行政院國家科學委員會專題研究計畫 成果報告

營建企業智能為基礎之專業服務平台技術研究—以工程顧問緊急問題解決為例

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行政院國家科學委員會補助專題研究計畫 **■ 成果報告**
□期中進度報告

營建企業智能為基礎之專業服務平台技術研究
—以工程顧問緊急問題解決為例

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目　錄

一、摘要

(一) 計畫中文摘要。(五百字以內)

營建業是以經驗為基礎之產業，過去所累積的知識與經驗對於未來專案之成功執行扮演重要之角色。過去十年間已經有越來越多的營建組織採用「知識管理系統(KMS)」作為其累積知識與經驗之工具，此一系統提供了營建業建立其企業智能之工具，特別是在緊急問題求解上提供了重要的解決方案。然而以前的知識管理系統式架構在「知識社群(CoP)」為基礎的問題解決系統上，此系統必須等待知識擁有者看到提問者的問題，並且撥出時間來回答。此一問題解決模式稱為「被動式問題解決模式(RPS)」，因此對於企業智能之應用效率不彰。有鑒於此，本研究提出一套「營建企業智能為基礎之專業服務平台模式 (CBI-PSP)」作為營建業應用過去所累積之企業智能來解決業務上所遭遇之問題的有效模式。CBI-PSP 與 RPS 模式主要不同之處在於它能夠主動地從過去所累積的「經驗學習檔案(LLF)」中找尋與提問者之問題最相關的解決方案給提問人,倘若提問者對於CBI-PSP所提供之解答不滿意，CBI-PSP 會再依據過去參與問題解答之紀錄判斷並找尋組織中最適合之相關專家，再將提問者所提出之問題主動地分派給相關專家，而達到更有效率的問題解決流程。經過 908 個案測試，發現本研究所提出之 CBI-PSP 系統可以比傳統 KMS 知識社群之問題解決模式提高 85.5%之時間與成本節省。因此，本研究所提出之 CBI-PSP 模式不論是在未來企業智能開發與應用上具有極大之潛在效益。

關鍵字：知識管理、問題解決、知識地圖、經驗學習、主動式系統

(二) 計畫英文摘要。(五百字以內)

Construction is an experience-based discipline, knowledge or experience accumulated from previous projects plays very important role in successful performance of new works. More and more construction organizations have adopted commercial Knowledge Management Systems (KMSs) for developing their own Knowledge Management (KM) functionalities. Most of the existing KMS's adopt Communities of Practice (CoPs) for knowledge sharing and exchange. Such approach founds on the reactive problem-solver (RPS); that is, the problem raised by the questioner in the CoP has to “wait” for the “solution knower” to respond (or reply). Previous research indicated that the RPS approach may suffer in poor time and cost effectiveness. This research proposes a Construction Business-based Professional Service Platform (CBI-PSP) approach for problems encountered in construction engineering and management. Unlike RPS, the CBI-PSP proactively solves the problem based on lessons learned from previous projects. Should the solution is not available; the CBI-PSP dispatches the problem to the most appropriate domain experts so that the problem can be tackled timely and efficiently. A case A/E firm is selected for implementation of the proposed CBI-PSP to demonstrate its applicability. It is shown that the proposed CBI-PSP improve more than 85.5% efficiency both for timeliness and cost-saving of problem-solving. The proposed CBI-PSP demonstrates great potentials for improvement of emergent problem solving and enhancement of market competitiveness.

Keywords: Knowledge management, problem-solving, knowledge map, lessons-learned, proactive system.

二、動機與目的

Problem-solving is the center of daily operations for construction organizations [1]. Since Construction Engineering is an experience-based discipline, knowledge accumulated from previous projects provides the key to solve similar problems encountered in the future projects. Current practice of knowledge management system (KMS) has established operational framework and platform for problem solving in construction engineering and management [2]. The KMS approach for problem solving poses several desirable features over other methods (such as systems engineering) including: (1) the experienced-based solutions that were implemented and verified in real world cases are more realistic and practical than theoretical solutions generated by analytic methods; (2) the collective intelligence supported by domain experts in CoP provides a broader knowledge base and diverse perspectives to generate a more effective solution; (3) the KMS records all discussions while deriving the solution in CoP, so that the “experiences” of problem solving are automatically stored for future use.

Although the KMS approach poses many desirable features for construction problem solving, there are also essential drawbacks exists in the traditional KMSs. The most critical disadvantage of KMS for solving emergent problems is its nature of “reactive mode” of KM (referred hereafter as Reactive Problem-Solver or RPS). That is, the problem raised by the questioner has to wait (passively) for replies and responses from the “solution knower” in the CoP of the KMS. Previous research has indicated that such approach can be the bottleneck to the performance of the KMS due to poor time and cost effectiveness of the RPS mode [2]. Moreover, the verification, storage and retrieval of previous solutions (also called “lessons-learned”) can cause difficulties of successfully application of traditional KMS for construction problem solving.

The present research aims at addressing the abovementioned problems encountered in the traditional KMS for construction problem solving. A proactive problem-solving system, namely Construction Business Intelligence-based Professional Service Platform (CBI-PSP), is proposed to improve the disadvantages of traditional RPS. In contrast to the traditional RPS, the proposed CBI-PSP proactively “tackles” the problem posed by questioner in a CoP and replies with the most appropriate solution based on previous lessons-learned. If the solution is not available from historic lessons, the CBI-PSP “proactively” dispatches the problem to the most appropriate domain experts in the organization who are knowledgeable of relevant implicit knowledge and solve the problem manually.

三、文獻探討

The term “Proactive Problem-Solving” is not found in literature. However, related issues and similar functions of CBI-PSP addressed in the problem statement can be found in some existing works.

3.1 Problem-Solving in Construction

Problem solving plays the central role of daily construction operations. Li and Love [1] developed a framework of problem-solving for construction engineering and management. Their research identified several characteristics of construction problems that should be tackled in order to solve them quickly, correctly, and cost-effectively, such as the ill-structure nature, inadequate vocabulary, little generalization and conceptualization, temporary multi-organization, uniqueness of problems, and hardness in reaching the optimal solution. Two areas of problem-solving researches tackle the abovementioned issues: the cognitive science and decision support system (DSS). In addition to these two areas, Yu et al. [2] propose a third approach called Knowledge Management integrated Problem-Solver (KMiPS) to solve emergent construction problems. The KMiPS adopts a KMS and a special designed CoP, namely SOS, for emergent problem solving. Yu et al. proved that the KMiPS achieved both quantitative and qualitative benefits better than traditional problem-solving approaches. Their research showed that KMS provides desirable functions to tackle the special characteristics of construction problems identified by Li and Love. However, some essential drawbacks (such as “reactive mode” of problem solving) exist in the traditional KMS, which may cause poor performance of timeliness and cost effectiveness.

3.2 Knowledge Classification and Knowledge Map

While applying KMS for construction problem solving, the storage and retrieval of previous lessons-learned are crucial. Such issues become critical as the number of historic lessons grows. As a result, the methods of knowledge classification or knowledge map are developed. Kim et al. [3] proposed a practical method for capturing and representing knowledge that is critical in knowledge management. The method employs a knowledge map as a tool to represent knowledge of the firm. Their procedure consists of six steps: (1) defining organizational knowledge; (2) analyzing process map; (3) extracting knowledge; (4) profiling knowledge; (5) linking knowledge; and (6) validating map knowledge. Effective knowledge maps help identify intellectual capital, socialize new members, enhance organizational learning, and anticipate impending threats and/or opportunities [4]. Caldas et al. [5] proposed an automatic document classification method based on text mining. Their work successfully classified 4,000 documents automatically with the Construction Document Classification System (CDCS) they developed. Although the abovementioned methods provide feasible alternatives for knowledge classification of the previously accumulated knowledge, none of them addresses the consideration of business domain and the organizational structure of the firm that may significantly affect the effectiveness of classification of knowledge for problem solving.

3.3 Automatic Answering System (AAS)

Automatic Answering System (AAS) serves as a domain expert who is able to answer the questions posed by the questioner instantly. Various types of AAS’s have been developed in construction industry. The Advanced Construction Technology System (ACTS) was developed in University of Michigan at Ann Arbor by Ioannou et al. [6]. ACTS provides a technology information system for construction planners and managers to select the most appropriate state-of-the-art construction technologies during the project planning stage. More than 400 technologies are recorded with 25 attributes such as general description, cost benefit, construction constraints, special application, operation environment, test criteria, etc. The Architecture and Engineering Performance Information Center (AEPIC) was developed by Loss at the University of Maryland [7]. The AEPIC provides information of failures so that the mistakes won’t be repeated again. The On-Line Reference Library (OLRL) was developed by Bechtel Inc. to provide engineers with real-time reference manuals of SPECs. The Civil Engineering Information

System (CEIS) of Kajima Corp. is similar to ACTS and OLRL, which stores more than 300,000 documents [8]. Even though the abovementioned systems provide some features of AAS, most of them are database systems equipped with search functions. None of them provides complete functionalities required for proactive problem solving, such as automatic problem characterizing, intelligent information retrieval, problem dispatching, and solution repository. Moreover, they are information system rather than problem-solving system.

