Web-based Safety Knowledge Management System for Builders: A Conceptual Framework

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Keywords

Construction, Occupational health and safety, Knowledge management, Intranet

INTRODUCTION

Construction is Australia's third most dangerous industry. The construction industry employed approximately 5% of the Australian workforce but accounted for 9% of the workers' compensation claims (Dingsdag, Biggs & Sheaham, 2006). The incidents of workplace fatalities were 9.2 per 100000 workers in construction, compared with the national average of 3.1 fatalities per 100000 workers (NOHSC, 2005). The fatality rate is three times higher than the all industries rate. On average, 49 construction workers have been killed at work each year (Fraser, 2007). The industry's incident rate for workplace injuries and diseases remains at 28 per 1000 workers, which is nearly double that of all other industries (16 incidents per 1000 workers) (MBAI, 2005). In addition to the social costs on the community, construction accidents inflict direct and indirect costs on a contractor's business. The direct costs include: increased workers' compensations insurance premiums, equipment repair and replacement costs, fines, fees and legal settlements, and damages to works and temporary structures. The indirect costs refer to the cost of production downtime and tarnished company image. Despite the currently available 144 laws, 200 standards and numerous codes of practice that cover occupational health and safety (OHS) in construction throughout Australia (Robinson, 2002) may have improved OHS performance, it still appears to be difficult to curtail accident rates due to the existence of the following peculiar dilemmas (Preston & Cruickshank, 2000; Trajkovski & Loosemore, 2005):

- Construction process is dynamic. Factors such as the working environment, activity, workforce mix, equipment and tools usage and site layout change rapidly and constantly over the period of construction. This makes safety on site volatile.
- Every construction project is unique. Parameters such as the scope of work, location and materials used are different between projects, and therefore every project faces new challenges in OHS management. Moreover, it is unlikely that a project team will possess all the expertise and knowledge to meet the challenges despite they may be experienced.
- Employee (both professionals and workforce) turnover in the construction industry is relatively higher. Thus, there is a need for a continual safety training system in place.
- Safety knowledge that resides in codes of practice, best practice manuals, databases and papers evolve overtime and it is abundant. The project management team is required to be abreast of the contents and changes. This is rather difficult for them to refer to written documents and attend workshops due to tight project schedules and work pressure.
- The Australian construction industry has migrant workers and professionals. They pose skill shortages that have become a significant contributor to accidents.

The strategy to overcome these dilemmas towards implementing better safety systems is to adopt a knowledge based safety strategy, in other words introducing a safety knowledge management system in contractor organisations. It can help capture a company's collective expertise wherever it resides—in databases, on paper, or in people's heads—and distribute it to wherever it can help produce the biggest payoff (Hadikusumo & Rowlinson, 2004). Lingard & Rowlinson (2005) also argued that the concept of organisational learning is critical to the construction industry's ability to improve its OHS performance, and suggested that, with regards to OHS, construction organisations need to develop the ability to learn. A construction company may have several professionals and team players. Each professional/team may have some knowledge and experience in OHS. Likewise, there are plenty of literatures on OHS best practices from many sources and they evolve from time to time in pace with the changes in construction technology. If these experiences and knowledge were collated and transformed into a rich OHS knowledgebase, it may help overcome the aforementioned OHS challenges.

This research aims at integrating knowledge management and web-based technologies to provide an innovative means for improving construction safety in the construction industry. The objectives of this research are:

1. Identifying and analysing the components of an effective and innovative safety knowledge management system for builders.
2. Formulating the conceptual model of a web-based safety knowledge management system.
3. Prototyping and validating the system.

However, the paper discusses only around the first two objectives. Firstly an introduction is provided to the paper to put the matter in context. Then a detailed literature review on knowledge-based OHS management is presented followed by the conceptual framework of the proposed safety knowledge management system. Finally, a conclusion is drawn.

