KNOWLEDGE-BASED OCCUPATIONAL HEALTH AND SAFETY PLANNING FOR CONSTRUCTION PROJECTS

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The ability to identify safety and health hazards as early as possible and implement good occupational health and safety (OHS) plans is vital to a project of any size and scale. It is also a core requirement in safety regulations and standards. Nonetheless, OHS planning faces significant difficulties and challenges owing to: large scope, abundance of OHS standards and manuals in unorganized formats, fragmented nature of construction and skills shortage. Amalgamating OHS and knowledge management and ICT technology techniques, a web-based system was developed for implementing knowledge-based OHS planning practices in construction. The system was then evaluated by its potential end users. The evaluation results suggest that the system: (1) is capable of providing on-demand OHS planning information, (2) captures OHS knowledge from different sources and retains it in a single, easily accessible virtual location, (3) helps site staff with on-the-job learning of OHS skills. These functionalities of the proposed system alleviate the challenges facing OHS planning and could help minimize accidents on site and thereby save time and money for builders.

Keywords: occupational health and safety, knowledge management, web-based system.

INTRODUCTION

Construction accidents cause many human tragedies, de-motivate construction workers, disrupt construction processes, delay progress, and adversely affect the cost, productivity and reputation of the constructor (Kartam, 1997). Pre-project and pre-task OHS planning is among the critical measures required to achieve a zero accident target (Saurin *et al.*, 2004). The ability to identify safety and health hazards as early as possible and implement adequate controls is vital to a project of any size and scale (Cheung *et al.*, 2004). Therefore, the use of effective OHS planning and control techniques on construction sites to prevent accidents can have significant human, social and financial impacts. Moreover, OHS planning often appears as a core requirement in OHS regulations and standards. Nonetheless, OHS planning faces significant difficulties and challenges because.

- Construction projects have large scopes. It is unlikely a site team possess all the knowledge and experiences required to identify every potential hazard in the broad scope of work (Carter and Smith, 2006).
- OHS knowledge is in abundance and it resides in various formats (codes of practice, best practice manuals and databases). It is: (1) unlikely that project teams would know the whole contents of these resources for developing

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effective OHS plans, and (2) nearly impossible for them to refer to these resources due to work pressure.
- In the globalized economic system, construction industries feature professionals from different countries. There is therefore a serious issue of skills shortage that is a significant contributor to ineffective OHS planning (Trajkovski and Loosemore, 2005).

Carter and Smith (2006) suggested that implementing the concept of knowledge management (KM) into OHS planning will eliminate these challenges and improve the OHS planning process continually. KM is a method of exploiting or transforming knowledge from various sources as an asset for organizational use to facilitate continuous improvement. It is a recent and evolving practice for construction organizations. KM can help capture a company's collective expertise wherever it resides – in databases, on papers or in people's heads – and distributing it to wherever it can help produce the biggest payoff (Hadikusumo and Rowlinson, 2004). Lingard and Rowlinson (2005) also argued that the concept of KM and organizational learning is one that critical to the construction industry's ability to improve its OHS performance. Many have suggested different approaches to implement KM and organizational learning into OHS planning as expounded below.

- Sorine and Walls (1996) urged the need for a system that facilitates the dynamic compilation, updating and dissemination of: (1) information on standard job procedures, potential hazards of these procedures and recommended controls, (2) regulatory mandates, and (3) related safety information for OHS planning.
- Lehtinen *et al.* (2005) suggested organizations identify knowledge and information gap in OHS and draw up a plan for producing relevant packages of OHS information and disseminating to projects through the Internet.
- Carter and Smith (2006) explored various options to develop an OHS knowledgebase and concluded that a web-based tool is a better approach as it will be available on virtually every construction project within an organization. Moreover, it will be platform independent and can be used within an ordinary web browser without the need for high-specification hardware and software.

Hence this research aimed at developing a centrally located, dynamic virtual OHS knowledgebase that is updated continually to help effective OHS planning. The aim was achieved via a systematic three-step approach as outlined below.

- Developing the concepts and contents of a knowledge-based OHS planning framework
- Formulating the conceptual model of a web-based system for knowledge-based OHS planning
- Prototyping and validating the web-based system.

