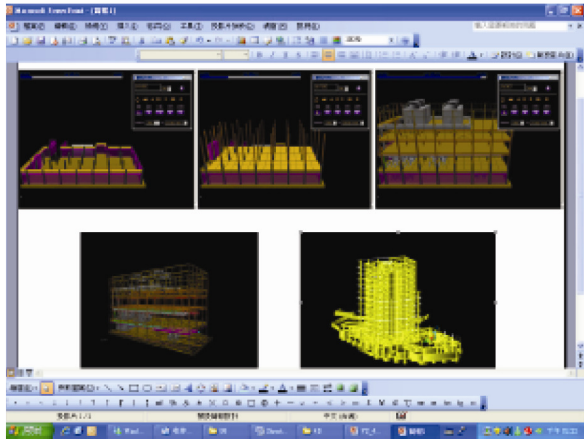


Fig. 1. Construction simulation

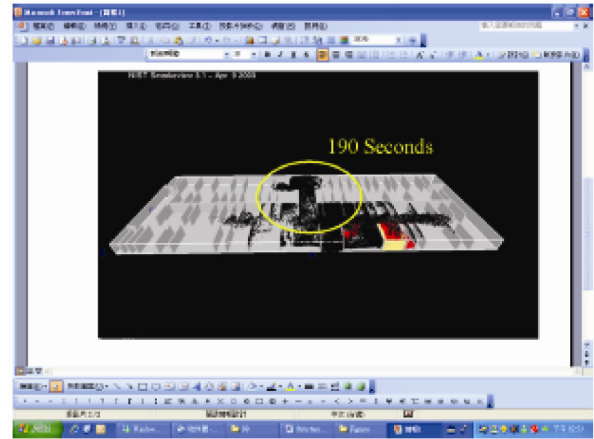


Fig. 2. Fire dynamics simulation

## 2. Development and current situation of construction industry in Taiwan

In the past 40 years, the global economy made big influence to the social economic development, resource allocation and quality of the life. From 1951 to 1969, due to the shortage of funding and labour, public construction projects in Taiwan had focused on improving the agriculture and light industry production. Then from 1971 to 1979, the government had developed 12 national construction projects. After that, the government continuously had developed 14 national construction projects from 1981 to 1989 (Wang 2005; *Construction and Planning...* 2009). Besides the basic construction, government begins to focus on improving the quality of life. Due to the international skyrocketing price and the bubble economy, caused the price of land and worker rapidly go up. This will also cause a lot of project progress to lag behind. For example, from Tables 1 and 2 can calculated that the average total building construction cost per year in

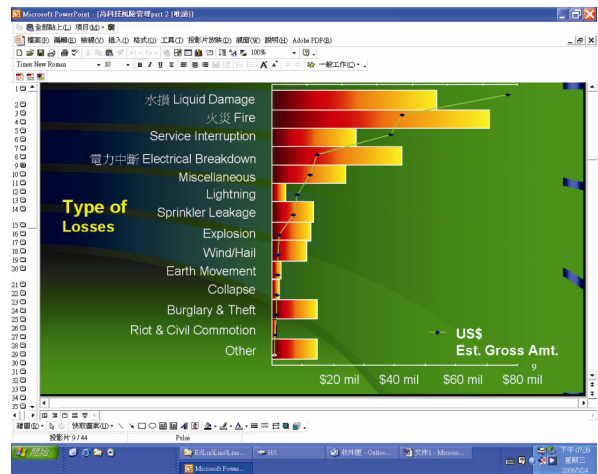


Fig. 3. Computing analysis

Taiwan is about 9,157,800,000 NT dollars (277,509,091 US dollars). Such construction investment is fully relative with nation’s economy situation.

Table 1. Total building construction cost per year in Taiwan (*Construction and Planning...* 2009; *Republic Construction Commissions* 2009)

| Year | Quantity | Increment rate (%) | Total construction cost (Ten thousand NT dollars) |
|------|----------|--------------------|---|
| 1989 | 62,078   | —                  | 89,243  |
| 1990 | 49,122   | -20.87             | 84,987  |
| 1991 | 65,100   | 32.53              | 113,848   |
| 1992 | 86,539   | 32.93              | 162,148   |
| 1993 | 76,578   | -11.51             | 153,769   |
| 1994 | 67,431   | -11.94             | 129,850   |
| 1995 | 54,295   | -19.48             | 96,915  |
| 1996 | 42,669   | -21.41             | 79,947  |
| 1997 | 42,207   | -1.08              | 97,104  |
| 1998 | 37,221   | -11.81             | 90,755  |
| 1999 | 28,067   | -24.59             | 78,813  |
| 2000 | 29,493   | 5.08               | 74,221  |
| 2001 | 22,175   | -24.81             | 45,882  |
| 2002 | 25,282   | 14.01              | 48,958  |
| 2003 | 34,468   | 36.33              | 60,160  |
| 2004 | 45,934   | 33.27              | 90,152  |
| 2005 | 43,805   | -4.63              | 76,460  |
| 2006 | 35,027   | -20.04             | 85,405  |
| 2007 | 31,429   | -10.27             | 81,359  |

**Table 2.** Total quantity of construction companies in Taiwan (*Construction and Planning... 2009*)

| Year | Quantity | Increment rate (%) | Investment (Ten thousand NT dollars) |
|------|----------|--------------------|--------------------------------------|
| 1996 | 6,478    | –                  | 14,473,681                           |
| 1997 | 7,789    | 20.24              | 18,135,218                           |
| 1998 | 9,086    | 16.65              | 22,714,410                           |
| 1999 | 9,876    | 8.69               | 27,792,140                           |
| 2000 | 11,232   | 13.73              | 31,971,183                           |
| 2001 | 10,966   | –2.37              | 27,852,771                           |
| 2002 | 12,513   | 14.11              | 33,551,662                           |
| 2003 | 12,638   | 1.00               | 36,810,305                           |
| 2004 | 8,822    | –30.19             | 29,978,443                           |
| 2005 | 8,979    | 1.78               | 30,150,982                           |
| 2006 | 13,268   | 47.77              | 45,767,093                           |
| 2007 | 10,115   | –23.76             | 39,685,118                           |

### 3. Development of knowledge management and applications in construction industries

In this 21st century, information technology (IT) is an important issue for economic growth of each country. The professional knowledge of IT and construction is a key factor to develop construction industry. Without such knowledge for sharing among construction project practitioners, construction management techniques may not be appropriately applied to future projects. In each country, most construction projects are built for every citizen's use. The quality of such construction projects will directly influence all users once these projects were finished. Meanwhile, if the performance of construction management doesn't work well, it not only makes worse quality but also threatens each citizen's life. Construction projects contain many different aspects such as economy, society, culture and education, medical treatment, and so on. During the whole life cycle with each construction project, life cycle includes conceptual phase, designing phase, bidding phase, construction phase and maintenance phase (Lin *et al.* 2005), there are lot of professional knowledge need to be supplied from every engineer. That means knowledge sharing between construction companies and employers is an important competition factor in construction industry.

