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Application of geographic information systems in construction safety planning

V.K. Bansal

Department of Civil Engineering, National Institute of Technology (NIT) Hamirpur, Hamirpur, Himachal Pradesh 177 005, India

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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

E-mail address: vijaybansal18@yahoo.com

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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 found useful in the identification of potential hazardous situations prior to the construction.

Despite of much research in 4D CAD technologies their use is not very common in the construction industry. These technologies are somewhat difficult to use and the visualisation provided by them is not easily customisable (Issa et al., 2003). Existing 4D CAD systems are unable to aggregate and distribute the information between spatial and non-spatial databases. These tools are based upon the object-oriented concepts and are used primarily for planning, design phase and appraisal types of analysis. Furthermore, 4D CAD models have a single level of detail which hinders the collaboration among general contractors and sub-contractors (Poku and Arditi, 2006). Koo and Fischer (2000) suggested that the construction industry requires a tool that can generate, manipulate and link the execution schedule and 3D components in a single environment. Therefore, after 4D CAD there is a major revolution of BIM that provides strong premises to overcome the fragmented nature of the construction industry. The main idea behind BIM is a single repository where every item is described only once (Aouald et al., 2007). The invention of BIM facilitates 3D modelling, scheduling and linking them together to visualise the execution sequence in generating the safe construction alternatives.

1.2. Why GIS in construction safety planning

Safety planning is not solitary related to construction sequence visualisation developed in BIM or 4D models. For example, safety planning of gravity dam construction where topography plays a major role could not be simulated without the geospatial capabilities which are missing in BIM and 4D CAD (Isikdag et al., 2008). There are other factors like environmental conditions, site topography, thermal comforts, access route planning, etc., which influence workers safety but cannot be modelled with BIM. Both, BIM and 4D CAD lack in geospatial analysis like: evaluation of new job site with respect to flooding (because during flood entire safety measure planned earlier need to be modified), site drainage planning in the event of flood, thermal comfort at work places, route planning of vehicle carrying consignment from different access routes to job site, etc. All these factors need to be considered in safety planning because of their important role during the construction stage. Keeping the importance of geospatial capabilities in view contractors and organisations create, store and share information about 3D modelling up to floor level detail along with surrounding topography. Therefore, 3D model along with surrounding, 4D scheduling and geospatial analysis capabilities together on a single platform may help in effective safety planning process.

This work brings 4D sequence visualisation along with its surrounding topography, database management and geospatial analysis capabilities on a common platform for construction safety planning by using GIS. It improves execution planning and safety planning by integrating geospatial-editing with spatial and non-spatial information in a single environment. Study makes use of 4D GIS tool developed earlier by Bansal and Pal (2008). They generated and linked construction schedule with corresponding spatial details to make the construction sequence easier to understand in GIS. Several other studies have also suggested the usefulness of GIS to handle various construction projects' requirements such as data management, integrating information, complex visualisation, cost estimation, site layout, construction planning (Bansal, 2007).

Hadikusumo and Rowlinson (2002, 2003) developed safety database in *MS Access* while this work discusses the development of the *safety database* in GIS itself from which safety measures can be retrieved and linked with the schedule/components. Hadikusumo and Rowlinson (2002, 2003) used virtual reality in safety management without giving much importance to geospatial factors on other hand this work gives significance to geospatial capabilities which is the main reason to use GIS in safety planning. Chantawit et al. (2005) used early start and finish time for construction simulation in safety planning and recommended future research to incorporate late start and finish time. In this work, construction sequence may be developed either by early start and finish time or by late start and finish time. Chantawit et al. (2005) stored schedule in *MS Access* after importing it from *MS Project*, therefore, their system do not support real time schedule update because it cannot be corrected/updated in 4D CAD/*MS Access*. In this work, during safety review process or during construction if planned construction sequence results a hazardous situation it may be corrected/updated within GIS itself.

This paper discusses how safety planning approach was designed and tested in GIS environment. 4D modelling along with project site conditions and *safety database* in a single environment assist safety planner in examining *what* safety measures are required *when*, *where* and *why*. The proposed approach may also be used in integration with earlier studies made by the authors on 4D GIS (Bansal and Pal, 2008, 2009a), cost estimates (Bansal and Pal, 2007) and direct sunlight visualisation (Bansal and Pal, 2009b).

