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An integrated safety management with construction management using 4D CAD model

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ABSTRACT

This paper describes an integrated system for safety and construction management using the 4D CAD model. Safety is integrated with the construction management process throughout design, planning and control phases. Design information about building components and planning information about activities has been gathered to formulate the 4D CAD model. The rule-based system analyzes this combined information to automatically detect any working-at-height hazards and also indicates necessary safety measures in terms of activities and requirements. These safety measures are inserted into the construction schedule and visualized on the 4D CAD together with the other construction sequences. A prototype is developed and verified with a project case study. The results show that the developed system can be a collaboration tool for designers, project engineers, safety officers, and other project participants. It can raise safety awareness of the team and it leads to revisions of design and plan to be consistent with safety. Safety measures are apparently on the schedule; therefore, right resources are allocated, safety constraints are considered and alleviated ahead of time, and the safety control can explicitly refer to as well. This contributes to the success of safety management in the construction industry.

1. Introduction

Construction industry has a poor reputation of a high accident rate and hazardous activities on site. This reflects by the statistics of high accident rates in recent years in many countries (BLS, 2007; HSE, 2008; SSO, 2008). This problem causes loss of many lives, health, skilled personnel, compensation, and disrupting the production. It is a consequence of the failure of safety management on construction site.

Traditionally, safety is managed separately from the construction (Hare et al., 2006). The construction management is focusing on productivity in aspects of time and cost. Safety usually conflicts with the production work and it is to blame for hindering the production work and costing some money. Construction management which is fragmented from safety management tends to disregard safety constraints within the construction process. Unless they are well integrated, the construction project never achieves the optimum benefit of the three vital objectives i.e. cost, time, and safety.

Many research studies have addressed on the lack of integration between construction and safety (Kartam, 1997; Gambatese and Hinze, 1999; Saurin et al., 2004; Cameron et al., 2004; Chantawit et al., 2005; Navon and Kolton, 2006; Hare et al., 2006). These researchers suggested various approaches to integrate safety into the construction process including design, planning, and control phases. The issue is strongly reinforced by the Construction Design and Management Safety (CDM) Regulations (HSE, 2007) which are aimed at improving the overall management and coordination of health and safety throughout all stages of a construction project. The regulations were introduced with the intention of creating an integrated approach to health and safety through the increased involvement of clients and designers (Hare et al., 2006).

At the design phase, designers can actually play an important role in early influencing construction safety (Behm, 2005; Gambatese et al., 2007). Their designs direct the choice of construction methods. Designers must realize their privilege and be capable of identifying risks and hazards in the resulting construction methods. They then avoided or reduced any risks and hazards through safer designs (Baxendale and Jones, 2000). A design tool was developed to assist designers in identifying project-specific safety hazards and to provide best practices to eliminate the hazards. These safety design suggestions can be accumulated to form the database of knowledge (Gambatese and Hinze, 1999). In addition, a virtual reality was used to stimulate and bring back perception of hazards and safety knowledge in both explicit and implicit forms. It could assist on the design-for-safety process (Hadikusumo and Rowlinson, 2004). A study indicated that designing for

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safety is a viable intervention in construction. It just needs a new design tool that assists designers in addressing safety in the design (Gambatese et al., 2005). However, some hazards may still be inherent even in the safest designs as it is the nature of the construction work. These remaining hazards need to be handled further in the following phase.

During the planning phase, safety must be regarded as important as construction activities (Kartam, 1997). Safety and health requirements should be defined the same as the construction activities are in the work breakdown structure. These safety-related activities then must be included into the project schedule or Critical Path Method (CPM). The result is a proactive safety plan and an early involvement of safety in the project before hazards being created. The project team can be aware of the safety requirements along with their own tasks when reviewing the project schedule. Necessary resources for safety performance can also be properly allocated and procured in advance. Research studies explored planning tools for integrating health and safety in construction (Hare et al., 2006). Several tools such as safety information on drawings, a responsibility chart were attempted to cut off an amount of bureaucratic paper-work (Cameron and Hare, 2008). However, these proposed planning tools required a lot of effort and cooperation of the project team. It will be better if both construction and safety can be simultaneously planned or if a new tool can automatically give safety considerations for planners.