There are several famous businesses with their knowledge management and sharing systems. One of them is Braodvision Co. Braodvision is established in 1993 and is famous as renowned electronic commerce software supplier by the personal platform and one to one platform in worldwide, so as to assistance enterprise promotes the competitive ability and the ability to make a profit. Its customers include financial, retail sales, high tech manufacture and international telecommunication industry primarily. Braodvision's personal platform provides the formidable development tool, it's also can be used according to the customer different demand to develop the application procedure, full display the personal platform formidable function, as the knowledge management development system platform, also the highest market share knowledge management platform in U.S.A. Its software provides the enterprise toward three ways of

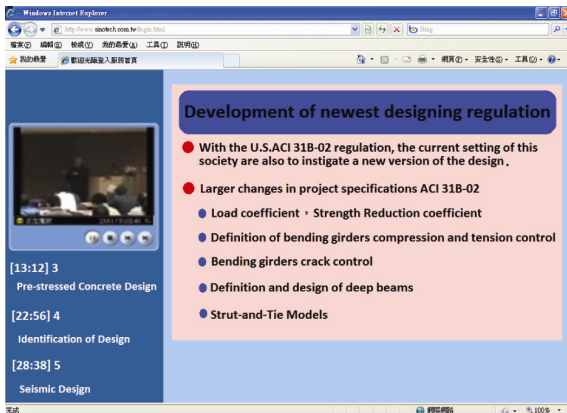
development. Emphasized one to one personal platform service mechanism especially helps the operator establishment intimate relationship between the staff, customer and consumer. Braodvision specifically manifests the knowledge economy in two stratification planes. It already penetrates the knowledge management, causes own management to be more effective, more importantly it provides a tool. The official assistance enterprise creates the knowledge and the economy to take the initiative's product is the platform which provides the enterprise a knowledge management and penetration information share, then creation value, transforms the knowledge into the profit. Provided software product establishes the function integrity web site with the enterprise information and assistances enterprise penetrates. The personal channel can connect customer, cooperation merchant supplier and staff. For example, when general manager as soon as turns on the computer, not needs to do any search, system will automatically send the newest progress in his South Korean investment or the financial analyst forecast into his folder. This method can deliver the correct information fast to relevant staff (Chang *et al.* 2008; Stewart 1998; Norman 1969).

In current, there are many companies which have developed knowledge management and relative technologies. Such developments include: (1) intelligent text searching tool, (2) flexible organization for personnel management (department/group/personal authorized control environment), (3) process control tool, (4) personal message management system, (5) data analyzing tool, (6) directory-based data management system, (7) automatic reminding management system, (8) online educational management system, (9) network multimedia development system, (10) enterprise information portal system. Moreover, there are some researches on the adoption of knowledge management system (Norman 1969).

In Taiwan, only a few construction companies have been developed knowledge management within their business. Fig. 4 is the system contents of a consultant company. Figs 5 and 6 are program examples of two construction companies (*Sinotech... 2009*; Bornemann *et al.* 1999; Ruentex Group 2009).



a) Homepage



b) E-learning

Fig. 4. System contents of a consultant company (Sinotech... 2009)

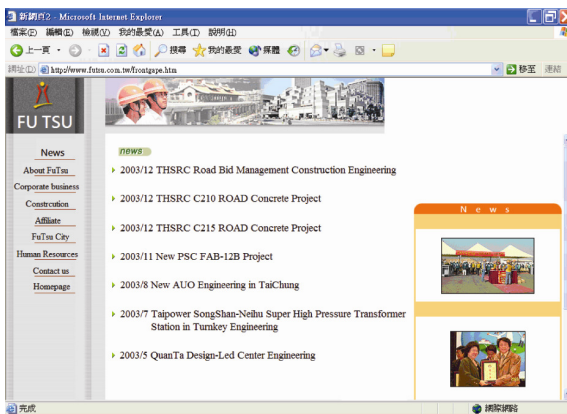
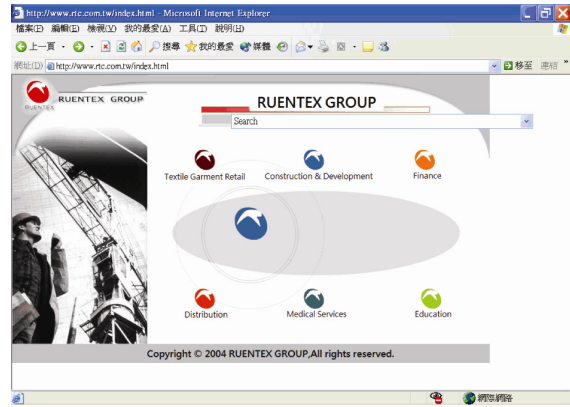


Fig. 5. Knowledge management system of company A

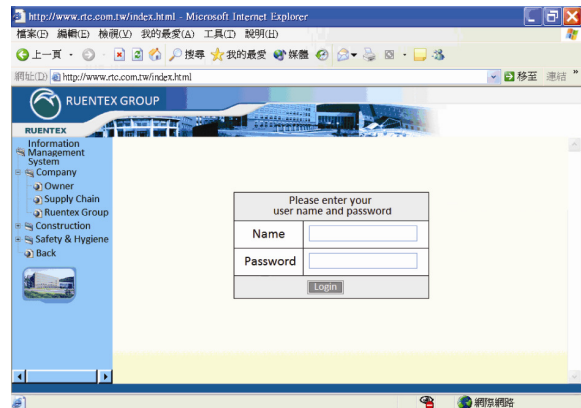
#### 4. Structure development of construction knowledge management system

Knowledge sharing and decision acquisition are problems solving expertise from knowledge sources such as human experts, texts, data and documents to another human or computer program (Buchanan *et al.* 1983).

People are interested in acquiring knowledge because: (1) it may help solve major problems of today and future with technological solutions; and (2) it may satisfy certain needs by filling the gap between what is at present, and what will be tomorrow (Modesitt 1992).



a) Discussion region



b) Entrance control

Fig. 6. Knowledge management system of company B (Ruentex Group 2009)

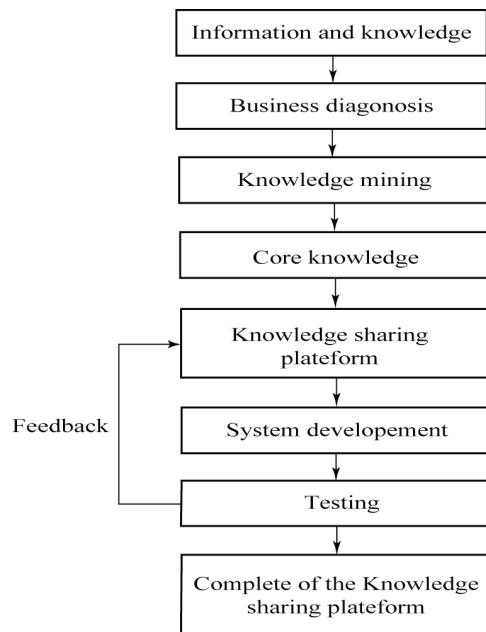


Fig. 7. Flow chart of program development

The knowledge management system completed by combining the development for the system framework with the suitable editing software usually includes planning for the client-server model and making a study of the demand for knowledge databases. The purpose of this research