The study was demonstrated in the context of conventional formwork for suspended slabs. Nonetheless, the knowledgebase can be populated with information for other trades using the frameworks and the system model incorporated into the proposed system. The study was carried out in four stages namely model development, knowledge acquisition, system implementation and system validation. Firstly, a thorough literature review supported the identification of terms of reference for the proposed system and consequently the development of the conceptual model of the system. Subsequently, the knowledge acquisition to populate the knowledgebase of the system was performed by analyses of documents and publications that describe job

procedures, hazards, best practices and control measures. Then the conceptual model was implemented using Joomla!, an open source contents management system. Finally, the system was validated with construction industry practitioners.

KNOWLEDGE-BASED OHS PLANNING FRAMEWORK

A framework was developed for the knowledge-based OHS planning strategy advocated in this study as depicted in Figure 1. The framework explains the activity flow and resources essentially involved in the planning process.

- The kernel of knowledge-based OHS planning is the OHS knowledgebase, which is constructed by collating knowledge from codes of practice, best practice manuals and research publications. This knowledgebase is updated continually by a dedicated knowledge worker when new knowledge emerges.
- Knowledge-based OHS planning involves analysing the situational variables, retrieving OHS knowledge from the knowledgebase, devizing effective plans for the situation, implementing them on site, and then updating the knowledge base with new knowledge from the site.
- Situational variables include the type of activity to be carried out, work method, location, interacting work, materials used, plant used, and the nature of operatives. These variables are studied meticulously for each activity, and relevant potential hazards and control measures are tapped from the knowledgebase. These lead to the development of an OHS plan for the activity.
- The OHS plan is implemented on site and monitored. If any new hazards and risk controls are identified, these will update the knowledgebase.

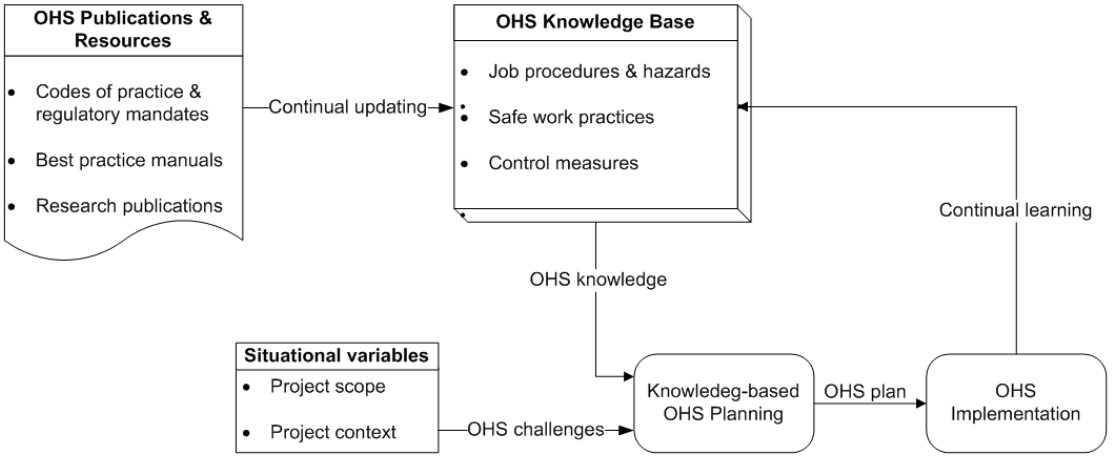

Figure 1: Knowledge-based OHS planning framework

WEB-BASED OHS PLANNING SYSTEM DEVELOPMENT

In order to reap the best outcome from the proposed knowledge-based OHS planning strategy, the model above was translated into a web-based system that.

- Provides a centralized and commonly accessible means of storing OHS knowledge.
- Enables the capture and retention of job procedure-based hazards and safe work practices in easily retrievable and exploitable formats.
- Allows team members of different sites of a contractor to have access to the central knowledgebase for use and updating.