3.4 Lessons-Learned System

Another issue related to construction problem-solving is the compilation of previous learned knowledge that is useful to solve future problems. Such knowledge is usually called "lessons-learned". There have been many existing lessons-learned systems reported in literature, which provides references for the present research. The Hypermedia Constructability System (HCS), Indiana Department of Transportation (INDOT) was developed in collaboration between INDOT and Purdue University [9]. The HCS stores historic lessons-learned in multi-media format so that construction engineers can learn from previous lessons more effectively. The Constructability Lessons Learned Database (CLLD) & Integrated Knowledge-Intensive System (IKIS) were developed by Kartam and Flood [8][10] to provide a repository for previously learned lessons. The major difference between CLLD & IKIS and the abovementioned lessons-learned systems is that the latter verifies historic lessons-learned by the domain experts before storing in the database.

A recent work by Mohamed and AbouRizk developed a knowledge representation schema for construction problem solutions (lessons-learned) [12] based on the theory of inventive problem-solving (TRIZ) [13]. Their schema consists of three major components: (1) the main functions/effects of the solution; (2) the contradiction set of the encountered problem; (3) the resolution principle that best represents the solution. Mohamed and AbouRizk also developed a computer system to implement the proposed schema. Their method provides a framework for efficient knowledge representation for construction lessons-learned. One weakness of the schema is that only principles but no details of problem resolution lessons are stored, which may cause difficulty of users to reapply the lessons-learned.

The Construction Industry Institute (CII) developed a Lessons-Learned Wizard (LLW) with the package of constructability program [11]. The LLW is a computer aided information system that helps the engineers to record and retrieve the lessons learned from historic projects. The major components of a lesson-learned file (LLF) captured by LLW consists of: (1) problem description—describing the problem encountered in construction process; (2) information of the LLF writer and approvers—providing contacting information for further consultation; (3) solution description—describing the technical and procedural details of problem resolution; (4)

evaluation of solution—assessment of the effects and benefits resulted from the lesson-learned. Compared with the other methods mentioned above, the CII's LLF is more suitable for construction problem-solving due to two reasons: first, more technical and procedural details are provided so that it is easier for users to apply the LLF; moreover, the LLFs are verified and assessed before compilation, so that solution stored in the LLF is more reliable and practical.

四、研究方法

CONSTRUCTION BUSINESS INTELLIGENCE-BASED PREOFESSIONAL SERVICE PLATFORM (CBI-PSP)

4.1 Description of Required Functions

According to the problem statement and literature reviews, several functionalities are identified for the proposed CBI-PSP, including: (1) a knowledge classifications scheme (namely Knowledge Map or KMap) that appropriately represents the lessons-learned of the organization and accurately defines problem encountered; (2) a descriptive scheme for the expertise of the domain experts (namely Expert Map or EMap), which properly reflects knowledge (expertise) of the domain experts accumulated previously; (3) a set of algorithms for retrieval of the most relevant lessons-learned in repository; (4) a problem dispatching mechanism for diverting the posed problem to the most appropriate domain experts; and (5) a repository of lesson-learned files (LLFs) from previous projects and the required functions of lesson learning.

Four modules are proposed to fulfill the functionalities identified above: (1) the Knowledge/Expert Map (K/EMap)—providing classification scheme for knowledge and expertise of the domain experts; (2) Automatic Problem Answering (APA) module—solving the posed questions automatically based on the historic LLFs; (3) Automatic Problem Dispatching (APD) module—dispatching the posed problem to the most appropriate domain expert when the problem is unsolved by APA; (4) Lesson-Learned Wizard (LLW)—accumulating historic LLFs based on the classification scheme of K/EMap.

4.2 Knowledge/Expert Map (K/EMap)

The proposed CBI-PSP is kernelled with the knowledge and the expert holding the knowledge. In CBI-PSP, the domain knowledge is classified by Knowledge Map (KMap); while the domain experts are characterized by Expert Map (EMap). The KMap and EMap provide the ontology for modeling the knowledge and human assets of the construction firm.

A Multi-dimensional Knowledge Ontology (MKO) scheme is adopted for construction of the KMap. The multiple dimensions of MKO are represented with numeric codes. Figure 1 shows the representation of MKO. The MKO consists of three dimensions: “Lifecycle code”, “Product code”, and “Technical code”.

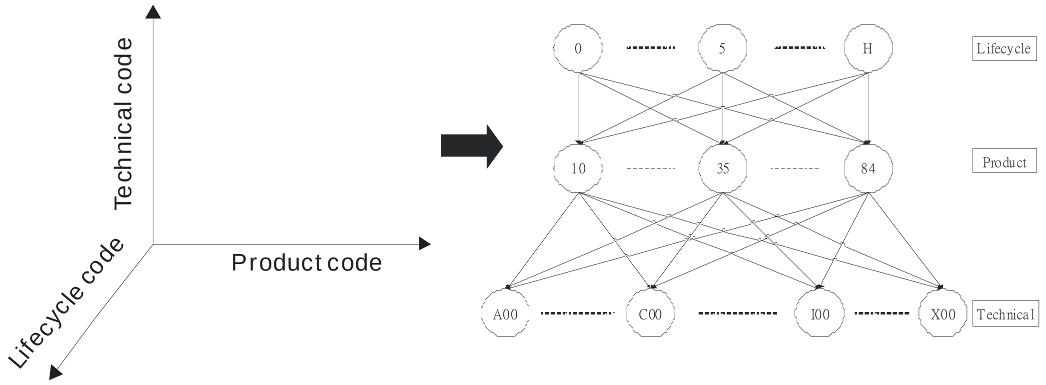


Figure 1 Representation of Multi-dimensional Knowledge Ontology (MKO)

The MKO scheme represents a knowledge documents (e.g., LLF) with a vector of codes including: (1) Lifecycle code—describing the time reference of the knowledge, such as all life cycle, feasibility analysis, comprehensive planning, basic design, detail design, construction/installation, testing, operation/maintenance, recycle, change, etc.; (2) Product code—describing the service/product related to the knowledge, such as bidding proposal, execution plan, QA plan, procurement plan, SPEC, alternative report, inspection report, calculation report, drawing, etc.; (3) Technical code—the technical classification of the knowledge, such as administration, human resource, civil (excavation, refill, site preparation, piping, etc.), structural (RC, PC, SS, underground construction, retaining structure, etc.), architecture (urban planning, building design, interior design, landscape, model, finishing, etc.), geotechnic (site investigation, pile, foundation, drainage, rock, stability, etc.), survey, highway, transportation, logistics, airport, hydraulics, harbor, material testing, etc; An example vector (13, 20, 35) can be interpreted as “the ***design criteria*** (product) for ***segmental precast bridge construction*** (technical) in ***basic design*** phase (lifecycle)”.

The MKO model is adopted in light of: (1) effective and efficient classification of LLFs—MKO does not only provide a coding system for classification of knowledge documents, it also offers a hierarchical framework for association of relevant knowledge; (2) correct and accurate characterization of the problem—with KMO, the temporal dimension, product type, and detailed technical field of the problem and the associated solution (LLF) are accurately characterized, it makes future retrieval of historical lesson-learned more easily; (3) provides a basis for construction of the EMap—the domain expert is represented by the knowledge he/she holds. Therefore, MKO also provides a key attribute for characterization of the domain experts in the

EMap.

Similar to KMap, the Knowledge Capacity Matrix (KCM) is adopted for representing the expertise of the domain experts. The KCM describes the knowledge capacity of a domain expert with a row vector containing three dimensions: (1) Seniority—recording the professional seniority (in years) of the expert, which reflects how experienced the domain expert is in a specific technical area; (2) Intensity—recording the intensity of work (work hours/ seniority years) of a specific technical domain, which reflects the strength of expertise of the expert in a specific domain; (3) Enthusiasm—recording the historic performance of the expert in participation of KM activities automatically provided by the KMS, which reflects what technical domain the expert is especially interested in. The second (Intensity) and the third (Enthusiasm) dimensions are characterized with the MKO described above, so that the specific technical domain of knowledge that the domain expert associated with is identified. The KCM adopts a nested row-vector representation scheme. An example of KCM is shown in Figure 2. In Figure 2, the Seniority dimension consists of the experience records (in years) of three fields: Design, (Construction) Supervision, and Project Management. The other two (Intensity and Enthusiasm) dimensions are represented with the values of expertise intensity and knowledge value adding (KVA) [14] scores characterized with MKO.

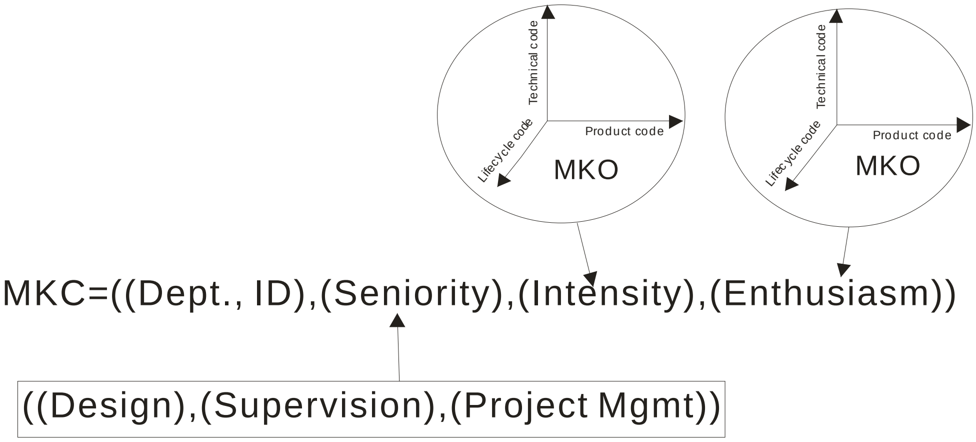


Figure 2 Representation of Knowledge Capacity Matrix (KCM)

With schemes of KMO and KCM, a domain expert is characterized according to his/her experiences, not only by a specific technical field but also by how experiences and intensively he/she was involved and how enthusiastic he/she is in that area.