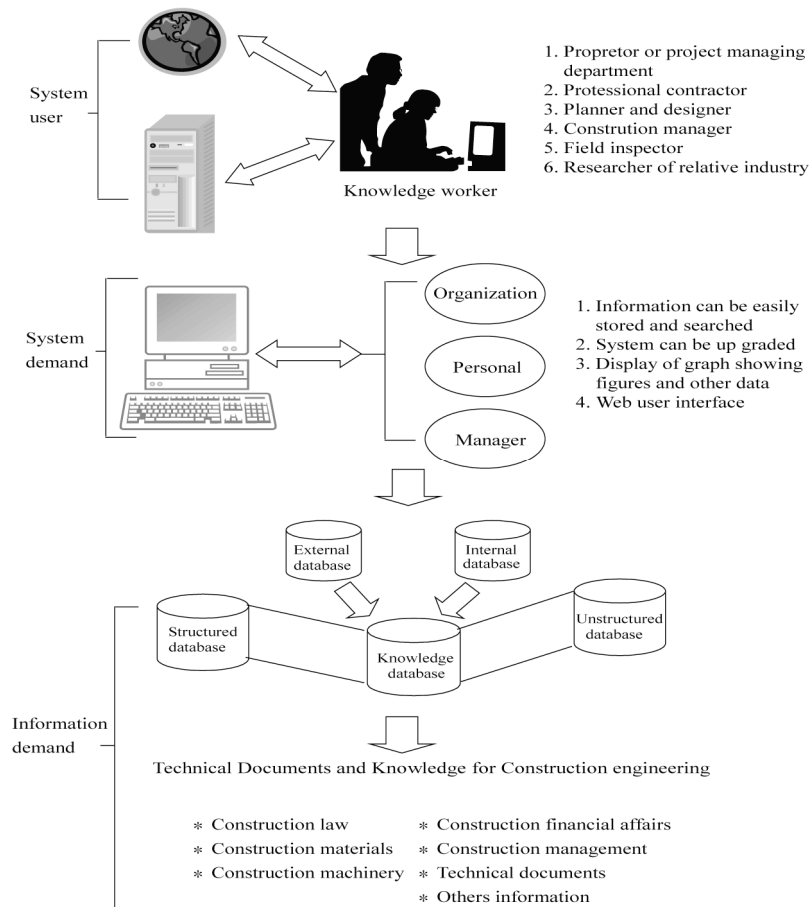


Fig. 8. Analysis of system requirements

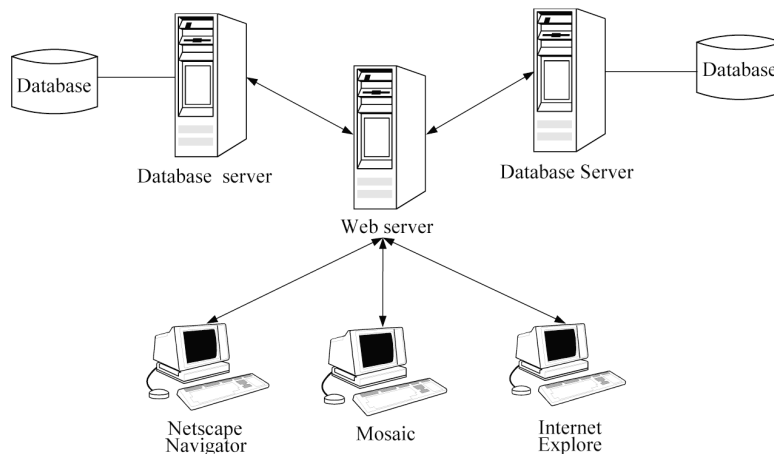


Fig. 9. Three-tier architecture

develops a prototype management sharing system. The processes are shown in Figs 7 and 8. The Windows 2003 Server IIS Ver. 5.0 is used as the platform to develop this program system. The following three sections will describe relevant information of the program.

#### 4.1. The concept for the client-server model

Centralized processing is applied to the operation in traditional mainframe: all the works were processed by the mainframe itself; the user only needs to use the keyboard

to control the mainframe and the data transmitted is received and displayed by the terminal. However, when the amount of data and users increases, even with the super computer, a single mainframe is not capable of processing all the works. As the price of personal computer drops and becomes more and more powerful; the networking technology and the distributed data base management fulfills the possibility to process part of the works with the personal computer to form the client-server model (Lin and Shi 2004). Under this model, personal computers can share some of the processing works from the mainframe; it can-



not break apart from the centralized processing model so the workstation gradually replaces the mainframe since the price for the mainframe is too expensive.

The functions of the World-Wide Web (WWW), Web Browser and other software (Java from Sun and ActiveX from Microsoft) are becoming more powerful. This makes the application software developing to the Multi-Tier Architecture as shown in Fig. 9. It includes client, web server and database server (Lin and Shi 2004).

#### 4.2. System demonstration

The basic structure of this program is shown in Fig. 10. It develops a program with scientific process as mentioned above and consults more than six senior engineers to get feedback information for revising the prototype program. Finally, the contents of this prototype program include: (1) front page, (2) bulletin board, (3) revised announce, (4) discussion area, (5) knowledge sharing area and (6) knowledge mining. Fig. 11 shows several different contents of the program demonstration screens.

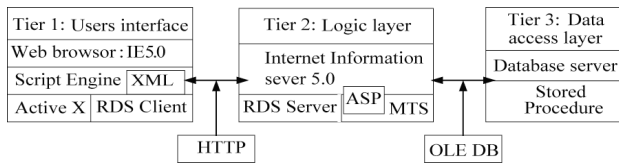
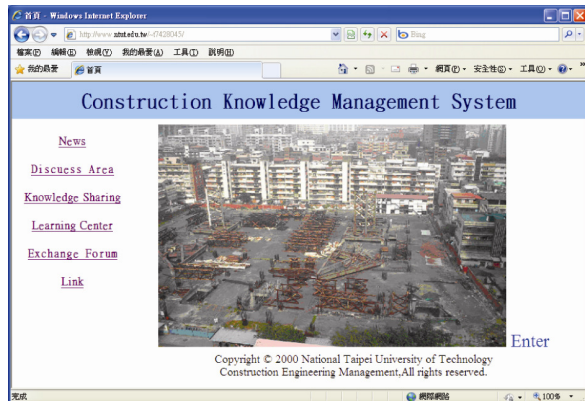