KNOWLEDGE-BASED OHS MANAGEMENT IN CONSTRUCTION

Managing hazards on construction sites may be facilitated by the implementation of a dynamic occupational health and safety management system (OHSMS). On-site OHSMSs contain three essential components as seen in Figure 1.

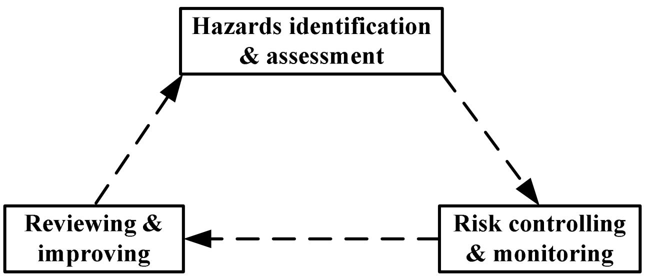

Figure 1: Basic elements of OHSMS (modified from Toohey, Borthwick & Archer, 2005).

Traditionally, OHSMSs are site independent. However, knowledge-based OHSMSs integrate information and knowledge from various sites, professionals and sources and thus making the traditional OHSMSs dynamic. The account below describes knowledge-based approaches for each of the components.

HAZARDS IDENTIFICATION AND ASSESSMENT

A hazard is simply a situation that has the potential to harm people physically or psychologically. Fatalities, injuries, health damages or ergonomic are the possible outcomes of a person being exposed to the hazard (Toohey et al, 2005). The project team is required to identify task-based hazards by analysing the: (1) nature of the task, sub-tasks, processes and procedures; (2) location of the work; (3) interface with other activities; (4) materials, equipment and tools used; and (5) nature of the work crew (alcohol addiction, language barrier, worker mix, and demography). Lingard & Rowlinson (2005), Toohey et al (2005), and Trait & Cox (1998) suggested that:

1. The prime source of OSH knowledge would be line managers, safety officers, professional safety consultants and OSH management. Their expertise, past experiences, intuitions and perceptions are vital.
2. Records of incidents may help learn: (a) the area of workplace/sub task of an activity where the incident occurred, (b) the nature of injury, (c) the occupation/trade of the victim, (d) the time of the day/month/year incidents occurred, and (e) the causes of the incident.
3. Workplace inspections, audits and walkthrough surveys and the use of checklists can assist in the risk identification process.
4. Suppliers of hazardous substances and suppliers of plant and equipment.
5. Compensation cases and insurance claims.

Hence, it is understandable that hazards should be identified in tasks based on the sub-processes involved, materials used, plant and tools used, interfaces with other tasks and zones and the nature of the work crew. Meticulous studies of these situational variables with the assistance of checklists, perceptions, experiences, past incident records, and the collective involvement of site management and supervisors, technical specialists, OHS advisors, and subcontractors are crucial for a productive hazards identification and assessment process.

RISK CONTROLLING AND MONITORING

Risk controlling and monitoring on site pursues a hierarchy of control, which offers a number of ways to approach the hazard control process. The project team has to work the below list down and implement the best measure possible for the situation: (1) eliminate the hazard, if not possible; (2) substitute the hazard with a lesser risk, if not possible, (3) isolate the hazard, if not possible, (4) use engineering controls, if not possible, (5) use administrative controls, if not possible, or (6) use personal protective equipment. The project team is required to be well-versed with the knowledge relating to certain aspects to better implement the hierarchy of controls, including: (1) Safe work practices; (2) Safe use of machinery and tools; (3) Regular safety inspections of activities and the work site; (4) Safety training and workers’ involvement in safety; (5) Involving subcontractors in safety; and (6) Emergency management (Mohamed, 2002; Holt, 2005; Teo, Ling & Chong, 2005; Imriyas, 2007; Choudhry, Fang & Ahmed, 2008).