4.3 Automatic Problem Answering (APA) Module

The Automatic Problem Answering module (APA) is an automatic answering system (AAS) that searches the solution database to retrieve the most appropriate answer for the questioner. Several requirements are expected for an ideal AAS [15]: (1) tolerance of simple errors; (2) embodiment of some degree of "common sense"; (3) a relatively large and complete vocabulary for the subject matter to be treated; (4) acceptance of wide range grammatical constructions; (5) capability of dealing sensibly with partly understood input; and (6) providing the information and computations requested by the user. Previous research has developed AAS for internet service [16] and tutoring assistant [17]. The APA module is planned as shown in Figure 3 based on the AAS of Wu et al.[17]. The conceptual design of APA module is shown in Figure 3.

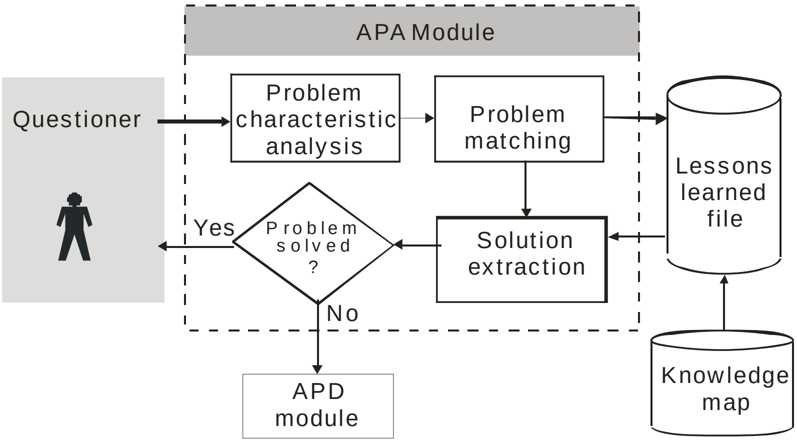


Figure 3 Conceptual design of APA module

In Figure 3, a question is posed by the questioner. The characteristics of the posed problem are analyzed by APA. Then, APA searches the repository of historic lesson-learned files (LLFs) to find the most relevant LLFs. Finally, the solution is extracted from the relevant LLFs. The underlying algorithm for APA is described below:

1. Transforming problem description into a characteristic vector (CV)

In this step, the problem description of the LLF is transformed into a CV using the Vector Space Model (VSM) [18][19]. At first, the problem description is segmented into semantic fragments (terms) according to the domain keywords. In the present research, the Chinese Knowledge Information Processing (CKIP) provided by the Institute of Information of the Academia Sinica, Taiwan is adopted for the segmentation of the document [20]. Second, the importance weightings of the CV associated with the keywords (terms) are calculated using the Importance Factor (IMF) method proposed by Wu et al. [17] as described in the following equation:

$$IMF_{ij} = \frac{L_j}{L_{i,\max}}(0.5+0.5\frac{TF_{ij}}{TF_{i,\max}})IDF_j,\ IDF_j = \log\left(N \Big/ \sum_{i=1}^{N} C_{ij} \right), \qquad (1)$$

where IMF_{ij} is the weighting of the j^{th} term in the i^{th} question (Q_i) of the LLF repository; L_j is the length of the j^{th} term; $L_{i,max}$ is the maximum length of terms in Q_i; TF_{ij} is the number of occurrences for the j^{th} term in Q_i; $TF_{i,max}$ is the maximum number of occurrences for the terms in Q_i; N is the number of LLFs in the repository; and $C_{ij} = 1$ if Q_i contains term j, $C_{ij} = 0$, otherwise.

The CV of question Q_i can be represented with the following equation:

$$CV(Q_i) = \{(k_1, w_{i1}), (k_2, w_{i2}), \ldots, (k_j, w_{ij}), \ldots, (k_n, w_{in})\}, \qquad (2)$$

where $CV(Q_i)$ is the characteristic vector of the i^{th} question; K_j represents j^{th} keyword; and W_{ij} is the weighting value of K_j in question Q_i.

2. A new question posed by the questioner is transformed into CV using the similar method of Step 1.
3. The CV of the posed question is compared with all historic CV's stored in the LLF repository using the inner product similarity measure described in the following equation:

$$S_i = \sum_{j=1}^{n} \left(W_j \times W_{ij} \right), \qquad (3)$$

where S_i is the similarity between question Q and the problem description of the i^{th} LLF; W_j is the weighting of the j^{th} element of the $CV(Q)$; W_{ij} is the weighting of the j^{th} element of the problem description of the i^{th} LLF, *i.e.*, $CV(Q_i)$.

4. The LLFs with higher similarity are considered more relevant to the question Q posed by the questioner, thus they are recommended as the solutions to the posed quation.

If the solution is found (according to a predetermined similarity threshold), it is replied to the questioner. However, if the solution is not found, the problem is unsolved and diverted to APD module.

4.4 Automatic Problem Dispatching (APD) Module

Figure 4 shows the conceptual design of the APD module. In figure 4, the unsolved problem is posed to the CoP of the KMS as an emergent problem and diverted simultaneously to APD module at the same time. In APD module, the problem characteristics is analyzed and used to find the most appropriate domain experts based on the Expert Map (EMap) described previously. Then, the problem is dispatched to the most related domain experts for possible solution. Finally, the experts respond to the problem in a special COP called SOS of the KMS.

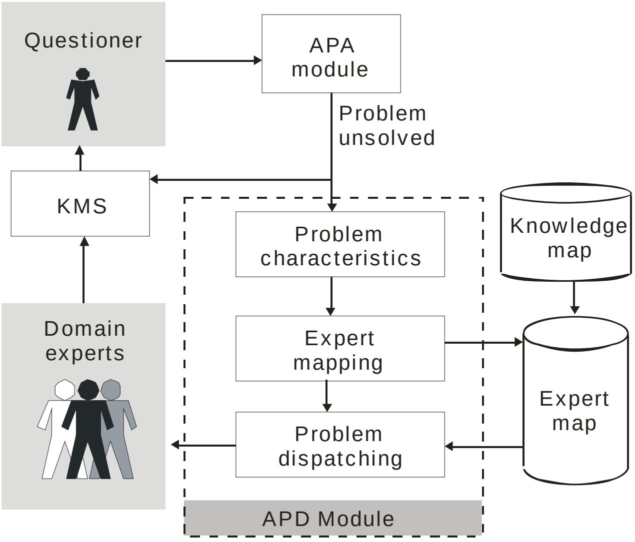


Figure 4 Conceptual planning of APD module

The algorithm for problem dispatching is also based similarity measurement. All domain experts (basically all staffs of the firm are included) are characterized with the KCM scheme described previously. Since two of the three dimensions of the KCM model are associated with MKO, they can be transformed in to characteristic vectors (CVs), too. Applying the similarity measurement method of APA, the most relevant domain experts in EMap can be identified. A matching score is calculated for each identified domain expert with respect to the posed question using the following equation:

$$Score_i = W_1 \times Score_{Si} + W_2 \times Score_{Ii} + W_3 \times Score_{Ei}, \tag{4}$$

where $Score_i$ is the overall matching score of the i^{th} domain expert with respect to the posed question; $Score_{Si}$ is the *Seniority* score of the i^{th} domain expert; $Score_{Ii}$ is the *Intensity* score of the i^{th} domain expert; $Score_{Ei}$ is the *Enthusiasm* score of the i^{th} domain expert; W_1, W_2 and W_3 are arbitrarily determined weightings for the three dimensions.

In Equation (4), the weightings of the three dimensions are arbitrarily determined by the questioner based on his/her understanding of the characteristics or nature the question. For example, solving some question relies more on experience, then the weighting of *Seniority* is emphasized, and so forth.

The *Seniority* score in Equation (4) is further calculated with the following equation:

$$Score_{Si} = W_{11} \times Design\_Experience + W_{12} \times Supervision\_Experience + W_{13} \times PM\_Experience, \tag{5}$$

where W_{11}, W_{12} and W_{13} are arbitrarily determined weightings for Design, Supervision and PM experiences, respectively; *Design_Experience* is the seniority of the design experience for the domain expert measured in years; *Supervision_Experience* is the seniority of the construction site supervision experience for the domain expert (in years); *PM_Experience* is the seniority of the project management experience for the domain expert (in years).

Similar to Equation (4), the questioner can determine the weightings (W_{11}, W_{12} and W_{13}) arbitrarily according to his/her understanding of the characteristics or nature the question.