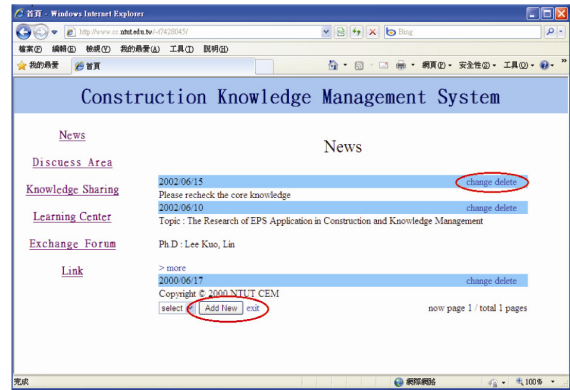
Fig. 10. Basic structure of program



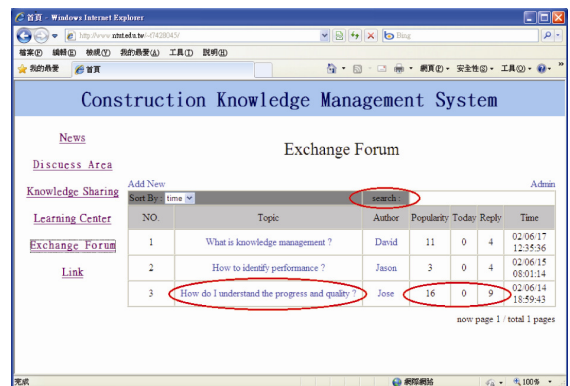
a) Front page



b) Bulletin board



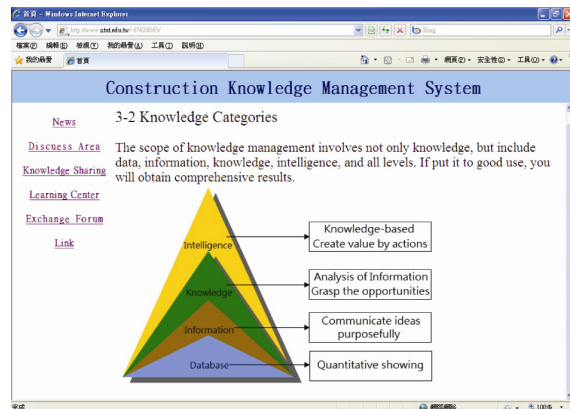
c) Revised announce



d) Discussion area



e) Knowledge sharing area



f) Knowledge mining

Fig. 11. Program demonstration

### 4.3. Program command code

The overall structure of this prototype program system is integrated with sever appropriate program shells. The logic tier is developed with Microsoft Internet Information Server (IIS) 5.0. Meanwhile it uses Active Server Pages (ASP), MTS and Component Object Model/Distributed Component Object Model (COM/DCOM), such as MTS Component, ADO Component and RDS Data Space Component, to build the system content, then transmits to the front part by using hypertext transmission

```

<center>
<%
... if fields = "" or fields = "order" then
... sqlstr="select * from query_DT where use=0 order by T_DT desc"
... rs.open sqlstr,conn,1,3
... else
... sqlstr="select * from report where use=0 order by "& fields & " desc"
... rs.open sqlstr,conn,1,3
... end if
... rs.PageSize=25
Page = CLng(Request("Page"))
If Page < 1 Then Page = 1
If Page > rs.PageCount Then Page = rs.PageCount
If Not rs.eof Then
... RS.AbsolutePage = PAGE
End if
pagecount = rs.PageCount
%>
<table border="1" width="100%" height="45" bordercolor="#FFFFFF">
... <tr>
... <td width="5%" height="39">
... <td width="95%" height="39">
... <p style="line-height: 100%">
... <p align="center" style="line-height: 100%">
... <p align="center">
... </tr>
</table>
<table width="95%" border="0" cellspacing="0" cellpadding="0" height="19" align="center">
... <tr>
... <td width=305 height="2">
... <div align="center">
... 
... 

```

#### a) Example code 1

```

... <td width=126 height="2">
... <div align="center">
... </td>
... <td width=168 height="2">
... <div align="center">
... </td>
... </tr>
</table>
<center>
<table width="95%" border="0" cellspacing="0" cellpadding="0" height="19" bordercolorlight="#999999" bordercolordark="#FFFFFF">
... <tr bgcolor="#9CCCF">
... <td colspan="2" nowrap bgcolor="#C0C0C0">
... <form method="post" action="index.asp">
... <div align="center">
... <select name="fields" size="1" style="BACKGROUND-COLOR: #FFFFFF; BORDER-BOTTOM: 1px solid; BORDER-LEFT: 1px solid; BORDER-RIGHT: 1px solid; BORDER-TOP: 1px solid;">
... <option value="mailhit" <%if fields="mailhit" then response.write "selected" end if %>>
... <option value="reply" <%if fields="reply" then response.write "selected" end if %>>
... <option value="" <%if fields="" then response.write "selected" end if %>>
... <option value="hits" <%if fields="hits" then response.write "selected" end if %>>
... </select>
... <input type="submit" value=" " style="BACKGROUND-COLOR: #FFCC00; BORDER-BOTTOM: 1px solid; BORDER-LEFT: 1px solid; BORDER-RIGHT: 1px solid; BORDER-TOP: 1px solid; HEIGHT: 19px; WIDTH: 30px">
... </div>
... </form>
... </td>
... <td width="64%" nowrap bgcolor="#C0C0C0">

```

#### b) Example code 2

Fig. 12. Examples of program command

protocol (http) and connects data base by using Open Database Connectivity (ODBC). Fig. 12 shows several program codes of this prototype system.

## 5. Analysis and development of performance evaluation model

It is also an important issue for keeping knowledge system in well condition to guarantee its performance. To develop an appropriate evaluation algorithm, this research uses analysis tools of Delphi, Analytic Hierarchy Process (AHP) and fuzzy theory with questionnaires to build up the model of assessing factors and to establish the evaluation weight. For practical application this research also uses computing technology to build up an analysis system for decision strategy.

### 5.1. Assessment structure calculation and development

There are three steps to build the original assessment model: (1) identifying of the assessment factors, (2) identifying of the relationship of assessment factors and (3) identifying of the grade of assessment factors. The model can be built as follows:

1. Identifying the assessment factors: according to literature and some experts' opinion, selecting fit factors were used to assess the system performance;

2. Identifying the weighting of key performance index (KPI): This part uses Analytic Hierarchy Process (AHP) to find out the weight of each factor. The analysis process of AHP is described as follows (Satty 1980; Osadnik and Lange 1999; Timothy 2000):

- (1) Building up comparison matrix. In order to compare each assessment factor, it must use nominal scale as a matrix to calculate. If a specific index contains  $n$  factors to analysis, it will have  $n \times (n-1)/2$  pairs to compare.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & 1 & \vdots & \vdots & a_{2n} \\ \vdots & \vdots & 1 & \vdots & \vdots \\ \vdots & \vdots & \vdots & 1 & \vdots \\ a_{n1} & a_{n2} & \cdots & \vdots & 1 \end{bmatrix} \quad (1)$$

- (2) Calculating weighting. The calculating method is shown in Eq. (2).

$$w_i = \frac{a_{ij}}{GM_i}, \quad (2)$$

where:  $GM_i$  is the geometric mean of one row in compare matrix;  $i$  – row number;  $j$  – column number;  $a_{ij}$  – factor  $i$  compared with factor  $j$ .

- (3) Calculating consistency ration (CR). In order to get value of consistency ratio (CR) Eqs. (3), (4) and (5) can be used.

$$\lambda_{\max} = \sum_{j=1}^n a_{ij} \times w_i \quad i = 1 \sim n, \quad (3)$$

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

$$CR = \frac{CI}{RI}. \tag{5}$$

3. Establishing the level of KPI. Each assessment factor has its different cognition, so it must be identified with every situation for each factor. This research uses fuzzy theory to statistics the cognition of citizens from these assessment factors. The membership value calculated from questionnaire to derive three grades of its membership function within each assessment factor.