Finally, at the control phase, the three-levels of effective monitoring of safety performance were suggested (Saurin et al., 2004). The percentage of safe work packages was used as an indicator of this multi-level safety plan against the actual work being performed. Also, a web-based safety and health monitoring system was developed to automatically assess the actual performance and advice corrective actions required using the knowledge base (Cheung et al., 2004). Despite a large investment required, sensor and transmitter devices were installed at the guardrails to real-time monitor their existence and alert when they were misplaced (Navon and Kolton, 2006). In addition, the degree of hazard, expressing in terms of accident costs, of each construction activity is evaluated using the simulation-based model (Wang et al., 2006). The results from the simulation would specify the critical factors relating to activities and then urge management to control them in order to reduce the possibility of accidents. Although the monitoring and control are the last resort to prevent an accident, they are heavily relied on the safety plan. The safety planning is very important because we cannot control what we did not plan for. Any unidentified hazards will not be planned for safety measures and still have potential to cause harms.

It can be concluded that risks and hazards inherent in designs or construction methods must be identified as many as possible during the design and planning phases. Then, safety measures against those risks must be incorporated into the construction schedule as ordinary activities. Safety activities become visible through the project participants and have their own working time in the construction sequence. Also, necessary resources including time, responsible workers, and budget can be optimized and allocated. The planning and design phases provide a vital opportunity to eliminate hazards before they appear on the site and the ability to eliminate hazards diminishes as the project progresses (Gambatese et al., 2007). Finally, the safety performance can be properly measured and controlled.

Although some concepts and developments have already existed, an effective and comprehensive tool for the integrated safety management is still lacking. A tool is needed for collaborating between construction and safety throughout the process (Hare et al., 2006). This research, therefore, aims to develop a holistic and automatic system tool that integrates safety into design, planning and control processes. The system is supported with database that encapsulated and accumulated safety knowledge including both explicit and implicit forms. Hence, it supports an early involvement of the relevant parties, provides decisive information about budget, schedule, and training. It also improves communication, raises awareness of the parties, and can be used for allocating resources and tracking performance. This paper presents the research which includes an investigation of the current practice on construction sites in Thailand and reviews of relevant literature. The design concept, development, result and evaluation of the system are described in the following sections.

2. Safety management practice in construction

This research has conducted a survey study to realize the current practice of safety management in construction projects in Thailand. Eleven ongoing construction projects have been used for the interview sessions. These projects varied in size and type i.e. a high-rise commercial building, condominiums, academic buildings, a hospital, a metropolitan water-supply plant and mass transit infrastructures. Details of these projects are given in Table 1. These projects were purposively selected to reflect the safety problem of the industry. Project engineers and/or safety officers were asked with the series of questions regarding their current safety management process and the troubles of implementation. Role and responsibility of safety officers were also asked.

It was found that most projects did not systematically implement the safety management on site. Some projects which were a relatively small size did not have a safety officer. Project engineers took responsibility of managing safety. They were usually pressured by the work progress; hence, gave a focus on the production work. Safety instructions were inconsistently given to workers

Table 1
Descriptions of the construction project cases.

Construction project no.	Descriptions			
	Project value (million dollar)	Project type	Participant age (years)	Working experience (years)
1	0.22	Academic building	38	5
2	0.63	High-rise commercial building	27	1
3	2.71	Academic building	46	13
4	2.79	Academic building	44	15
5	3.00	Hospital building	31	6
6	3.61	Academic building	32	7
7	7.14	Condominium	29	5
8	8.34	Condominium	34	8
9	90.1	Metropolitan water-supply plant	30	8
10	129.1	Mass transit infrastructure	39	10
11	740.0	Mass transit infrastructure	42	10