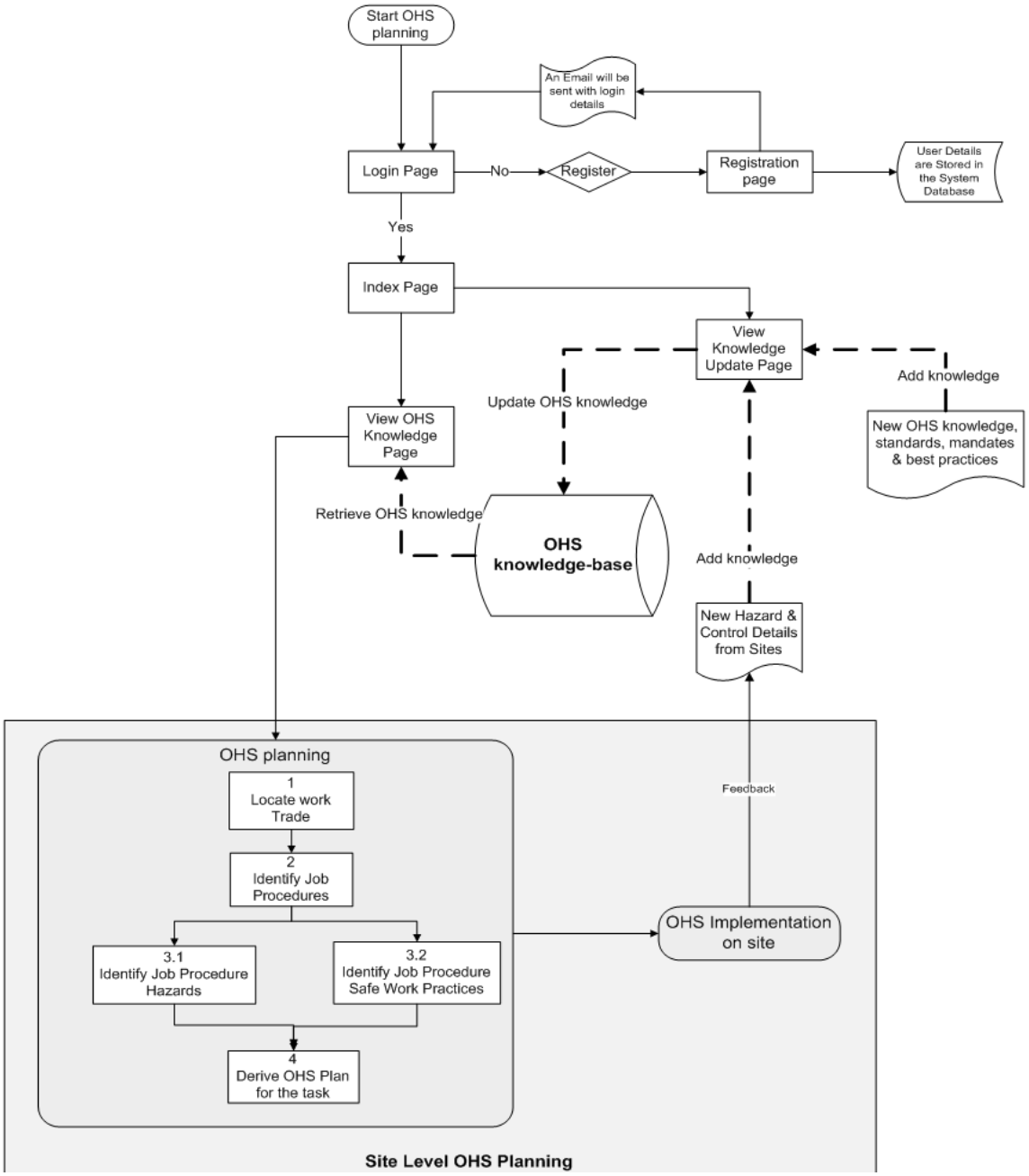

Figure2: Web-based OHS planning system architecture

Figure 2 depicts the system architecture of the web-based OHS planning system and delineates the various functional components within the system. The use of the system starts with the Login Page. Once the authentication is verified, the user is allowed access into the Index Page, if not the user is advised to register. The Index Page directs the user either for: (1) retrieving OHS knowledge for OHS planning or (2) updating OHS knowledge content in the knowledge-base. Knowledge retrieval allows users to access the knowledge about hazards, safe work practices and regulatory mandates for job procedures. The knowledge update path houses templates and forms for updating knowledge on job procedure hazards, regulatory mandates and safe work practices in the knowledgebase.

Prototype development

A website may be developed by one of the two methods: (1) by coding using web development languages such as HTML, PHP, Cold Fusion, ASP, JSP etc., or (2) by

using a Content Management System (CMS). A CMS is a software programme that allows users with little knowledge of programming languages or markup languages to create, edit, maintain and manage dynamic websites using built-in tools and templates. Robertson (2003) suggested that a wide range of benefits can be obtained by using a CMS, including: streamlined authoring process, faster turnaround time for new pages and changes, greater consistency, improved site navigation, increased site flexibility, support for decentralized authoring, increased security, reduced duplication of information, greater capacity for growth and reduced site maintenance costs. Hence, it was decided to use a CMS to make the prototype of the proposed system. There is a plethora of CMS available, both commercially and free general public licences (GPL). Joomla is one of the free CMSs available for researchers and businesses for developing dynamic websites and e-business solutions. The prototype of the proposed OHS planning system was also developed using Joomla.