**5.2. Development of the evaluation model**

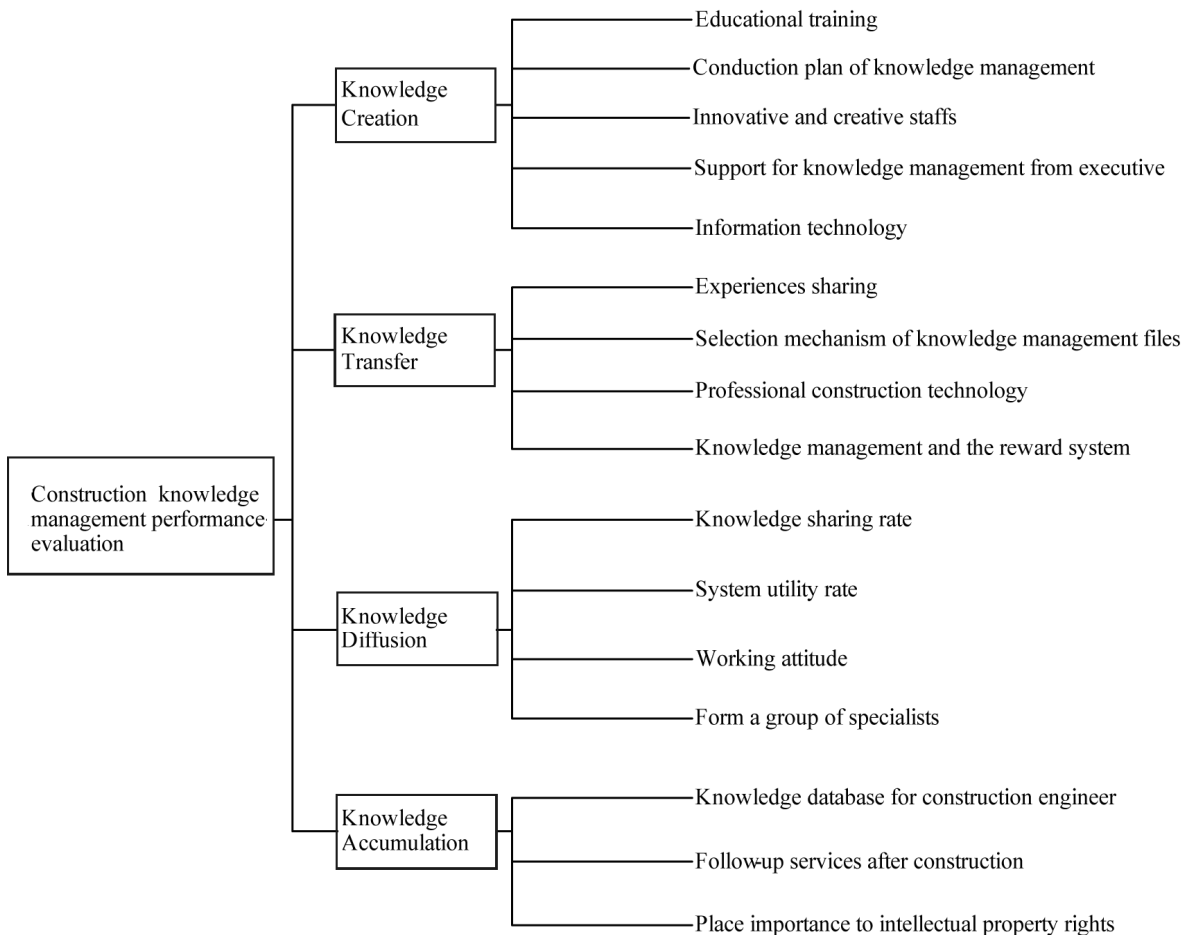
There are two major steps to build the performance evaluation model of knowledge management following with the original assessment model in this research. The first step is choosing evaluation factors and the second step is evaluating index of every factor. The performance evaluation model, which was built from this research, is depending on a cycling structure of knowledge management; such evaluation model is fully focusing on the core value of constructional knowledge sharing and according to the references about performance evaluation (Lin and Shi 2004; Kaplan and Norton 1996; Zadeh 1965; Csutora

and Buckley 2001). This model contains design of performance evaluation factors, estimation of performance evaluating structure, algorithm of evaluating process and discussion and improvement of performance evaluation. Scientific analysis including fuzzy Delphi method, Fuzzy Analytic Hierarchy Process (FAHP) and fuzzy theory are used to build and calculate the performance result.

This evaluation model includes four levels:

- (1) Knowledge creation, including educational training, construction plan of knowledge management, innovative and creative staff, support for knowledge management from executive and information technology;
- (2) Knowledge transportation, including experiences sharing, selection mechanism of knowledge management files, professional construction technology and knowledge management and the reward system;
- (3) Knowledge diffusion, including knowledge sharing rate, system utility rate, working attitude, and form a group of specialists;
- (4) Knowledge accumulation, including knowledge database for construction engineer, follow-up services after construction, and place importance to intellectual property rights.

The total involves sixteen indexes within this evaluation model (Fig. 13). The calculating procedures of each weighting factor are briefly described below.



**Fig. 13.** Performance evaluation model



### 5.3. Deriving procedure of weighting factor

The calculation method for the principle weighting of this study was based on the analytic hierarchy process and used the concept of the triangular fuzzy number to gather and calculate all the valid data from the second stage of expert questionnaires.

In order to get the construction knowledge management performance evaluation to be symbolically standard, this study used the fuzzy Delphi method for the finding indexes and then used the analytic hierarchy process to calculate the weighting of the 16 indexes. 15 copies of the expert questionnaires were sent out and

withdrew 12 copies. The number of valid questionnaires was 12 copies.

After obtaining the decision group opinions from the expert questionnaires, this study used the multi-decision software, *Expert Choice*, to calculate the relative weightings for the indexes. For example, in the evaluation aspect of knowledge creation, the calculating results of the minimum weighting factor ( $L_{\min}$ ) is 0.048, the maximum weighting factor ( $U_{\max}$ ) is 0.516 and the average weighting factor ( $M$ ) is 0.139 (Fig. 14). In order to ensure the validity of each expert questionnaire, the consistency index (CI) for each questionnaire must not be greater than 0.1. Tables 3 and 4 show the calculation results.

**Table 3.** Fuzzy weighting of each evaluation index

| Evaluation Aspects     | Weighting ( $L_{\min}$ , $M$ , $U_{\max}$ ) | Evaluation Index                                  | Weighting ( $L_{\min}$ , $M$ , $U_{\max}$ ) |
|------------------------|---|---|---|
| Knowledge Creation     | (0.048,0.139,0.516)                         | Educational training                              | (0.074,0.086,0.195)                         |
|                        |   | Conduction plan of knowledge management           | (0.082,0.201,0.534)                         |
|                        |   | Innovative and creative staff                     | (0.055,0.165,0.252)                         |
|                        |   | Support for knowledge management from executive   | (0.120,0.331,0.577)                         |
|                        |   | Information technology                            | (0.044,0.093,0.215)                         |
| Knowledge Transfer     | (0.155,0.262,0.378)                         | Experiences sharing                               | (0.107,0.307,0.543)                         |
|                        |   | Selection mechanism of knowledge management files | (0.089,0.198,0.395)                         |
|                        |   | Professional construction technology              | (0.052,0.139,0.240)                         |
|                        |   | Knowledge management and the reward system        | (0.048,0.178,0.645)                         |
| Knowledge Diffusion    | (0.108,0.228,0.442)                         | Knowledge sharing rate                            | (0.050,0.226,0.509)                         |
|                        |   | System utility rate                               | (0.066,0.174,0.499)                         |
|                        |   | Working attitude                                  | (0.158,0.285,0.639)                         |
|                        |   | Form a group of specialists                       | (0.105,0.136,0.211)                         |
| Knowledge Accumulation | (0.105,0.221,0.394)                         | Knowledge database for construction engineer      | (0.285,0.564,0.761)                         |
|                        |   | Follow-up services after construction             | (0.166,0.219,0.320)                         |
|                        |   | Place importance to intellectual property rights  | (0.073,0.149,0.498)                         |

