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Application of geographic information systems in construction safety planning

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Abstract

Execution schedule and 2D drawings are generally used for hazards identification in the construction safety planning process. Planner visualises 2D drawings into a 3D model and mentally links its components with the respective activities defined in the schedule to understand the execution sequence in safety planning. Sequence interpretation and accordingly the hazards identification vary with the level of experience, knowledge and individual perspective of the safety planner. Therefore, researchers suggest the use of four dimensional (4D) modelling or building information modelling (BIM) to create the simulation of construction process by linking execution schedule with the 3D model. Both however lack in the features like: generation and updating of schedule, 3D components editing, topography modelling and geospatial analysis within a single platform which is now a major requirement of the construction industry. This work facilitates 4D modelling, geospatial analysis and topography modelling in the development of safe execution sequence by using geographic information systems (GIS), both 3D model along with its surrounding topography and schedule were developed and linked together within the same environment. During safety review process if planned sequence results a hazard situation, it may be corrected within the GIS itself before actual implementation. Paper also discusses the use of GIS in the development of *safety database* from which safety information are retrieved and linked with the activities of the schedule or components of a building model. 4D modelling along with topographical conditions and *safety database* in a single environment assist safety planner in examining *what* safety measures are required *when*, *where* and *why*. Developed methodology was tested on a real life project in India, lessons learned from the implementation have been discussed in the *potential benefits and limitations* section. At last, paper highlights major research areas for further improvements.

Keywords: 4D; Construction management; Construction safety; GIS

1. Introduction

1.1. Current state of safety planning

Construction industry is under resourced and under planned in relation to any other industry. In addition to this construction sites are extremely busy places where working environment is ever changing that becomes difficult to predict before or during construction. Poor safety planning and ever-changing environment of construction sites often lead to accidents which affect people, project economics, and social life and bring additional legal liabilities. Poor safety on site keeps workers and their relatives always in physical and psychological troubles which economically affect the project by increasing direct and indirect costs.

Workers in the construction industry face a greater risk of fatality or injury than the workers in other industries; therefore, their protection is of great concern than any other sector. Construction site safety is one of the project's success factors along with time, cost and quality. Effective safety planning contributes in the prevention of accidents and ill health of site personals. Planning well for safety plays an important role in reducing unnecessary cost and

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delays. Design and construction professionals must be aware of the relevant safety issues which need to be looked at the earliest stages of project planning (Hare et al., 2006).

Johnson et al. (1998) found that workers' risk-taking behaviour is a significant contributor to the accidents. Organisations which manage complex and potentially hazardous technical operations with a surprisingly low rate of serious incidents show that operational safety is more than the management or avoidance of risk or error (Rochlin, 1999). Langford et al. (2000) studied the attitudes of construction workers towards safe behaviour on the construction sites by using a research model that links three themes: safety management implementation strategies, attitudes of workers about safety and behavioural factors displayed by construction workers. Glendon and Litherland (2001) used a behaviour sampling technique to evaluate the safety performance of each construction crew. Lee and Halpin (2003) depicted that supervision and training are also related to the safety performance. Study by Saurin et al. (2005) analysed safety planning and control model from the human error perspective.

Dejoy (2005) compared two prominent safety management rubrics: the behaviour change and culture change approaches in terms of their conceptual and theoretical foundations, defining characteristics and apparent strengths and weaknesses. Safety culture is also becoming important to the safety of employees within the construction site environment. Choudhry et al. (2007) reviewed the literature on safety culture focusing on researches undertaken from 1998 onwards. Safety culture was thought to influence workers' attitude and behaviour in relation to an organisation's ongoing health and safety performance. Some clarifications in terms of positive safety culture, safety culture models, levels of aggregation and safety performance were provided by presenting appropriate evidences. Although, the concept of safety culture is relatively new within the construction industry; it is gaining popularity due to its ability to embrace all perception, psychological, behavioural and managerial factors according to Choudhry et al. (2007).

Suraji et al. (2001) concluded that planning and control are the two major causes of site accidents. Huang and Hinze (2003) identified the pattern of accidents due to falls from heights. Tam et al. (2002) after comparing safety improvement measures in the construction industry devised a method for allocating resources according to the order of priority. Hare et al. (2006) integrated health and safety with pre-construction planning. All these studies were set out to identify the risk of accidents and plan measures to reduce them. Analysis and causation of accidents provide basic information for safety planning but these are not sufficient to predict *when* and *where* accidents occur. Such predictions need coordination with the schedule that provides necessary information about the identification of time of high risk (Yi and Langford, 2006).

Lots of efforts, for example, association of safety with design, schedule and cost have been made to improve safety management strategies. Cagno et al. (2001) developed an algorithm for scheduling of safety measures within the safety improvement programme. Hadikusumo and Rowlinson (2002) developed a tool for the visualisation of construction process that identifies the safety hazards. Saurin et al. (2004) developed *Safety Planning and Control* model that integrates safety management with production planning and control process. Kartam (1997) developed *Integrated Knowledge Intensive System* (IKIS-safety system) for construction safety and health performance control by integrating safety and health requirements with the critical path method (CPM) schedule. This integration provides a way to manage safety and health performance proactively rather than reactively. IKIS-safety system helps user to know *when* and *what* safety measure is needed. However, it does not provide adequate information for analysis like *where* and *why* a safety measure is important.

Safety planning in the construction industry is generally done separately from the project execution planning; however, there must be a link between them (Chantawit et al., 2005). There are two reasons behind the importance of this link. First, because safety engineers need to identify *when* and *where* safety measures are required. Secondly, because design drawings/procedures have the information related to *why* and *what* safety measures are needed (Chantawit et al., 2005). Therefore, safety planner needs to be involved in analyzing construction drawings/procedures for developing a safety plan during the project planning stage. Safety planning involves the identification of all potential hazards and accordingly deciding the safety measures. Identification of safety hazards is the most important part in the safety planning process because failure in the hazards identification indicates that construction sequence is not adequately investigated. Project execution planning and safety planning together convey *what* is to be built, *what* safety measures are necessary *when*, *where* and *why*.

To carry out project execution and safety planning prior to actual construction, planners use 2D drawings and mentally associate their components with corresponding activities defined in the execution schedule to visualise the construction sequence and accordingly decide the safety measures. There is no dynamic linkage between the schedule and drawings that results variations in construction sequence interpretation which affect safety planning. The sequence interpretation depends upon the level of experience, knowledge and individual perspective of safety planners. The use of such approach in project execution and safety planning results dissimilarities in construction sequence interpretation that lead to the poor safety planning.

Chantawit et al. (2005) and Hadikusumo and Rowlinson (2002, 2003) removed the variations in sequence interpretation in safety planning by using 4D CAD and virtual reality for hazards identifications. 4D CAD facilitates 3D visualisation of construction processes on a computer screen; users need not to interpret sequence in their minds. In these studies construction process visualisation was