A Joomla website has two parts: a front-end and a back-end. The front-end is that part of the website that is visible to users. The back-end is the administration area where the website is set-up, modified and managed. At the back-end, Joomla stores website contents in articles, which may contain written information, graphics and/or footages that are added to the webpage. Articles are organized in a hierarchy of sections and categories within the website. An article must belong to a section and a category simultaneously. It is important that initial sections and categories for the website are planed and created before adding contents (articles) for individual pages on the website. Another important element in Joomla is menu manager, which helps create navigational menus for the website.

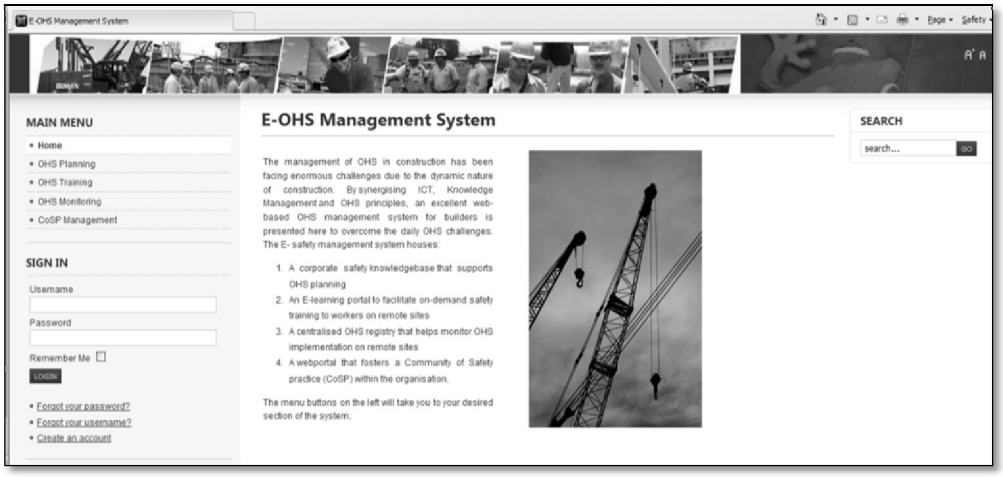

Figure3: Website front-end

The ultimate aim for the proposed system was set to develop a complete E-OHS Management System with four key modules namely OHS Planning, OHS Monitoring, OHS Training and Community of Safety Practice (CoSP) Management. Hence, it was decided to have four major sections for these modules in the initial planning for the website. Subsequently, categories were decided for the OHS Planning section. Construction trades made the categories whereby 14 categories were created for the OHS Planning section. Then, 11 articles were created for the selected demonstration case of horizontal formwork in this study, which consists of 11 subtasks/job procedures. One article was devoted to describe hazards, risks and best practices for each job procedure and this information is displayed in varying formats such as texts, tables, pictures and video clips. Figure 3 illustrated the front-end of it.

How is the website updated continually

The continual updating of the OHS knowledgebase is facilitated through the access level configuration in the proposed website. Joomla supports strong access level configurations for the front-end of the website. There are four front-end user groups available in a standard Joomla website known as Registered, Author, Editor and Publisher.

- Registered users have the access permission to log in to the website, view all content that is classified as registered access as well as public access content.
- The Author user group inherits the access permission of the registered user group and, in addition, they are allowed to create new content items for the front-end.
- The Editor user group inherits the access permission of the author user group and, in addition, its members are allowed to edit all published content items for the front-end.
- The Publisher user group inherits the access permissions of the Editor user group, and in addition, its members are allowed to publish new Content Items to the front-end.

The continual updating of the OHS-knowledgebase with new knowledge is achieved by providing selected users with Author and Editor Permissions to the website. This allows them submit new articles to the website and/or add value to the existing contents. Then the administrator, who has the ultimate control of both the back-end and front-end of the website, decides on the suitability of these new addenda for the website. The newly submitted articles may be either left as they are, incorporated into the existing article contents or rejected by the administrator, as the case may be.

Evaluation of the prototype system

The evaluation for the proposed web-based system prototype had the following objectives.

- To demonstrate that the concept and principles underlie the prototype system could address the challenges facing OHS planning that are outlined in the introduction section.
- To identify aspects of the prototype system and underlying theory that require improvements.
- To assess the usefulness of the system for its target users.
- To demonstrate that implementing knowledge management into OHS planning, underpinned by web technologies, could: (1) minimize accidents on site, (2) facilitate learning on-the-job for less-experienced site staff, and (3) provide an effective mode for capturing and retaining OHS planning knowledge from different sources.
- To obtain comments and recommendations for further improvements and future developments.