4.5 Lessons-Learned Wizard (LLW)

The LLF repository required in APA module is constructed by a Lessons-Learned Wizard (LLW) proposed by the Construction Industry Institute (CII) [11].The LLW captures lessons-learned right after a problem is solved in the KMS. The LLW is integrated with an internet questionnaire surveying system that allows the questioner to evaluate the solution he/she obtains. The LLF associated with the problem contains the following information: (1) the subject of the problem—titling the problem; (2) the description of the problem—detailed descriptions of the posed question; (3) the questioner—the name and department of questioner; (4) the solution—detailed descriptions of the suggested solution; (5) the responder—the name and department of the responder who provided the suggested solution; (6) attachments—the supplementary materials for the solution; (7) benefits evaluation—assessments of all benefits resulted by the solution including time, cost, quality, technical improvement, regulation impacts, etc. The LLFs stored in the LLF repository are classified with the MKO scheme of KMap.

4.6 Integrated Model of Proactive Problem Solving (MPPS)

The integrated framework of MPPS is depicted in Figure 5. In the integrated framework, MPPS solves construction problems in two modes: (1) Automatic problem answering mode (APA mode)—the problem-solving process is shown in Figure 5 as bold solid arrows, where the solution is searched automatically from LLF repository according to the problem characteristics; (2) Automatic problem dispatching (APD) mode—the problem-solving process is shown in Figure 5 as dashed arrows, where the unsolved problems (by APA mode) is automatically dispatched to the most relevant domain experts according to the problem characteristics and the Knowledge Capacity Matrix (KCM). The functions of problem solving in the traditional KMS is preserved and exercised in MPPS as shown in Figure 5 where the unsolved problem is posted in the CoPs of the KMS before entering the APD mode.

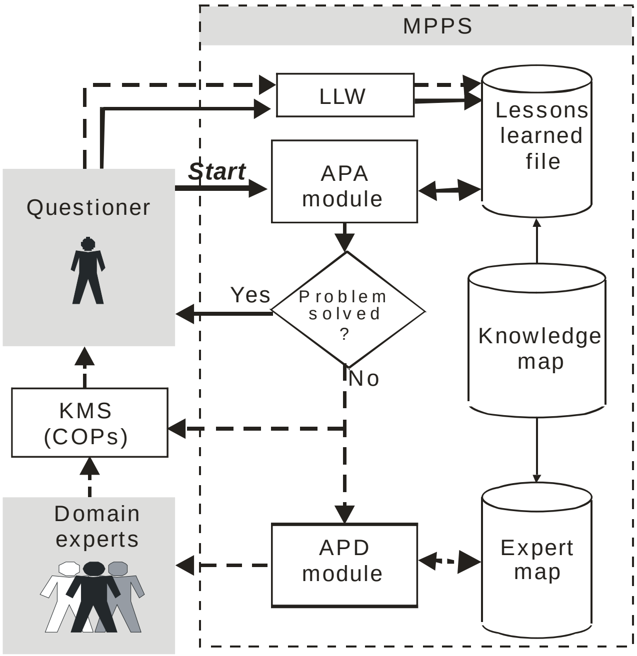


Figure 5 Integrated framework of MPPS

Bothe the problems solved in APA and APD modes are considered new lessons learned for future problems. This process is actually a verification of the knowledge to generate a higher level of intellectual asset called “wisdom” [14]. This process is performed by LLW as shown in Figure 5.

五、結果與討論

5.1 System Implementation

The proposed MPPS has been implemented in the KMS of a leading A/E consulting firm in Taiwan, CECI. The KMS of CECI is developed based a commercial platform—Microsoft SharePoint®. However, the original software has been customized to fit in the specific requirements of the firm. One of the major customizations is the specialized emergent problem-solving system, called SOS, to provide real-time aids for engineers/managers who are encountered with emergent problems. The SOS system has been proved to be very beneficial to the firm. Both tangible and intangible benefits were resulted significantly [21].

5.1.1 Problems faced the existing system

The SOS system is actually a specialized CoP that includes all staffs of the firm as its members. Once a Question is posed by a questioner in SOS, it will prompts automatically on the portal page of the KMS of every member. As described in Introduction, the essential problem of existing CoP in solving emergent problems is that the posed problem needs to wait (passively) for replies and responses from the “solution knower” to provide his/her solutions. Such “passive” mode of problem solving assumes that the domain experts can “see” the problem and respond with their solution timely. However, previous research found that such RPS approach has caused inefficiency of timeliness and cost-effectiveness of the KMS [2]. A proactive problem-solving approach should be developed.

5.1.2 System implementation

The proposed MPPS has been implemented with the SOS system of CECI. A System named CBI-PSP is developed and tested. The prototype CBI-PSP consists of all four required elements of MPPS: (1) K/EMap—a knowledge map (KMap) is constructed based on the MKO scheme and an Expert Map (EMap) is constructed based on KCM scheme; (2) APA module—the APA module is developed to perform the APA problem-solving mode (APA mode); (3) APD module—the APD module is developed to perform the APD problem-solving mode (APD mode); (4) LLW—the LLF repository is established consisting of 908 historic problem-solving LLFs of SOS system accumulated in the last three years.

5.2 System Testing and Performance Evaluation

In order to verify the proposed CBI-PSP, system evaluation experiments are designed and conducted. The experiments consist of two parts: (1) effectiveness test—testing the validity of MPPS and correctness of CBI-PSP in finding the solutions for the posed questions; (2) efficiency test—testing the timeliness and cost-saving performance of CBI-PSP compared with the traditional approaches.

5.2.1 Data collection and experiment design

The testing data were collected from real world emergent problem-solving cases of the case A/E firm, CECI, from 2005/01 to 2009/08. Totally 908 historical cases and the associated LLFs are collected. The major problem categories and their associated percentages of the 908 cases are: Architectural (14.76%), Civil (13.51%), Structural (13.51%), Geotechnic (10.04%), Electrical (7.16%), Railway (5.76%), Environmental (4.80%), Mechanical (4.72%), Highway (4.43%), Materials (3.47%), Hydraulic (2.58%), and Others (15.26%).

Assume that every problem-solving case has one “correct” (most relevant) solution, which is stored in the LLF repository. The experiments are designed to test CBI-PSP with two sets of data: (1) Original Set—testing the capability of CBI-PSP to retrieve the correct solution for a specific question with the original question description as the LLF; and (2) Similar Set—testing the capability of CBI-PSP to retrieve the correct solution for a specific question with the modified Similar (but literally different) question description from the original one of the LLF. If the

CBI-PSP is able to retrieve the correct solution both sets of testing data, the CBI-PSP system is verified and the proposed CBI-PSP is validated. In order to generate the testing data for the Similar Set, sixty-three mangers/senior engineers of the case A/E firm are asked to play the role of the domain experts. The problem descriptions of the 908 historic LLFs are then presented to the 63 domain experts who are requested to provide 1~3 similar but literally different question descriptions for testing of CBI-PSP. After collection, 1,368 question descriptions are generated for Similar Set based on the 908 original questions. Both sets of questions are used to test the effectiveness and efficiency of CBI-PSP.

5.2.2 Testing of effectiveness

There are two types of testing for the effectiveness of information retrieval systems: (1) *Precision*—measurement of the effectiveness of a retrieval system to retrieve only the relevant answers; and (2) *Recall*—measurement of the effectiveness of a retrieval system to retrieve all the relevant answers. Since the *Recall* is more important than *Precision* in the information retrieval system such as emergent problem solver [22], only *Recall* is adopted for effectiveness testing of CBI-PSP. The index of *Recall* is defined in the following equation [22]:

$$Recall = \frac{Number\ of\ relevant\ answers\ retrieved}{Total\ number\ of\ relevant\ answers}, \tag{6}$$

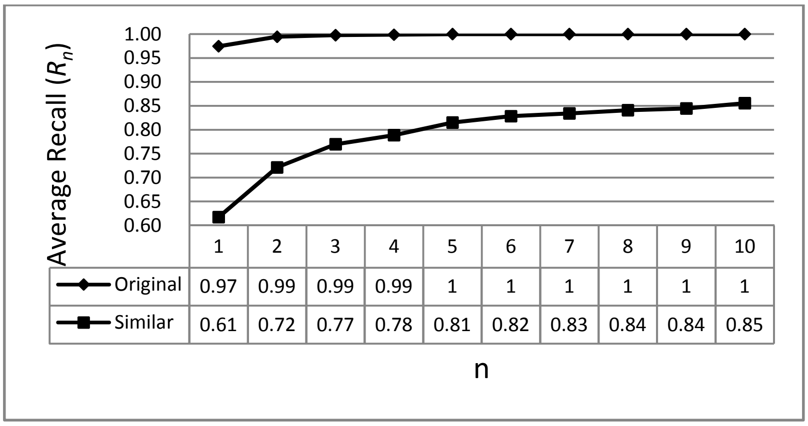
where the numerator is the total number of relevant LLFs retrieved by CBI-PSP, and the denominator is the total number of all relevant LLFs stored in the LLF repository.

In the present research, it is assumed that there is only one relevant LLF for each question. Let R_n be the probability that APA is able to retrieve the relevant solution for the posed question with n retrieved (recommended) LLFs, i.e. the *Recall*, the R_n is defined as follows:

$$R_n = \sum_{i=1}^{N} \frac{R_{ni}}{N}, \begin{cases} R_{ni} = 0, \text{if the retrieved LLFs does not include the correct answer.} \\ R_{ni} = 1, \text{if the retrieved LLFs includes the correct answer.} \end{cases}, \tag{7}$$

where N is the total number of testing questions; n is the number of retrieved LLFs; R_{ni} is a true/false testing value (“1” for true, “0” for false) of whether the retrieved LLFs include the correct answer.