**Table 4.** Total weighting calculation

| Evaluation Aspects     | Weighting $W1$ | Evaluation Index                                  | Weighting $W2$ | Total weighting ( $W1 \times W2$ ) |
|------------------------|----------------|---|----------------|------------------------------------|
| Knowledge Creation     | 0.234          | Educational training                              | 0.121          | 0.028                              |
|                        |                | Conduction plan of knowledge management           | 0.313          | 0.073                              |
|                        |                | Innovative and creative staff                     | 0.218          | 0.051                              |
|                        |                | Support for knowledge management from executive   | 0.367          | 0.086                              |
|                        |                | Information technology                            | 0.122          | 0.029                              |
| Knowledge Transfer     | 0.265          | Experiences sharing                               | 0.362          | 0.085                              |
|                        |                | Selection mechanism of knowledge management files | 0.215          | 0.050                              |
|                        |                | Professional construction technology              | 0.144          | 0.034                              |
|                        |                | Knowledge management and the reward system        | 0.333          | 0.078                              |
| Knowledge Diffusion    | 0.259          | Knowledge sharing rate                            | 0.273          | 0.064                              |
|                        |                | System utility rate                               | 0.263          | 0.062                              |
|                        |                | Working attitude                                  | 0.357          | 0.084                              |
|                        |                | Form a group of specialists                       | 0.150          | 0.035                              |
| Knowledge Accumulation | 0.240          | Knowledge database for construction engineer      | 0.517          | 0.121                              |
|                        |                | Follow-up services after construction             | 0.233          | 0.055                              |
|                        |                | Place importance to intellectual property rights  | 0.271          | 0.064                              |

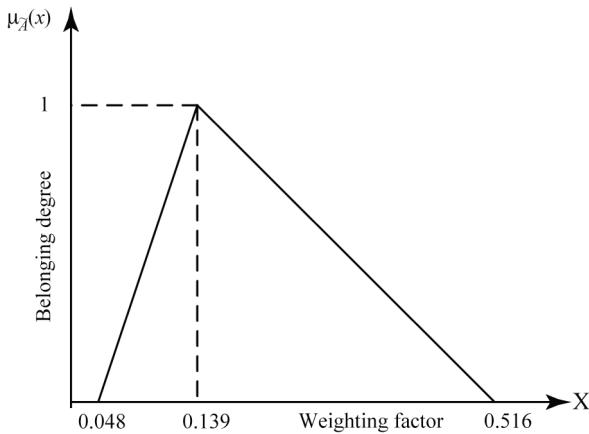


Fig. 14. Triangular fuzzy number of knowledge creation aspect

**6. Illustration of performance evaluation**

For the practical application of the construction knowledge management performance evaluation system the case study on a domestic engineering consulting company A was performed (for the confidentiality, the company is named A company). In order to obtain the objective evaluation value of the A engineering consulting company, therefore the evaluation was performed on 3 different groups: 1 system developer, 1 senior director and 13 system users. The evaluation procedure was followed as depicted in Fig. 15.

In this study the evaluation value of different indexes was compared and analyzed in order to understand the satisfaction of the system constructor, decision layer and system users. This research used the arithmetic average from the performance value to make the contribution identical. Table 5 shows the overall average performance value for each index. Fig. 16 depicts the detail results obtained from different evaluators.

From the sorting, the highest performance value is the knowledge creation, the knowledge accumulation is

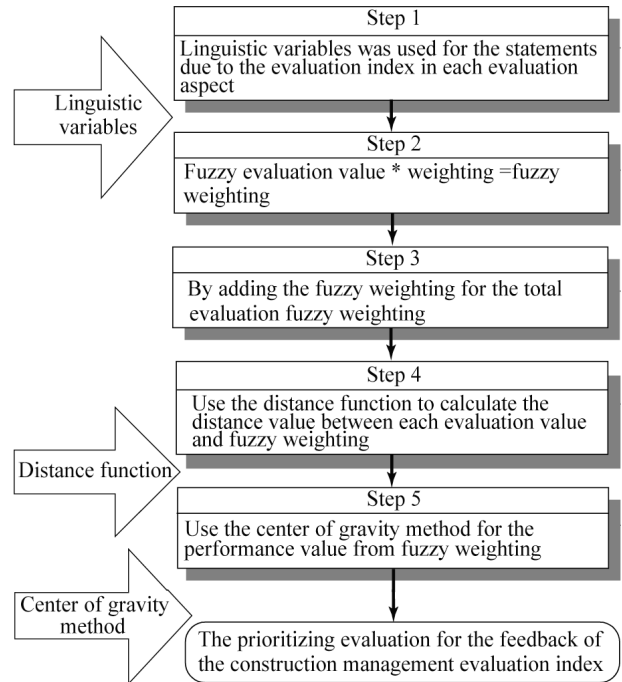


Fig. 15. Evaluation process

next and the knowledge transferring is the lowest. The difference of the evaluation value for the four aspects not varies. The biggest difference of the value is only 0.032. The highest value of the evaluation index in Table 5 is the knowledge database for construction engineer, support for knowledge management from executive is next and educational training is the lowest. The biggest difference of the value is only 0.082. Also Fig. 16 clearly shows the difference of the performance value between different groups and the distribution chart allows coming to some conclusions:

1. Basically, the acknowledgement and the knowledge management performance index for different evaluator are similar.

Table 5. Practice evaluation result

| Evaluation Index                                  | Indicator | Performance value | Sorting |
|---|-----------|-------------------|---------|
| Knowledge database for construction engineer      |           | 0.104             | 1       |
| Support for knowledge management from executive   |           | 0.069             | 2       |
| Working attitude                                  |           | 0.068             | 3       |
| Experiences sharing                               |           | 0.064             | 4       |
| Conduction plan of knowledge management           |           | 0.057             | 5       |
| Place importance to intellectual property rights  |           | 0.056             | 6       |
| System utility rate                               |           | 0.052             | 7       |
| Knowledge management and the reward system        |           | 0.051             | 8       |
| Knowledge sharing rate                            |           | 0.049             | 9       |
| Follow-up services after construction             |           | 0.046             | 10      |
| Innovative and creative staffs                    |           | 0.039             | 11      |
| Selection mechanism of knowledge management files |           | 0.037             | 12      |
| Form a group of specialists                       |           | 0.030             | 13      |
| Professional construction technology              |           | 0.028             | 14      |
| Information technology                            |           | 0.025             | 15      |
| Educational training                              |           | 0.022             | 16      |