To achieve these objectives, it was decided that potential end-users of the proposed system need to see a live demonstration of its features and use. They would then be requested to complete a questionnaire that will allow them to express their opinions on various aspects of the system. The evaluation exercise for the proposed system was carried out with 20 representatives from the New South Wales' construction industry. The sample size of 20 was considered adequate owing to two reasons: (1) system evaluation exercises for similar web-based system in previous research suggest that a sample size ranging between 10 and 20 potential end-users would be adequate (Cooke

et al., 2008; Udeaja *et al.*, 2008), and (2) as the evaluation exercise progressed similarities were noted in responses.

Questionnaire design

A questionnaire was designed so that the above objectives of the evaluation exercise are achieved successfully. The questionnaire was divided into four sections. Section 1 obtained participant's details. Section 2 evaluated the efficacy of knowledge representation and dissemination approach fostered by the proposed system for OHS planning and accident minimization. Section 3 analysed the effectiveness of web-based approach for knowledge-based OHS planning and organizational learning. Section 4 assessed how the proposed system could help overcome challenges facing OHS planning. Additionally, participants were given the opportunity to make further comments under section 2 through to section 4.

Evaluation results

Tables 1 to 3 show the average ratings of the system by the survey participants for different criteria. In order for calculating the weighted consensus ratings for each criterion, the following numerical points were allocated for the rating scales: Strongly agree (SA) = 5, Agree (A) = 4, Mildly agree (MA) = 3, Disagree (DA)=2 and Strongly disagree (SDA)=1. Subsequently the following formula was used to compute the weighted consensus rating (WCR) for each criterion:

WCR = [(Fraction of responses for SA x 5) + (Fraction of responses for A x 4) + (Fraction of responses for MA x 3) + (Fraction of responses for DA x 2) + (Fraction of responses for SDA x 1)]

These WCR values explain the strength of consensus by the survey participants for the variable assessed. A detailed analysis of the results for the various sections of the questionnaire is presented below.

Functional features of the web-based system

None of the participants disagreed that the proposed system and the underlying theoretical model are effective methods and they could help reduce accidents. And, the weighted consensus ratings for the six variables were greater than or equal to 4.00, which justifies that the conceptual frameworks of knowledge-based OHS planning and the web-based system are sound.

Benefits of web-based approach for OHS planning

One participant disagreed with variable number two and five. The reason mentioned by him is "the construction industry still experiences resistance to change from a portion of practitioners and they prefer a paper-based office. However, 95% of the participants favoured the idea, which is reinforced by the weighted consensus ratings that these variables have obtained. One more participant disagreed that the web-based approach could help improve OHS performance on site. The reasons quoted by him are: (1) despite the system clearly demonstrating the risks and how to deal with them, it is not an enforced system in the industry. If this exercise was enforceable to specific tradesman as well as people overseeing these tradesmen it would increase OHS awareness and practice onsite. Hence, the top management should make it compulsory on site staff the use the system on site for enjoying the benefits of it, and (2) availability and accessibility of the system would be an issue for small-sized contractors and subcontractors, who may not have a computer with internet connection on site. Nonetheless, the rest of the participants believe the proposed approach could help improve OHS performance on site.

Table 1: Effectiveness of the methodology

Functional Features of the Web-based System	Strongly Agree	Agree	Mildly Agree	Disagree	Strongly Disagree	WCR
The demonstrated system is a good method for highlighting the hazards and risks in job procedures to help risk assessments.	35%	45%	20%	0%	0%	4.15
The demonstrated system is a good method of explaining the best practices and precautions.	35%	45%	20%	0%	0%	4.15
The demonstrated system is an effective and informative tool for OHS planning.	40%	45%	15%	0%	0%	4.25
The demonstrated system could help reduce accidents significantly.	35%	45%	20%	0%	0%	4.15
Overall, the system could be an effective tool for OHS planning and reducing accidents.	20%	60%	20%	0%	0%	4.00
If the system is extended to hold information and videos about job procedures, hazards, risks and best practices for all activities in construction (excavation, concreting, brickwork etc., the system could help reduce accidents significantly on site.	35%	50%	10%	0%	0%	4.05

Challenges overcome by the web-based OHS planning system

While participants rated many variables in this section favourably, they rated low the suitability of the proposed system for addressing OHS skills shortage issue among site professionals. The reason being: many site professional still have the attitude to overlook safety as opposed to budget and time objectives of the project. As a consequence, the pressure to finish the work seems to take priority over learning new skills on-the-job.