Both of the Original Set and the Similar Set are used for testing. The parameter n is a varied from 1 (retrieve only the LLF with highest similarity) to 10 (retrieve top ten LLFs with higher similarity). The testing results are shown in Figure 6.



	1	2	3	4	5	6	7	8	9	10
Original	0.97	0.99	0.99	0.99	1	1	1	1	1	1
Similar	0.61	0.72	0.77	0.78	0.81	0.82	0.83	0.84	0.84	0.85

Figure 6 Comparison of Recall (Original vs. Similar Set)

It is found from Figure 6 that the *Recall* of Original Set is very close to 1 (100% correct), while the *Recall* of Similar Set is over 85% after as n =10.

5.2.3 Testing of efficiency

The two indexes of efficiency for CBI-PSP are the timeliness and cost-saving of the system. According to previous research by the authors, the average cost for solving (finding preliminary solution) a single problem by the traditional KMS is TWD 4,075 (USD 123.5) [21]. With aid of CBI-PSP, the cost for retrieving the relevant LLF, if it exists in the LLF repository, is almost zero. Thus, the cost-saving efficiency of CBI-PSP over the traditional approach is verified.

In regard to the timeliness of CBI-PSP, three components of time required for problem-solving with CBI-PSP are identified:

(1) Processing time of CBI-PSP (S)

Assume that S is the system time required to search the relevant LLFs with CBI-PSP. It is considered constant for all questions. By monitoring the execution time of CBI-PSP, the average duration of S is about 3.2 seconds.

(2) The processing time of questioner

The time required for the questioner to find out the really relevant LLF from all LLFs retrieved by CBI-PSP. Assume F seconds are required to process one LLF, then m LLFs require F×m seconds. In the present research, F is assumed to be 10 seconds.

(3) The time required to generate solution manually (p)

As the APA is unable to retrieve the relevant solution (it may be due to that there is no relevant LLF or CBI-PSP is unable to identify the relevant LLF), the solution need to be generated manually by the domain experts. Assume that it takes time p to generate solution manually. According to the previous research of the authors [21], the average time required to generate the solution for a posed question is 2.68 days. This time is required only when there is no relevant LLF found by CBI-PSP. Thus, the time required to generate solution manually can be calculated by $(1-R_n)\times p$.

Based on the above analysis, the time required to generate a solution with CBI-PSP can be calculated with the following equation:

$$T = S + F \times m + (1 - R_n) \times p, \qquad (8)$$

where T is the measure of timeliness of problem-solving; S, F, m, and R_n are defined previously.

Based on Equation (8), the timeliness of CBI-PSP for the two sets of testing data are compared and shown in Figure 7. It is found that the average time required to solve the Original Set is 0.88 minute as $n = 5$. It increases a little bit as n increase due to the time required to identify the relevant LLF. The average time required to solve Similar Set is much higher. This is due to the time required for manual problem-solving (p). However, the problem-solving time of CBI-PSP is about 600 minutes (10 hours) as $n > 9$. It is much lower than the traditional KMS (which required 2.68 days = 3859.2 minutes). Thus, the timeliness efficiency of CBI-PSP is also verified.

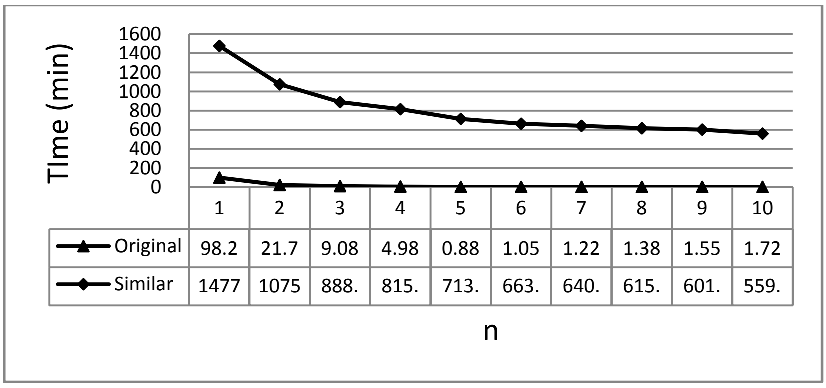


Figure 7 Comparison of timeliness (Original vs. Similar set)

5.3 Discussions

The proposed CBI-PSP provides construction engineers and managers a different approach of problem-solving. This section addresses the strengths, limitations, and potential extensions of the proposed CBI-PSP.

5.3.1 Strengths of CBI-PSP over traditional problem-solving approaches

The primary strength of the proposed CBI-PSP over traditional KMS is its proactive mode of problem-solving. Instead of “waiting for” solution, the proposed CBI-PSP take initiative to retrieve relevant solutions from historic LLFs and the domain experts who are most capable of resolving the posed question. Based on the results of case study, the benefit of time-saving is

99.99% for Original Set and 85.5% for Similar Set. Moreover, the problem-solving is almost costless if the relevant historic LLFs exist. Nevertheless, the improvement of timeliness in problem-solving by CBI-PSP should enhance the competitiveness of the firm in the market since it equip the firm with a powerful tool to react with all kinds of emergent issues happen in the firm’s daily business operations. Any of the issues can become a trouble source of increased costs or time delays if it is not tackled properly.

An advantage of the proposed CBI-PSP over the traditional KMS is that it facilitates the intellectualization of the firm’s implicit and explicit knowledge assets. Refer to Figure 5, the historic lessons-learned for solving construction problems need to be compiled into LLFs; KMap and EMap are then constructed to visualize the firm’s intellectual assets. The top management can plan the firm’s knowledge management more effectively based on the profile of the firm’s intellectual assets. Moreover, the proposed CBI-PSP provides a mechanism to incorporate the implicit knowledge of all staffs of the firm to generate solutions for the posed questions. Such mechanism offers a perfect environment for the Nonaka’s knowledge creation spiral so that Medici’s Effect [25] can take place. As a result, the knowledge creation of the firm is expedited and more fruitful.

5.3.2 Potential extensions and applications of CBI-PSP

The proposed CBI-PSP has demonstrated its potentials in emergent problem solving for construction. Some future extensions may be pursued. An application of CBI-PSP is to help engineers in preparation of the proposals. A critical component (may be the most important one) of the proposal is “Critical issues analysis”. The CBI-PSP can provide solutions to those issues addressed in the request for proposal (RFP).

A second extension of the current research is to integrate CBI-PSP with the ubiquitous technology to enhance the real time problem solving. For example, the wireless communication technology provides possibility of accessing CBI-PSP anytime anywhere. Such technology is very desirable especially for emergent problem solving on construction site. The integration of the two technologies will enable the site engineers/managers to fully utilize the advantages CBI-PSP.

The methodology developed in the current research can also be applied to problem-solving of the other domains. For example, the legal affairs and management consulting are two promising areas for application of the proposed CBI-PSP. Extensions to other fields such as disaster rescue and prevention are also possible, as long as the nature of problem solving remains the same.

5.3.3 Limitations and suggestions

One major limitation of the proposed CBI-PSP is the requirement of the historic LLFs.

Compilation of previous experience of problem solving is expensive. The LLW provided by CII may be employed to establish the LLF repository [11][27]. In the case study, the LLFs are compiled manually by the questioner who obtained solution from the domain experts. It is recommended to build the functionality of automatic LLF compilation with the established KMS [27]. Moreover, the project final reports, plans, proposals, and other knowledge documents contain tremendous engineering experiences that are valuable for solving future problems. Automatic system should be developed to compile the explicit knowledge stored in those documents into the LLFs.

A second limitation while implementing CBI-PSP in the case study was that the LLFs were not classified correctly. The current timesheet classification system is primarily for bookkeeping of payroll, rather than for knowledge management or problem-solving. Misclassifications are found frequently in the case study. Such misclassifications can lead to malfunction of APA module. A more accurate timesheet and document classification system should be established in order to improve the performance of APA.

Another major limitation of CBI-PSP found from the case study was the keyword database. The present research adopted the Chinese Knowledge Information Processing (CKIP) provided by the Institute of Information of the Academia Sinica [20]. The CKIP database provides only commonly used Chinese keywords rather than the construction-specific keyword database. It is recommended to the A/E firms who implement CBI-PSP to establish their own special purpose keyword database.

The system testing of the present research also faces difficulty since the domain experts were extremely busy. It is almost impossible to ask them to perform testing experiments for CBI-PSP. It was found that some domain experts provided invalid questions for Similar Set while conducting the testing experiment of the research. Those data may mislead the testing results. Some standard testing data for the domain problem of construction should be established for verification of the proposed system.

六、結論與建議

This report presents the development of a new problem-solving method, CBI-PSP, for construction. The proposed CBI-PSP differentiates itself from the traditional reactive problem-solver approaches by providing a proactive mode of problem solving. Such proactive problem solving is realized with the integration of following components: a Multi-dimensional Knowledge Ontology (MKO) representation of the historic Knowledge Map (KMap), a Knowledge Capacity Matrix (KCM) model for characterization of the domain Expert Map

(EMap), an Automatic Problem Answering (APA) module for retrieval of historical Lesson-Learned Files (LLFs), Automatic Problem Dispatching (APD) module for diverting unsolved problems to the most appropriate domain experts of the firm, and a repository for storing the historical Lesson-Learned Files. From the case study results of a local leading A/E consulting firm of Taiwan, it is found that both timeliness and cost-saving performances are significant. The *Recall* ratio of correct answers is 85% for Similar Set (similar but differently literal questions) as the number of retrieved LLFs is 10. The timeliness efficiency of problem solving is improved for 85.5% for Similar Set. With the proposed CBI-PSP, the problems encountered by construction engineers and managers in their daily operations and works can be solved more efficiently and effectively. It is concluded that the proposed CBI-PSP has great potential for improvement of construction problem solving.