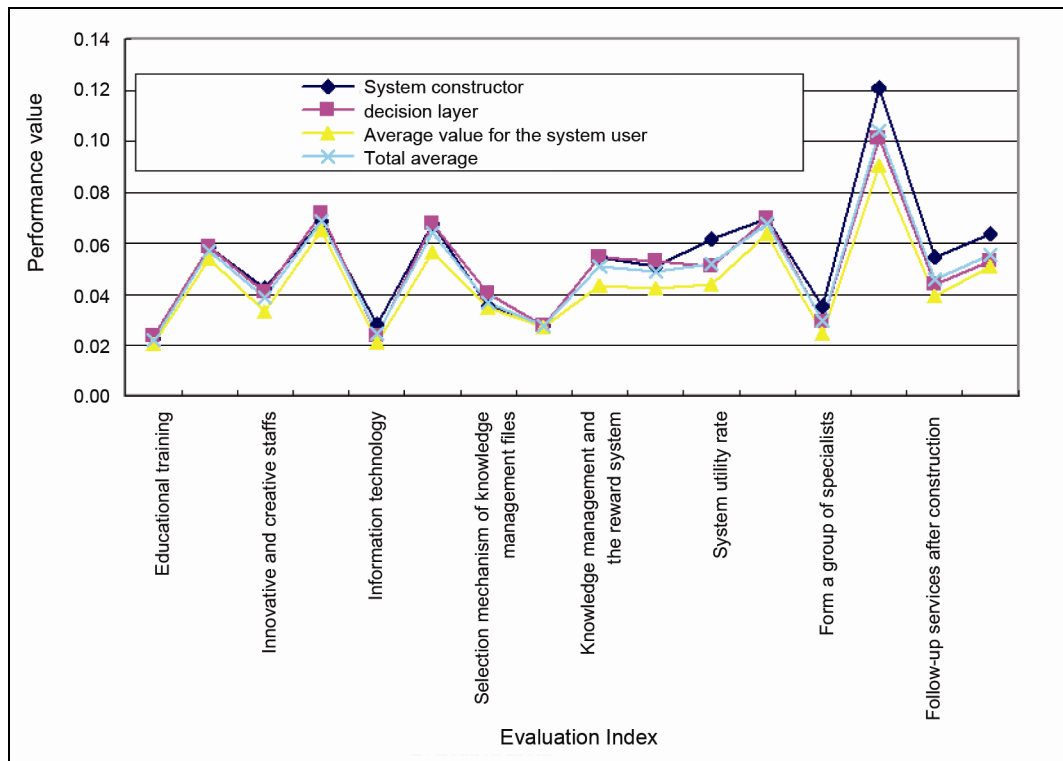


Fig. 16. Detailed evaluation result of different evaluators

2. The average performance value of the system user is lower than the others. Therefore there is big difference of understanding between the system user, system constructor and decision manager.

3. The performance value of the education training for the system user is low. This study infers that the evaluators might all be senior staff, so the education training for them was not performed by the system.

4. The performance value of the knowledge database for construction engineer is high. This is because the company's knowledge management system uses the technique document management system. The weighting

of the knowledge database for construction engineer is much higher than the others so that the evaluation result is high.

5. The difference value between the highest performance value and the overall performance average value indicates there is still improvement for each index. The bigger the difference is, the more improvement it is needed. From Table 6, the difference between the highest and the average value of the knowledge management and the reward system is 0.027, which is the biggest difference of the 16 evaluation indexes so that it is the first priority needed to be improved.

Table 6. Differences and sorting of each performance index

| Evaluation Index                                  | Highest performance value H | Total performance average value T | Difference (H-T) | Sorting |
|---|-----------------------------|-----------------------------------|------------------|---------|
| Knowledge management and the reward system        | 0.078                       | 0.051                             | 0.027            | 1       |
| Experiences sharing                               | 0.085                       | 0.064                             | 0.021            | 2       |
| Support for knowledge management from executive   | 0.086                       | 0.069                             | 0.017            | 3       |
| Knowledge database for construction engineer      | 0.121                       | 0.104                             | 0.017            | 4       |
| Conduction plan of knowledge management           | 0.073                       | 0.057                             | 0.016            | 5       |
| Working attitude                                  | 0.084                       | 0.068                             | 0.016            | 6       |
| Knowledge sharing rate                            | 0.064                       | 0.049                             | 0.015            | 7       |
| Selection mechanism of knowledge management files | 0.050                       | 0.037                             | 0.014            | 8       |
| Innovative and creative staffs                    | 0.051                       | 0.039                             | 0.012            | 9       |
| System utility rate                               | 0.062                       | 0.052                             | 0.009            | 10      |
| Follow-up services after construction             | 0.055                       | 0.046                             | 0.009            | 11      |
| Place importance to intellectual property rights  | 0.064                       | 0.056                             | 0.008            | 12      |
| Educational training                              | 0.028                       | 0.022                             | 0.006            | 13      |
| Professional construction technology              | 0.034                       | 0.028                             | 0.006            | 14      |
| Form a group of specialists                       | 0.035                       | 0.030                             | 0.005            | 15      |
| Information technology                            | 0.029                       | 0.025                             | 0.004            | 16      |

**Table 7.** Evaluation result between evaluators and model analysis

| Evaluator                          | Performance value | Evaluation result* | Model analysis result** |
|------------------------------------|-------------------|--------------------|-------------------------|
| System developer                   | 0.864             | Excellent          | Excellent               |
| Decision manager                   | 0.810             | Excellent          | Excellent               |
| System user 1                      | 0.654             | Good               | Good                    |
| System user 2*                     | 0.604             | Bad                | Normal                  |
| System user 3                      | 0.648             | Normal             | Normal                  |
| System user 4                      | 0.824             | Excellent          | Excellent               |
| System user 5                      | 0.794             | Very good          | Very good               |
| System user 6*                     | 0.788             | Excellent          | Very good               |
| System user 7                      | 0.668             | Good               | Good                    |
| System user 8*                     | 0.711             | Very good          | Good                    |
| System user 9                      | 0.769             | Very good          | Very good               |
| System user 10                     | 0.721             | Good               | Good                    |
| System user 11                     | 0.698             | Good               | Good                    |
| System user 12*                    | 0.688             | Very good          | Good                    |
| System user 13                     | 0.701             | Good               | Good                    |
| Total average of performance value | 0.796             | Good               |                         |

\* Evaluation result from the evaluator;

\*\* Analysis result was obtained by automated system.

6. The evaluation of the educational training, conduction plan of knowledge management, support for knowledge management from executive, information technology, professional construction technology, working attitude and forming a group of specialists is mostly the same.

7. The evaluation result of the knowledge management performance of the 13 evaluators is shown in Table 7. 3 evaluations were “excellent”, 3 – “very good”, 7 – “good” and 1 – “normal”. In general, the overall performance value is good.

## 7. Conclusions and suggestions

This research illustrates how to build a knowledge management system for construction companies, and shows how to develop the performance evaluation model and calculate the evaluation result. From the evaluation model's result by comparing the difference between current data and the highest performance data, also with the sequence of current index, company managers could know which part will be the priority criteria to improve the business of their construction company. By the algorithm of this study the competition capability of such construction company could be increased. Then after developing and testing, the proof of knowledge management could support construction industry, organization decision ability. Competitiveness in construction industry could be promoted through this system in order to achieve the objectives of knowledge economy.

In the future, this prototype program could be used in practice to illustrate the performance evaluation. The obtained feedback could be used to improve the knowledge sharing in management of construction.