CONCLUSIONS

The development of adequate OHS plans is vital to a construction project of any size and scale to identify hazards as early as possible and implement appropriate control measures. Site management teams face challenges for preparing effective OHS plans owing to factors leading to OHS knowledge shortage among site staff members. The integration of knowledge management, ICT and OHS principles provided with the ability to address these challenges. A knowledge-based OHS planning framework supported the development of a web-based OHS planning system. The web-based system was then tested and evaluated in the construction industry by its potential end user groups. The test results suggest that the proposed system has many advantages for builders.

- It can provide on-demand knowledge that is utilized at the operational site.
- It captures OHS knowledge from different sources, retains and disseminates it to users of it whenever and wherever needed, irrespective of their location. It also supports capture an organization's knowledge asset that is created on sites.
- It helps users with on-the-job learning of OHS skills.
- It provides with interactive media for safety inductions and toolbox talks for operatives on site.
- It could help minimize accidents on site.
- It saves time and money for builders that arise from poor OHS performance.

Table 2: Benefits of web-based approach

Benefits of Web-based Approach for OHS Planning	Strongly Agree	Agree	Mildly Agree	Disagree	Strongly Disagree	WCR
The web-based system summarizes OHS planning knowledge from different sources (hazard check lists, databases, best practice manuals, codes of practice etc., and stores it centrally in easily understandable and exploitable formats.	20%	75%	5%	0%	0%	4.15
The web-based approach could make OHS planning knowledge easily available and accessible to all users regardless of their site locations.	45%	40%	10%	5%	0%	4.25
The web-based system could save time spent on learning OHS planning knowledge from different sources (hazard checklists, databases, codes of practice, best practice manuals, etc..	30%	60%	10%	0%	0%	4.20
The web-based system could facilitate on-the-job learning of OHS planning knowledge.	30%	50%	20%	0%	0%	4.10
It needs no prior training or software skills to use the system but basic knowledge of using web browsers.	35%	50%	10%	5%	0%	4.15
Overall, the web-based approach could be an effective way to store and share OHS planning knowledge.	35%	60%	5%	0%	0%	4.30
Overall, the web-based approach could be an effective way to facilitate learning on-the-job for site teams.	30%	60%	10%	0%	0%	4.20
Overall, the web-based approach could help improve OHS performance on site significantly.	35%	40%	20%	5%	0%	4.05

Table 3: Challenges addressed by the system

Challenges overcome by the Web-based System	Strongly Agree	Agree	Mildly Agree	Disagree	Strongly Disagree	WCR
The web-based system could help inexperienced site team members to develop better OHS plans.	40%	50%	10%	0%	0%	4.30
If the web-based system is populated with more information and videos that cover all activities in a construction project, this could arm inexperienced/less skilled site teams with the necessary skills for effective OHS planning.	40%	50%	10%	0%	0%	4.30
The web-based system summarizes OHS knowledge from different documents and standards, and makes it easy for site teams to learn and apply, considering their tight schedule and work pressure.	35%	60%	5%	0%	0%	4.30
If the web-based system is enhanced with information and videos that summarize OHS knowledge relevant to all activities in a construction project, the system could be a valuable tool for on-the-job learning.	30%	65%	5%	0%	0%	4.25
The web-based system could provide a standardized method for capturing, storing and sharing OHS planning knowledge.	25%	55%	20%	0%	0%	4.05
If the web-based system is enriched with OHS planning knowledge for all activities in construction, it could be a rich and standardized repository that can be used across fragmented projects of a builder.	20%	65%	15%	0%	0%	4.05
The web-based system could help overcome the disparities in OHS planning knowledge among site team members that may arise due to differences in experience and training.	35%	50%	15%	0%	0%	4.20
If the web-based system is extended to have information and videos that cover OHS planning knowledge for all activities in construction, the system could help address coverage of knowledge issues with site professionals.	25%	45%	25%	5%	0%	3.90

The proposed system also has advantages for academia whereby it could be used to train students in OHS. The conceptual model behind the proposed system could be used in other industries, with necessary customizations for the industry, to develop similar knowledge-based OHS planning systems, leveraging on web technologies. Further studies are recommended in the direction of developing web-based systems for dynamically monitoring OHS implementations on sites.

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