Although CBI-PSP shows promising potentials, the case study also found some limitations of the present version of CBI-PSP including: (1) the keyword database is not construction-specific, which causes the incorrect retrievals of historic LLFs; (2) the scope of historic LLFs is limited to a special CoP (SOS) of the case A/E firm, it should be expanded to include other CoPs; (3) only the historic LLFs is employed for problem solving, other explicit knowledge documents (e.g., project final reports, plans, proposals, etc) should be included to build the historic LLFs; (4) misclassifications of knowledge documents and timesheets are commonly found, a more accurate technical classification system should be implemented.

Future extensions of the proposed CBI-PSP are also identified such as integrating with the ubiquitous technology to enhance the real time problem-solving, application of CBI-PSP to proposal preparation, application of similar methodology to problem-solving in other fields (e.g., legal affairs, disaster rescue, etc.) Ambitious researchers are encouraged to pursue in those directions.

七、誌謝

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十、可供推廣之研發成果資料表

□ 可申請專利　■ 可技術移轉　日期：98年09月28日

國科會補助計畫	計畫名稱：營建企業智能為基礎之專業服務平台技術研究—以工程顧問緊急問題解決為例 計畫主持人：余文德 計畫編號：NSC 97-2221-E-216 -039 學門領域：土木(營建)
技術/創作名稱	營建企業智能為基礎之專業服務平台模式暨系統
發明人/創作人	余文德、曾秋蓉、劉沇榮
技術說明	中文： 本「營建企業智能為基礎之專業服務平台模式暨系統」結合知識分析、專家人力分析、資訊再取、問題分派以及經驗學習等功能，成為一具有主動問題能力之企業智能系統。本系統對於營建產業(含工程顧問業)業務執行過程所遇到之問題的解決效率甚具提升效益，對於產業競爭力之提升亦具成效。
	英文： The proposed Construction Business Intelligence-based Professional Service Platform Model and System combines knowledge analysis, expertise analysis, problem answering, problem dispatching module, and a lessons learning. Such a system has been proved to be very beneficial for construction firms (including engineering consultants) in improving their problem-solving capability and efficiency, and thus enhancing their competitiveness.
可利用之產業及可開發之產品	本產品可以結合現有之知識管理系統(KMS)或獨立開發成為一網路服務系統(Web Service System)，可以輔助營建產業之業務執行(含緊急問題解決、備標、估價、監造…等)功能，亦可獨立開發成為單一專業服務功能(例如估算、求償、工程法律諮詢等)之系統。
技術特點	具有知識分析、專家人力分析、資訊再取、問題分派以及經驗學習等五大功能模組，可分析組織之智慧資產、人力資產，具有累積與再利用過去經驗與知識之功能，並能連結具有相關知識之專家的能力。

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※　1. 每項研發成果請填寫一式二份，一份隨成果報告送繳本會，一份送　貴單位研發成果推廣單位（如技術移轉中心）。

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

98 年　7 月　23 日

報告人姓名	吳誌銘 (本計畫研究助理代替計畫主持人進行論文報告)	服務機構及職稱	中華大學科技管理研究所博士生
時間 會議 地點	2009/7/10~2009/7/13 美國佛羅里達州，奧蘭多市	本會核定補助文號	NSC-97-2221-E-216-039
會議名稱	（中文）第二屆國際多領域工程與技術創新研討會 （英文）The 2nd International Multi-Conference on. Engineering and Technological Innovation(IMETI)		
發表論文題目	（中文）系統化技術創新流程（STIP）於道路人孔之創新 （英文）INNOVATING ROAD MANHOLE TECHNOLOGY WITH SYSTEMATIC TECHNOLOGY INNOVATION PROCESS (STIP)		

報告內容應包括下列各項：

一、參加會議經過

第二屆國際多領域工程與技術創新研討會舉辦時間為七月十日至七月十三日於美國佛羅里達州奧蘭多市 Rosen Centre Hotel 飯店舉辦，七月十日主要為註冊與報到日，該研討會為七月十一日正式舉行，該日上午為各主題之專家學者特邀演講，學生所發表之研究論文為七月十一日下午，該場次主題為 Disciplinary Research and Development I（學科研究與發展），本次學生與美國肯塔基大學(University of Kentucky)Zhi Chen 教授一同受邀擔任該場次的主持人（co-chair），負責主持該場次五篇論文發表。發表與主持完該場次後，學生後續亦參加研討會其餘天數之研討會活動。

二、與會心得

該研討會至今年雖僅舉辦第二屆，但研討會舉辦過程整體反映出來世界各地各領域專家學者皆對於「創新」的需求與發展趨勢（多達四十餘國專家學者參與，共計約兩百餘篇文章發表），另一方面，學生首次受邀擔任國際研討會的場次主持人（Co-chair），其寶貴經驗一使學生國際視野成長許多，擔任主持工作與聆聽各場次之報告，了解到大家雖然是不同工程或是管理領域，但對於創新的需求可說是無國界的共同語言，各研究論文皆爭相積極發展各領域之技術、管理、教育等創新，因此在該研討會中可看見各領域對於該技術的創新與發展，亦讓學生發現到許多其他領域之技術之原理以及應用上亦可應用於不同的其他領域中（包括學生研究的營建工程領域），讓學生了解到未來不管是技術發展或是技術創新，多方面與跨領域的合作與發展才有可能有機會突破既有的技術瓶頸。

三、考察參觀活動(無是項活動者省略)

無

四、建議

由於該研討會可說是草創期間（第二屆），該研討會具有不同工程與不同領域等之創新理念亦與學校發展創新校園不謀而合，因此建議學校可於研討會早期將每年研討會相關訊息發佈給有興趣參與之老師以及學生並持續參與。可增加中華大學發展創新至國際舞台之能見度與知名度的管道。

五、攜回資料名稱及內容

IMETI 2009 論文集書面資料
IMETI 2009 論文集光碟資料

六、其他

		
研討會報到情形	論文發表與主持前準備情形	與另一位主持人合照

Innovating road manhole technology with Systematic Technology Innovation Process (STIP)

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ABSTRACT

The technology innovation is recognized as a main driver for the advancement of construction industry. Due to the lack of systematic innovation method, the advancement of construction technologies was slow compared with the other industries, e.g., ICT and Biotech Engineering. This paper proposed a Systematic Technology Innovation Process (STIP) for innovation of construction technologies to speed up the technology innovation in construction engineering. The STIP method integrates several techniques adopted for product research and development in other fast innovating industries including patent mapping, root cause analysis, TRIZ, function modelling, simplify design, etc. Details of the proposed STIP method are described. The construciton technology for road man-hole work is selected for case study. A step-by-step application of the proposed STIP method to the selected construction technology is demonstrated. Deliverables obtained from each step of STIP is reviewed and evaluated via a technology stage gate (TSG) process, which is commonly adopted in high-tech manufacturing industry. Finally, an innovative design of a new man hole repairing technology is developed. Verification and testing of the developed innovative technology is also conducted to ensure its feasibility.

Keywords: Technology innovation, patent analysis, TRIZ, construction engineering

1. INTRODUCTION

Construction technology was defined as “the combination of construction methods, construction resources, work tasks, and project influences that define the manner of performing a construction operation” [1] to “accomplish a desired aim necessary for human sustenance and comfort” [2]. Robert Harris pointed out that “…there is more to the construction process than just management…there is more to the construction process than just structural design or geotechnical evaluation…[We need] to create better methods for construction…”[3]. Technology innovation can result in revolutionary advancement in construction practice that traditional management techniques and other skills cannot achieve. Therefore, it becomes the critical component for a company’s long-term competitive strategy [4].

However, the innovation of construction technologies has been slow compared with other areas in Civil Engineering and other industries, e.g., Information and Communication Technology (ICT), Bio Genetic Technology, Nano Materials, etc. (Nam and Tatum, 1989). One of the critical reasons and maybe the most important one is the lack of a systematic approach for fast innovation [5]. As pointed out by Daniel Halpin in his speech of the Seventh Peurifoy Construction Research Award: “…we need a common framework—a common language” [6].

A Systematic Technology Innovation Process (STIP) is proposed to respond the appeals posed by previous researchers. The goal of STIP was to provide a common framework for fast innovation of construction technologies based on modern product innovation methods adopted in other highly innovative industries. In this paper, the STIP method is demonstrated with the innovation of a new manhole technology for road construction work.

2. INNOVATION OF CONSTRUCTION TECHNOLOGIES

Innovation of construction technologies has resulted in dramatic revolutions in construction practice. For example, the introduction of Portland cement in 1824 has brought up thousands of new construction technologies and equipment that completely changed the way of construction engineering; furthermore, in the first quarter of the 20th century, the steel structural technology was invented and introduced to construction industry, which triggered a second revolution of construction technologies. During the late 1970's, construction industry suffered in low productivity, hence inspired the next generation of construction innovation. Issues such as constructability (O'Connor and Miller, 1994), prefabrication, modularization (Tatum et al., 1986), and automation (Sarah, 1997) have drawn numerous researchers to devote their efforts in the innovation of construction and management processes.