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## References

- Bonner, D. 2000. *In action: leading knowledge management and learning*. American Society for Training & Development. 304 p.
- Bornemann, M.; Knapp, A.; Schneider, U.; Sixl, K. I. 1999. Holistic measurement of intellectual capital, in *International Symposium "Measuring reporting intellectual capital: Experiences, issues, and prospects"*. Country covered: Austria. Technical Meeting, 9–10 June, 1999, Amsterdam. 35 p.
- Buchanan, B.; Bechtal, R.; Bennett, J.; Clansey, W.; Kulikowski, C.; Mitchell, T.; Waterman, D. A. 1983. Constructing an expert system, in *Building Expert Systems*. Ed. by F. Hayes-Roth, D. A. Waterman, D. Lenat. Reading, Mass: Addison-Wesley, 13–24.
- Chang, Ch.; Lin, L.; Chang, J. 2008. Program development of a construction knowledge management system, in *Conference of ICCCBE-XII & INCITE 2008*. October 15–17, 2008, Beijing, China, 20–22.
- Construction and Planning Agency Ministry of the Interior [accessed 10 July 2009]. Available from Internet: <<http://www.cpami.gov.tw/web/index.php>>.
- Csutora, R.; Buckley, J. J. 2001. Fuzzy hierarchical analysis: the Lambda-Max method, *Fuzzy Sets and Systems* 120(2): 181–195. doi:10.1016/S0165-0114(99)00155-4
- Kaplan, R. S.; Norton, D. P. 1996. *The balanced scorecard: Translating strategy into action*. Harvard Business School Press. 322 p.
- Lin, L.; Chang, Ch.; Cheng, Ch. 2004. A study of life cycle management in construction industry, *Journal of Building and Construction Technology* 1(1): 7–12.
- Lin, L.; Chang, Ch.; Cheng, Ch.; Chen, F. 2005. The management and assessment of life cycle cost in construction in-

- dustry, in *7th International Conference in Hong Kong Institute of Value Management*, Hong Kong, China, 1–5.
- Lin, L.; Shi, J. 2004. The development and application of construction knowledge management, *Journal of the Chinese Institute of Civil and Hydraulic Engineering* 16(4): 729–737.
- Lin, Y.; Lin, L. 2007. Developing maps-based communities of practice system for exchanging experience in construction projects, in *Proceedings of ASCE International Workshop on Computing in Civil Engineering*, USA, 2007, 135–142.
- Modesitt, K. L. 1992. Basic principles and techniques in knowledge acquisition, in *Knowledge Acquisition in Civil Engineering*. New York: American Society of Civil Engineers, 11–49.
- Nonaka, I.; Teece, D. J. (Eds.). 2001. *Managing industrial knowledge*. Sage Publications. 352 p.
- Norman, D. C. 1969. *The Delphi Method: an experimental study of group opinion*. California: The Rand Corporation. 79 p.
- O'Leary, D. E. 2002. Knowledge management across the enterprise resource planning systems life cycle, *International Journal of Accounting Information Systems* 3(2): 99–110. doi:10.1016/S1467-0895(02)00038-6
- Ossadnik, W.; Lange, O. 1999. AHP-Based evaluation of AHP-software, *European Journal of Operational Research* 118(3): 578–588. doi:10.1016/S0377-2217(98)00321-X
- Park, M.; Chu, Y.; Lee, H.-S.; Kim, W. 2009. Evaluation method for construction projects, *Journal of Civil Engineering and Management* 15(4): 349–359. doi:10.3846/1392-3730.2009.15.349-359
- Republic Construction Commissions. 2009 [Accessed 10 July 2009]. Available from Internet: <<http://www.pcc.gov.tw/epaper/9708/index.html>>.
- Ruentex Group. 2009 [accessed 10 July 2009]. Available from Internet: <<http://www.ruentex.net/httpdocs/news.htm>>.
- Satty, T. L. 1980. *The analytic hierarchy process: Planning, Priority Setting, Resource Allocation (Decision Making Series)*. McGraw-Hill. 287 p.
- Sayed, B. T.; Jabeur, N.; Aref, M. 2009. An archetype to sustain knowledge management systems through intranet, *International Journal of Human and Social Sciences* 4(4): 229–233.
- Sinotech Engineering Consultants Ltd [accessed 10 July 2009]. Available from Internet: <<http://www.sinotech.com.tw>>.
- Šiškina, A.; Juodis, A.; Apanavičienė, R. 2009. Evaluation of the competitiveness of construction company overhead costs, *Journal of Civil Engineering and Management* 15(2): 215–224. doi:10.3846/1392-3730.2009.15.215-224
- Stewart, T. A. 1998. *Intellectual capital: the new wealth of organizations*. Crown Business. 320 p.
- Timothy, J. R. 2000. *Fuzzy logic with engineering applications*. John Wiley & Sons. 650 p.
- Wang, Y. K. 2005. *Industrial parks in Taiwan*. Industrial Development Bureau. 45 p.
- Zadeh, L. A. 1965. Fuzzy Sets, *Information and Control* 8(3): 338–353. doi:10.1016/S0019-9958(65)90241-X

## STATYBŲ ŽINIŲ VALDYMO SISTEMA: STRUKTŪROS KŪRIMAS IR EFEKTYVUMO ĮVERTINIMAS

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Santrauka

Statyba yra vienas iš pagrindinių būtinų pramonės sektorių, kuris yra svarbus kiekvienam gyventojui. Dėl dalyviams būdingų sąvybių ir užduočių įvairovės šiame sektoriuje labai svarbus bendradarbiavimas ir profesinės žinios. Žinių vadyba gali pagerinti statybų sektoriaus veiklą. Norint pademonstruoti taikymo poveikį ir tinkamą valdymo sistemą, reikia sukurti tinkamą efektyvumo vertinimo modelį su statybos žinių valdymo sistema. Taigi šiame tyrime kaip platformą pasitelkus *Windows 2003 Server IIS Ver. 5.0* buvo sukurta statybos žinių valdymo sistema. Šioje sistemoje integruoti ir galutiniai vartotojai, ir sisteminė funkcija. Sistemoje naudojama trijų lygių struktūra, o internetinio serverio puslapiams redaguoti naudota *FrontPage*.

Šiame tyrime taip pat kuriamas efektyvumo vertinimo modelis, kurį naudojant patikrinami statybos žinių valdymo sistemos taikymo rezultatai. Taikant šio tyrimo rezultatus, galima padidinti statybų pramonės konkurencingumą. Remiantis pagrindine šio darbo idėja, pirmiausia surenkama literatūra apie efektyvumo vertinimą. Tuomet aprašoma esama vidinio statybos žinių valdymo situacija. O tuomet, pasitelkus mokslinę analizę, įskaitant neapibrėžtų aibių Delfi metodą, neapibrėžtų aibių analitinį hierarchijos procesą (FAHP) ir neapibrėžtų aibių teoriją, sukuriama žinių vadybos efektyvumo vertinimo sistema. Šis modelis turi keturis lygius: žinių kūrimo, žinių perdavimo, žinių platinimo ir žinių kaupimo.

Sukūrus ir išbandžius šios sistemos galimybes statybos pramonėje, šią sistemą būtų galima naudoti norint pagerinti organizacijos gebėjimą priimti sprendimus ir konkurencingumą; tai atitiktų žinių ekonomikos tikslus.

**Reikšminiai žodžiai:** žinių vadyba, efektyvumo vertinimas, dalijimasis žiniomis, neapibrėžtų aibių Delfi metodas, neapibrėžtų aibių analitinės hierarchijos procesas.

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