SAFE WORK PRACTICES

Having identified the hazards in an activity, the project team is required to implement controls through: (1) best construction practices; (2) personal protective equipment use; (3) permit-to-work systems; and (4) housekeeping systems. Choudhry et al (2008) suggested that it would be a good practice at construction sites to organise planning meetings with workers before they execute an activity to discuss about the abovementioned issues in relation to that activity and hazards. It is also encouraged that safety managers and safety advisors organise safety talks at project sites during lunch box meetings with workers to keep them constantly safety conscious. Successful implementation of this critical management task demands the project management team to be abreast of latest knowledge and information regarding the aspects above.

SAFE USE OF MACHINERY AND TOOLS

A particular project may have various machinery and tools and they may be used by various subcontractors. It is an inevitable role for the main contractor to ensure the safe use of machinery and tools on site. It is thus crucial to communicate information and share knowledge with supervisors of the main contractor and subcontractors regarding: (1) testing and inspection of the status of machinery and tools; (2) safe use of machinery and tools; and (3) maintenance systems for machinery.

REGULAR SAFETY INSPECTIONS OF ACTIVITIES AND THE WORKSITE

The site management team is suggested carrying out regular safety inspections on site and forward inspection reports to the sectional manager and subcontractors concerned. It is advised that safety inspectors use photographs of unsafe conditions and unsafe behaviours of workers on site to bring these to the attention of site staff and subcontractors for their immediate actions (Choudhry et al, 2008). There are two key needs to perform these tasks effectively by a site safety inspector: (1) thorough and latest knowledge about safe work practices for all the activities in the project; and (2) a medium for creating and communicating interactive reports and feedback in a timely fashion.

SAFETY TRAINING AND WORKERS' INVOLVEMENT IN SAFETY

Accidents may occur because of poor attitudes and unsafe behaviours of workers, which are difficult to monitor and control. There is a positive link between safety performance and workers' attitudes. In addition, negative behaviours and attitudes have prompted most workers not to wear their personal protective equipment whilst working on site. In this regard, workers need to possess the correct skills and knowledge for the nature of work and to be motivated to behave safely (Teo et al, 2005). This is therefore crucial to have an in-house/on-site safety training programme in place for workers on: (1) safe work practices and behaviours; (2) checking tools and equipment before use and their safe use; (3) housekeeping; (4) emergency responses; and (5) hazard communications with co-workers.

Berghaus (2007) compared the outcomes of instruction-based (standard) safety training and behaviour-based safety training and found that the behaviour-based safety training improved occupational safety significantly even among inexperienced young workers. Under the standard safety training programme, all new employees receive the same basic safety training which is entirely classroom based, and consists of reading materials and lectures supported by audio-visual aids such as video tapes and power point presentations. The behaviour skills programme includes trainers modelling correct safety behaviours, practice of safety behaviour, praise for correct responses and corrective feedback for incorrect responses, in situ training (training in an actual situation), realistic training materials in multiple training situations to promote an active learning approach, positive reinforcement for correct responses, and generalisation of skills. Heck et al. (2001) demonstrated that structured and interactive training and individual rewards based on overall group performance decreased risk taking behaviours. Hence in construction projects, work supervisors and other site staff need to possess the knowledge, skills and resources for conducting behavioural training for workers continually on changing work trades or tasks in the project. There must also be an incentive system in place to reward group safe behaviours, which will motivate a group member to be careful about her behaviours as well as of co-workers.