In spite of the tremendous efforts spent, innovation in construction industry has been relatively slow. Lack of a common framework, as pointed out by Halpin, may contribute significantly to this lag. Previous researchers have exploited many approaches for organization process innovation [1], technology evaluation [7], and advanced technology repositories [8]. However, few of these efforts targeted directly to design of new technologies. Halpin proposed a CYCLONE model for analysis of construction processes [9]. Many efforts on construction process simulation followed him, e.g., COOPS [10] and STROBOSCOPE [11]. Most of the functionalities of process simulation techniques are still limited to the modeling of existing processes, rather than the invention of new technologies.

Just recently, a new area of construction innovation has been developing on patent analysis (PA) [12][13] and the Theory of Innovative Problem Solving (TRIZ) [14][15]. The former innovated the target technology based on existing technologies of the other areas, which are stored in public patent databases; the latter applied a systematic procedure to identify potentially improvable engineering attributes with tools provided with TRIZ [16].

Unlike the simulation approach to innovate the existing construction processes, PA- or TRIZ-based technology innovations seek a different dimension of technology improvement. The former belongs to "incremental innovation", and the latter belongs to "system innovation" or "radical innovation" according to the classification of Sarah Slaughter [4]. The "system" or "radical" innovations usually involve tremendous amount of information and knowledge and need to be performed with assistance of computer aided tools [17]. Such tools are incorpoerated into a systematic technolog innovation process called STIP, which will be described in the next section.

3. PROPOSED SYSTEMATIC TECHNOLOGY INNOVATION PROCESS (STIP)

The objective of STIP method is to achieve fast innovation of construction technologies by integrating three modern techniques: (1) a product research and development procedure called Research and Development Project Management (R&D PM); (2) an inventive problem-solving method namely TRIZ; and (3) a computer aided innovation tool called Goldfire Innovator™. The STIP procedure consists of eight steps described as follows.

1. Root Cause Analysis (RCA)

The RCA step analyzes the potential opportunities for improvement with the identified technology problem. This step is associated with the Opportunity Analysis stage of the R&D PM Process. Two CAI tools are employed to perform RCA: the RCA module and knowledge database provided by Goldfire Innovator™.

2. Target Technology

The Target Technology step searches the patent database solutions for the root causes determined in the last step. This step is associated with the Concept Definition stage of the R&D PM Process. The patent databases and patent search tools can be employed to identify the target technology.

3. Function Modelling

The Function Modelling step constructs the function model (FM) of the target technology identified in the last step. This step is associated with the Conceptual Design stage of the R&D PM Process. The Function Modelling module of Goldfire Innovator™ can be employed to construct the FM of the target technology.

4. FM Modification

The FM Modification step modifies the FM of the target technology obtained in the last step. Principles of TRIZ, Creativity Templates (CT), value engineering, or simplify design can be adopted for this end. This step is associated with the System Analysis and Basic Design stage of the R&D PM Process. The Simplify Design module of Goldfire Innovator™ or any other innovative solution generator (ISG) commercial software can be employed to construct the FM for the target technology. The result of FM Modification is an "innovated alternative" that improve the problem of the target technology.

5. Alternative Evaluation

The Alternative Evaluation step evaluates the modified FM of an innovated alternative generated in the last step. The result of evaluation can be "approval" or "rejection". If the alternative is approved, the STIP proceeds to next step—Method Design; on the contrast, should the technology alternative be rejected, the process goes back to FM Modification to generate a new alternative. This step is similar to the technology stage gate (TSG) of the R&D PM Process [18], which provides the innovator a quality control function of product development.

6. Method Design

The Method Design step generates feasible solutions for an approved FM of an innovated alternative; that is, suggests a combination of resources (e.g., devices, materials, equipment, and human resources) and process to implement the innovated technology. This step is associated with the Product Design stage of the R&D PM Process. The knowledge database provided by Goldfire

Innovator™ can help the innovator in generating technology solutions. Other approaches for Method Design include brain storming, focus group, and expert interviews when the CAI is not available [18].

7. Prototyping

The Prototyping step implements the innovated technology generated in the last step with the available resources and methods. The implementation is experimental rather than formal. The objective is to test the feasibility of producing physical and practical methods that can be experimented or tested in the next step. This step is associated with the Prototyping stage of the R&D PM Process.

8. Experiment and Testing

The last step of STIP method is Experiment and Testing. In this step, the prototyped technology is tested with real world scenarios to verify its feasibility and applicability. Design of Experiment (DOE) can be adopted to plan the experiments for testing. Modifications and adjustments may be made to the previous steps (Method Design and Prototyping) if the experiment results show potential problems of the prototype technology.

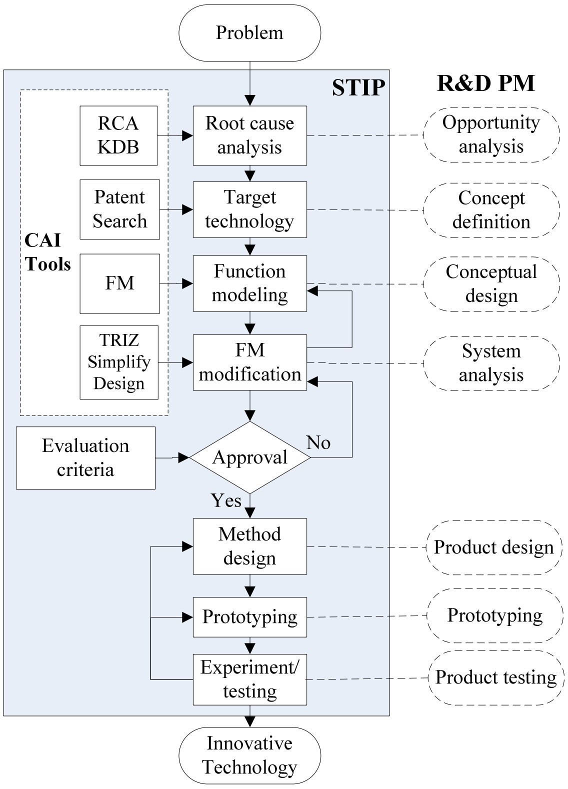


Figure 1 STIP procedure

4. CASE STUDY

The proposed STIP method has been applied to the innovation of a new road manhole construction technology. As Taiwan has become a developed country, many infrastructure systems are aging, including highways, utilities (e.g., electricity, water supply, and gas), sewage, communication (e.g., TV, telephone) conduits, etc. As common conduits are rarely adopted in Taiwan, most of the pipeline conduits are constructed separately under roadways in the urban and suburban areas. Manholes are constructed in order to maintain the utility pipelines. It is found that the average lifecycle of traditional manhole is less than two years. Such damaged manholes have become one of the major causes of deterioration of road pavement, see Figure 2.

Figure 2 deteriorated pavement surrounding manholes

Moreover, the deteriorated pavement surrounding manholes has contributed significant part of car and motorcycle accidents annually. There are more than seven millions constructed manholes in Taiwan. As a result, improvement of the lifecycle of manhole can not only save great amount of budget for public construction but also defer the deterioration of road pavement and improve the safety of road users. It is very desirable for public road agencies to develop an improved manhole construction technology so that the lifecycle of manhole is prolonged, the quality of road pavement surface is improved, and the lifecycle cost of manhole is reduced. In the case study, the STIP method is applied to improve the traditional manhole technology to achieve three objectives: (1) a longer lifecycle; (2) a better evenness of pavement surface surrounding the manhole; and (3) a lower lifecycle cost.

1. Scope of Case Study

The case study was conducted in Taiwan to innovate the manhole construction technology for asphalt concrete (AC) road pavement. Due to the limitation of time, the scope of patent search was limited to USTPO [19].

2. Application of STIP Method

(1) Root Cause Analysis (RCA)
By interviews with the experienced engineers of road maintenance, major cause for manhole deterioration is the re-leveling of manhole covers due to re-pavement of road. As the limited time allowed for concrete curing, the structure strength of manhole is not fully developed before undertaking the loads of traffics. The structure is cracked inside the manhole (see Figure 3) and the surrounding soils of the base layer could flew into the manhole with water when it rains. As a result, the base layer of road is damaged and the road pavement is deteriorated. The root causes of manhole damaged are shown in Figure 4.

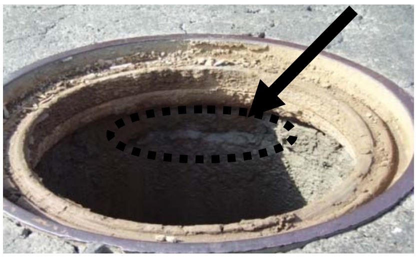


Figure 3 Cracked structure inside the manhole

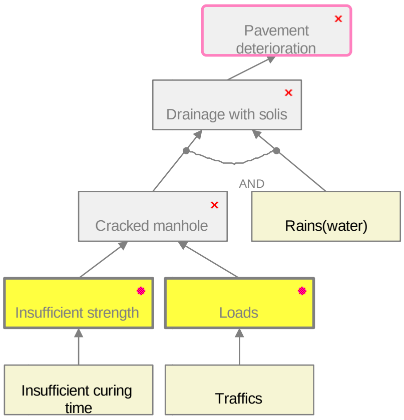


Figure 4 RCA diagram for manhole deterioration

In Figure 4, the root cause for road pavement deterioration surrounding manhole is the drainage with soils flowing into manhole. Two causes trigger the drainage with soils are: (1) cracked manhole; and (2) rains (water). Furthermore, the insufficient strength is the main cause of cracked concrete. Thus, the solution to the problem can be solved by providing sufficient structure strength and blocking the channel of drainage into the manhole.