INVOLVING SUBCONTRACTORS IN SAFETY

A chain of subcontractors (third/fourth party subcontractors) is commonly observed in construction. A major concern for managing safety is the effectiveness of control over the large numbers of subcontractors on construction sites due to diversification of activities. Thus, with higher numbers of subcontracting, the chances of accident occurrences will be more frequent (Debrah & Ofori, 2001). As such, the probability of the lack of communication, coordination and control will increase (Rowlinson, 1997). Furthermore, main contractors may shift all safety responsibilities to subcontractors and may not ensure that the subcontractors are capable of providing a safe working environment (Wilson & Kohen, 2000). But, safety is the responsibility of both because when a subcontractor's worker is killed at site, the WorkCover may fine the main contractor and often the main contractor's image is tarnished. Additionally, the subcontractor might be terminated and may have difficulties getting new jobs in the future. Smith (1998) thus suggested that the main contractor should ensure subcontractors have reasonable OHSMSs in place and needs to oversee their implementation on site. He further suggested that improving communication in general between all parties would improve safety. Daily meetings between site safety managers and subcontractors would help keep everyone informed about changing worksite conditions and provide an opportunity to share information and knowledge about safety and potential hazards. Subcontractors are often hired for specialised works that are beyond main contractor's scope/trade. Overseeing safety and having meaningful daily safety discussions may be a challenge for main contractor's team due to their experience and knowledge limitation. However, if a centralised safety knowledgebase can be maintained by the main contractor, the team members would be able to learn on demand.

EMERGENCY MANAGEMENT

Even with the best safety program and risk management strategies, a construction project is still vulnerable to incidents (Reid, 2000). It is essential that project managers give equal attention to both proactive and reactive managerial strategies (Rosenthal & Kouzmin, 1993). A construction company without an emergency management plan becomes a victim of the demands of the incident and cannot afford the luxury of being proactive (Reid, 2000). The importance of a well-conceived emergency management plan cannot be overemphasized since 80% of unprepared companies go out of business within two years of suffering a major crisis (Brown, 1993). Due to the narrow profit margin yielded in construction business, a mishandled incident can significantly impact on a company's bottom line. A single poorly handled job can affect the positive outcomes of twenty successful projects (Reid, 2000). A contractor relies heavily upon reputation and the public's perception of the company's ability to achieve the community's business goal. This reputation is built over the course of many years and many projects. A single incident has the potential to cause great harm to a company's reputation, particularly if the incident is mishandled. Hence, having a well developed and properly implemented emergency management sub system in place on each construction project, regardless of the size of the project, is essential in construction (Reid, 2000). The system could provide a first-hour response checklist with simulations to handle accidents of various natures.

REVIEWING AND IMPROVING

Chua & Goh (2004) argued that in order for the construction industry to improve its poor safety performance, it needs to learn from its mistakes and put the lessons learned to good use. This needs calls for effective feedback mechanisms that can transmit information derived from incident investigations to be utilized in safety planning. The feedback should be at two levels: first, feedback to the OHSMS that had failed; and second, feedback to the safety planning of future projects (see Figure **2**).

Additionally, Rivers (2006) recommended capturing direct and indirect costs of accidents, analysing these data and producing various accident cost summaries for the project and for the company as a whole for the attention of site and upper management. This information can motivate safety professionals to set safety benchmarks and goals both at organisational and site levels. Tang, Ying, Chan & Chan (2004) analysed construction accidents and recognised the following costs for contractors due to accidents: (1) Increased premiums for workers' compensation insurance; (2) Legislative fines and legal expenses; (3)

Adverse publicity; (4) Cost of administrative time for accident investigation and reporting by site management; (5) Cost of damaged machinery; (6) Cost of damaged materials, finished work and temporary structures; (7) Cost of idle machinery due to accidents; (8) Cost of idle workers due to accidents; (9) Cost of emergency supplies and management; (10) Cost of overtime necessitated by work disruptions due to accidents; (11) Cost of training to replacement personnel; (12) Cost of transportation of injured workers to medical facility; (13) Cost of clean-up; (14) Cost of productivity loss due to work stop and resume; and (15) Cost of productivity loss of the retuned worker due to a reduced capacity.

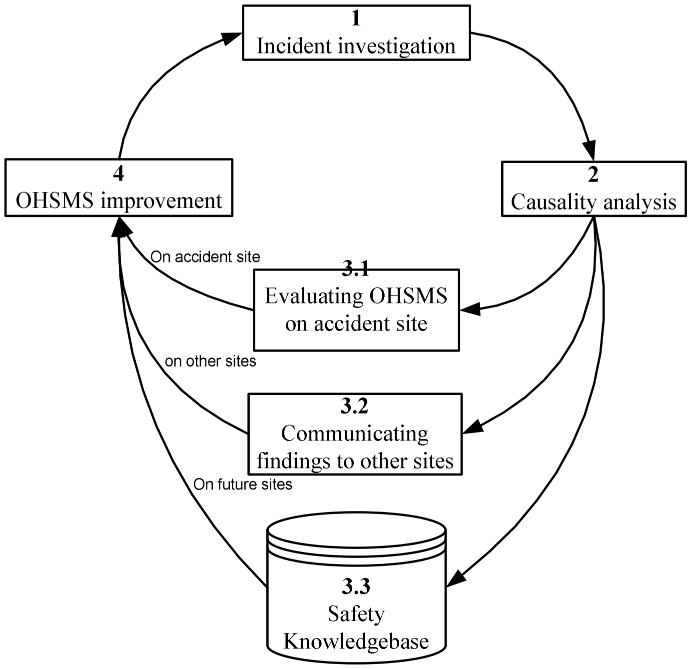

Figure 2: Learning from accidents

Four types of summaries may be produced by processing these cost data from sites: (1) Annual profit loss for the company due to accidents; (2) Project specific profit loss due to accidents/ratio between accident costs and the tender price; (3) Safety investments versus accident costs; and (4) Accident costs comparisons for all the projects on hand. These summaries may be used by contractors to: (1) Set goals and benchmarks for the company and for individual projects; (2) Devise a bonus system for site staff to motivate them to work towards a "zero" accident project; and (3) Measure the performance of the safety management team in the organisation as well as in individual projects.

PROPOSED SAFETY KNOWLEDGE MANAGEMENT SYSTEM

Under the knowledge-based approach, the process needs to be: (1) site boundary independent; (2) actively involving site staff, subcontractors, workers and head office safety staff; (3) learning and improving from the experiences of site teams and incidents in other projects; and (4) continually incorporating innovations in safety. The successful implementation of this innovative approach of OHS management entails a strong synergy of KM strategies and ICT technologies as described below.

- The formation of a Community of Safety Practice (CoSP) that integrates the organisational safety staff, site safety staff and external entities such as subcontractors, suppliers, manufacturers and consultants is necessary.
- A systematically developed corporate safety memory is crucial to continually capture and store OHS knowledge. The corporate memory would constitute the following compartments:

1. A knowledgebase that captures explicit and tacit OHS knowledge. The explicit OHS knowledge related to construction activities includes: (1) sub-steps, potential hazards associated with each sub-step and recommended precautionary measures (safe work practices); (2) safety inspection procedures; and (3) emergency procedures. It is preferred that the explicit knowledge to be stored in interactive media such as visual and audio records so that it will be easy for users to retrieve and use in a short time period. The activity-based tacit OHS knowledge refers to the experiences of site personnel and CoSP members in the form of stories, audio and video records, debriefings and images. This would include stories related to accidents and causes.
2. A database to capture direct and indirect costs of accidents, analyse these data and produce various accident cost summaries for the project and the company in general for the attention of site and upper management. This information would motivate them to set safety benchmarks and goals both at organisational and site levels.
3. An e-learning content catalogue that contains interactive training materials on safe work practices, emergency procedures and hazard communications as well as simulations and behavioural safety training assignments. This catalogue can be accessed by site personnel to train workers from time to time.