(2) Target Technology and Patent Search

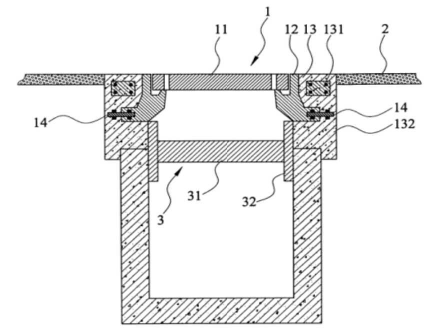
In this step, the patent databases are searched to find out the most appropriate technology that can be considered as the "target technology" for innovation. At first, patent maps are developed to visualize the status of the technological competitiveness in the considered technology domain.

Table 1 shows the search criteria for pavement repairing technologies used in this research to find out the relevant patents in USPTO. The International Patent Classification code (IPC) was adopted in searching. In Table 1, it is noticed that the IPC class: "E02D029/12" (fixed constructions, underground structures, manholes) was found to be most relevant to the problem domain of this case study.

Table 1 Search criteria for manhole technologies

(TTL/manhole OR ABST/manhole) and (ICL/E02D029/14 OR ICL/E02D29/14 OR ICL/E02D029/12): 406 patents
E02D029/12: fixed constructions, underground structures, manholes.

By reviewing the most relevant patents, the "US 3773428: Adjustable manhole support" is considered as the target technology for innovation. The target technology is considered "traditional manhole construction method (traditional method)" hereafter in this paper. The schematic diagram of traditional method is shown in Figure 5.



1 manhole system
11 Cover
12 Cover bed
13Manhole seat
131 RC
132 Concrete
14 Positioning bolt
2 Asphalt concrete pavement
3 Formwork system
31 Bracing
32 Form

Figure 5 Schematic diagram of traditional method

(3) Function Modelling

The target technology is converted into function model for further analysis. The Device Model (DM) provided by Goldfire Innovator™ is adopted for function modelling and technology representation of the target technology. Figure 6 shows the FM of the target technology based on the construction method described in the last step.

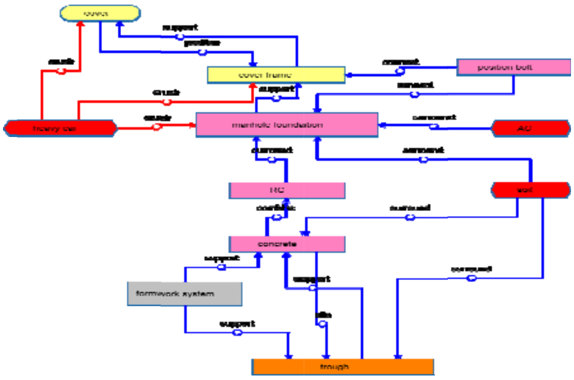


Figure 6 Function Model of traditional method

(4) FM Modification

As identified by RCA, the two root causes for pavement deterioration are cracked manhole and water drainage into manhole; directions for problem-solving are: (1) replacing cast-on-site method with a precast method to provide sufficient strength of manhole structure; (2) blocking the drainage channel. A modified FM is generated as shown in Figure 7.

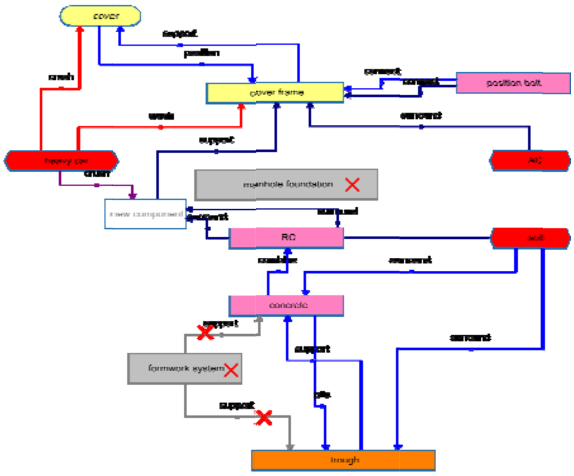


Figure 7 Modified FM

(5) Alternative Evaluation

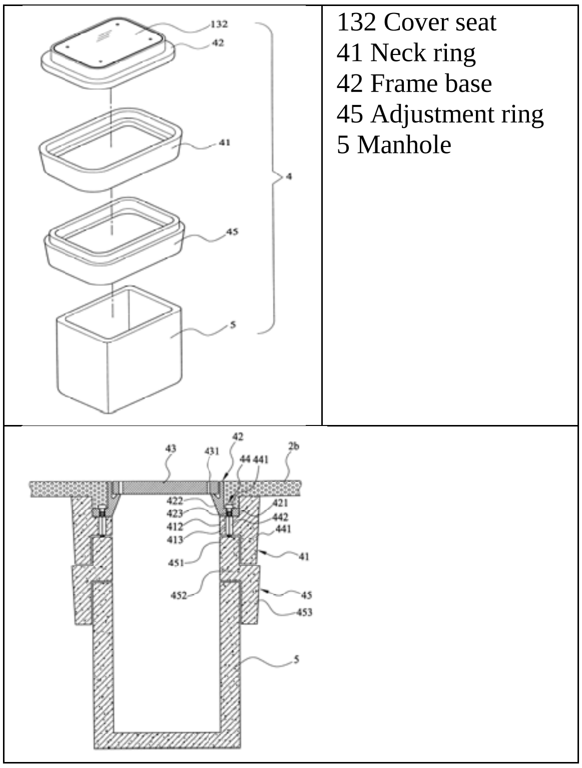
The alternative evaluation is performed qualitatively with the domain experts in terms of functionality, constructability, and cost effectiveness. The evaluation results are shown in Table 2. The traditional method employs laborers to construct the manhole seat and cover bed on site. They are replaced by precast structure. As a result, the functionality and constructability are improved. However, the innovative method requires additional equipment and precast unit, which will increase the initial cost, and thus is inferior cost effectiveness.

Table 2 Evaluation of the innovative technology

Criterion	Technology	
	Traditional	Innovative
Functionality	Poor	Good
Constructability	Medium	Good
Cost effectiveness	Good	Medium (high initial cost)

(6) Method Design

In this step, implementation method for the conceptual innovative technology is designed. The Computer Aided Innovation (CAI) tool, Goldfire Innovator™, is employed again to generate design scenarios. The schematic diagram of the innovative method is shown in Figure 8. In Figure 8, '45' indicate the 'adjustment ring' that can be used to adjust the level of manhole; '42' shows the 'frame base' that provides a block to the drainage channel so that soils of surrounding base layer would not flow into manhole.



132 Cover seat
41 Neck ring
42 Frame base
45 Adjustment ring
5 Manhole

Figure 8 Schematic diagram of innovative method

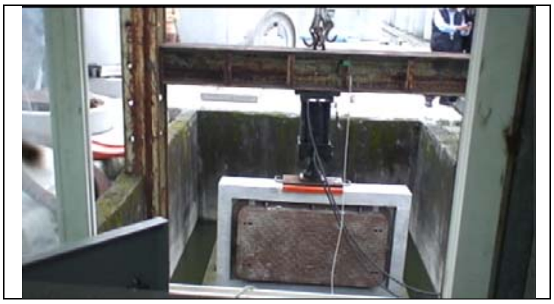
(7) Prototyping

The prototype of the innovative technology has been produced and assembled in the plant, see Figure 9.

Figure 9 Production of prototype product in plant

(8) Experiment and Testing

Experiment and testing was conducted for the innovative technology for the compression strength in order to fulfill the requirement of regulations and SPECs of public works by the government agencies, see Figure 10.



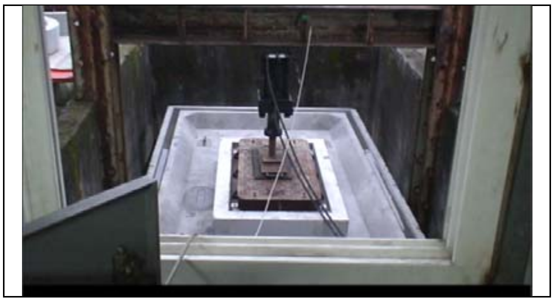


Figure 10 Compression testing

5. CONCLUSIONS

In the paper a proposed STIP method for fast innovation of construction technologies is proposed for innovation of road manhole construction technology. The STIP is demonstrated to provide a systematic approach for fast and cost-effectively technology innovation.

It is concluded that the proposed STIP method is feasible and applicability for innovation of product type technology such as manhole construction. It is convinced that such method can also be employed to innovate other types of construction technologies.

Although the prototype of the innovative technology has been developed and implemented, full-scale verification and cost-effectiveness of the proposed technology need to be further investigated. They will be the future works.

6. ACKNOWLEDGEMENT

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