- A well designed intranet is essential to host:
    1. The corporate safety memory to enable the exploitation and refinement of stored knowledge by users on dispersed construction sites of a contractor.
    2. A virtually interactive notice board facility to foster communications of daily events and news on construction sites to other remote sites and to keep the site staff informed of the updates to the knowledgebase. It can also help disseminate the accident cost summaries from the database in the corporate memory.
    3. A homepage for the CoSP that recognises the existence of the CoSP in the organisation while encouraging safety experts to subscribe to the community. This can also function as a Safety Expert Yellow Pages in which experts are mapped on their professional and specific trades and experiences. Users can access this service to locate relevant experts to seek help from for problems in their projects.
    4. A discussion portal that fosters interactive threaded discussions by CoSP members surrounding concerning OHS issues on sites. It may be done through audio conferencing, videoconferencing or text-based conferencing. The content of threaded discussions may be recorded and preserved in the knowledgebase for future use, which will avoid the possibilities of initiating discussions for already solved problems.
    5. A virtual learning portal to facilitate on-demand safety training to workers on remote sites. Learning on-demand is more effective than having a standard training because the on-demand knowledge is activity/context specific, and applied immediately and thoroughly. The e-learning portal would facilitate the training of new workers on site, which is quite important in the Australian context where the workforce is dynamic and possessing skill shortages. It is important to introduce simulations of safe work practices, emergency procedures, etc. in designing the e-courses because they are easily and completely grasped and registered in the human minds. It is also faster as opposed to reading through written descriptions and regulations. Additionally, it removes the problem posed by language barrier for foreign workers.
- Because construction is fieldwork-based, involving scattered stakeholders and projects at a time, and team members get rare opportunities to sit in front of a computer, it is essential to implant mobile computing technologies into the safety knowledge management system to ensure a successful implementation of knowledge-based safety management. PDAs, smart phones, Bluetooths and/or tablet PCs could be used to facilitate mobile interfaces with the safety knowledge management system by users.

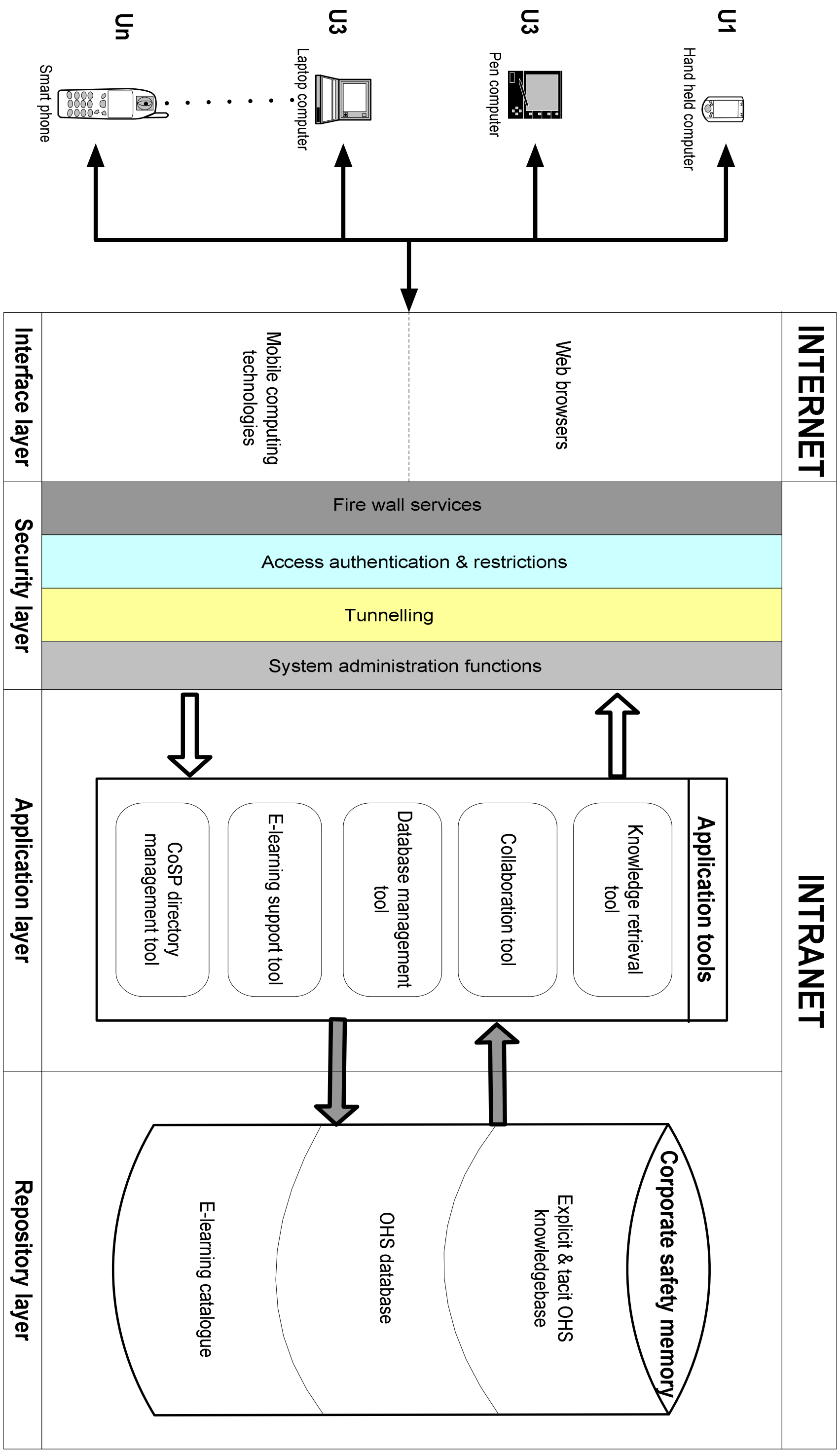

Figure 3: Top level system architecture – SKMS

The system architecture of the proposed safety knowledge management system, which addresses the functional requirements described above, is illustrated in Figure **3.** It constitutes the following four layers: (1) Repository layer; (2) Application layer; (3) Access and authentication layer; and (4) Interface layer. The repository layer houses the corporate safety memory, which contains an OHS knowledgebase, an OHS database, and an e-learning contents catalogue. The knowledge in the corporate memory may be retrieved, used and refined by users via the application layer. The application layer consists of various sub applications for managing the creation, storage, retrieval and dissemination of knowledge.

These sub applications offer facilities for the retrieval of stored knowledge, online collaborations, database management, e-learning support, and CoSP directory management. The access and authentication layer provides system security, access authentications and restrictions, firewall services, tunnelling and system administration functions. The interface layer defines the web browsers and mobile computing devices that users may use to access the intranet.

Figure **4** illustrates the semantic model that explains the objects and their relationship in the corporate safety memory. This was developed based on the finding of the literature review in the preceding sections, and comprises the information content needed for knowledge-based OHS management. The diagram is read by starting with object “work site”. Arrowed lines show the relationships between objects. An arrowed line leading from an object shows the relationship the object has with another object.

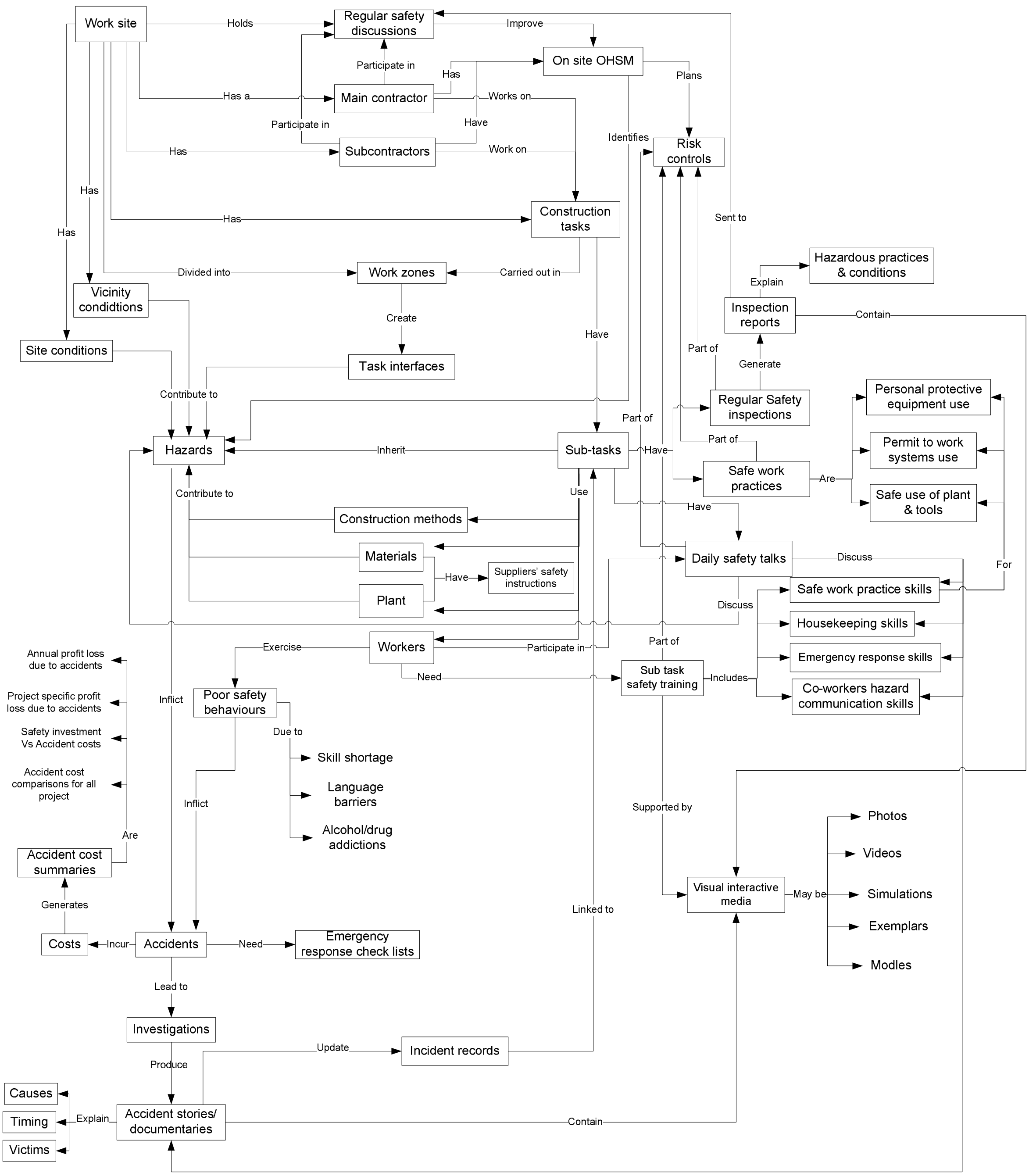

Figure 4: Semantic model for SKMS

Conclusions

The management of OHS in construction has been facing enormous challenges due to the dynamic nature of construction. The constantly changing nature of work activities, work environments, workforce and subcontractors necessitates the incorporation of knowledge management into OHS to keep the workforce and the site management team abreast of activity based OHS skills and knowledge. This would also enable explicit and tacit OHS knowledge to be captured from various sources and disseminated to wherever it is needed at a particular point in time. The synergy of IT, KM principles and OHS principles provided with an excellent platform for developing the conceptual framework of a web-based OHS management system for builders. The proposed system would pave the way to an innovative safety management approach in construction projects, departing from the traditional mode as exist in the Australian construction industry. This approach would also add value to the current knowledgebase of construction safety management. The author believes that, if implemented, the system would help: (1) Enhance safety and reduce accidents on sites; (2) Safeguard the interests of construction workers; (3) Improve productivity of the construction industry and thereby GDP growth; (4) Reduce social costs of construction accidents. Further research is underway to implement and test the system.

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