2. Research objectives

In safety planning for finalising a plan in terms of *when*, *where*, *what* and *why* the safety measures are important, a link between 3D model along with surrounding topography and project execution schedule was found significant. Therefore, main objective behind this work was to explore the use of 4D GIS in construction safety planning. The *safety database* was developed from which safety measures may be linked with activities of the execution schedule or components of the facility to be developed. Several new programmes as well as in-built functionality of GIS (*ArcGIS* in this work) were used. The system was designed in such a way that it may be used in different stages of the construction project, that is, from design and planning through construction stage. The achievement of the objective was accomplished mainly through:

1. Development of the *safety database* in GIS that solicits safety data from safety professionals, procedures and safety codes.
2. Establishment of a link between safety information in the *safety database* and activities in the CPM schedule or 3D components.
3. Development and update of the execution schedule, deciding project parameters, 3D components editing and update of the *safety database* in a single GIS environment to develop safe construction sequence.

3. GIS as a modelling tool for safety planning

GIS is an appropriate technology for many of the construction projects. It is capable in integrating diverse data sets, databases and applications together. GIS leads to the improvement in collective decision-making among planners, designers and contractors. It handles both spatial and attributes information which are synchronised so that both can be quarried, analysed and displayed. Spatial data describes features geometry whereas attribute data stored in tabular form describes the characteristics of different features (ArcGIS, 2004). GIS may maintain different kinds of information about a building such as site plan, drawings, sub-surface detail, component specifications, building evacuation plans, landscaping.

In order to answer *when*, *where*, *what* and *why* of construction safety planning GIS was used in three different areas. First, to develop the *safety database* that includes safety information related to different activities. Database can easily be processed to determine *what* types of safety measures are possible? Secondly, to develop construction sequence that helps in the identification of hazards situations and determine *when* and *where* safety measures are needed. Thirdly, to manage, retrieve and analyse spatial and non-spatial safety information. GIS generates and maintains spatial information regarding 3D modelling, geographic locations and site topographical conditions to answer *why* in safety planning. 4D GIS facilitates the analysis of execution sequence, project site, day lighting and predicting accidental situations to demonstrate how accident can be prevented from happening. Using GIS environment, safety planner and other project participants can match past accidents which were already occurred under the conditions that are similar in the ongoing project and prevent the occurrence of similar accidents again in future.

3.1. Safety database

The efficient organisation and management of vast amount of safety information in GIS relieves safety planner from the heavy task of project documentation. Safety planner has no longer needs to search design, blueprints, and specific procedures and data reports after the development of *safety database*. Graphical/spatial information such as construction drawings, layouts and blueprints may be maintained in the spatial database. GIS uses vector and raster data models to represent graphical features (Smith and Friedman, 2004). The vector data model uses points with x, y and z coordinates to construct features which are treated as discrete object in the space. The raster data model uses a grid to represent graphical variation of features where each cell of a grid has a value that corresponds to a characteristic of feature at that location.

The non-graphical information related to safety is maintained in non-spatial database. Currently the system's focus is on safety performance in different activities involved in the building construction. Different categories of safety information corresponding to each activity are maintained in separate files. For each activity *safety database* structure consists of two types of files: *safety documentation* files and a *linkage* file (Fig. 1). Initially, *safety documentation* files have been populated with the recommendations from safety practitioners (heuristic), provisions from Bureau of Indian Standards (BIS) codes (regulatory), activity's project specific procedures, risk factors related to an activity, name of the BIS codes from which regulatory data is collected and references for further readings. Heuristic data are the views received from the expert's experiences in identifying the problems and incorporating the effective/practical safety techniques. Personal interviews/interactions with safety professionals were used for heuristic knowledge acquisition. The source of regulatory data files are the BIS codes. Sometimes there may be few project specific changes in activity's procedure which may be maintained in a file of *safety documentation* later on that can be linked with the corresponding activity. To decide the level of hazards, database is also populated with activity's risk factors like: method of construction, period of the year, etc. *Safety documentation* carries a file for each activity to maintain the names of the BIS codes from which regulatory data corresponding to that activity is collected. The names of other related codes for further reference in addition to regulatory data are kept in a file of *safety documentation*. Additional information may be incorporated in each file of the *safety documentation* to ensure regular update and expansion of the system. The link between *safety documentation* and activity/component is achieved through *linkage* file. The *linkage* file corresponding to an activity carries the names of all six *safety documentation* files related to that activity.

4. Construction safety planning process

Researchers have shown that safety of construction workers could not be guaranteed only through legislation but need to be extended beyond that (Hinze and Wiegan, 1992). Generally, workers safety is considered a sole responsibility of contractor. Occupational Safety and Health Administration (OSHA) also states that employers

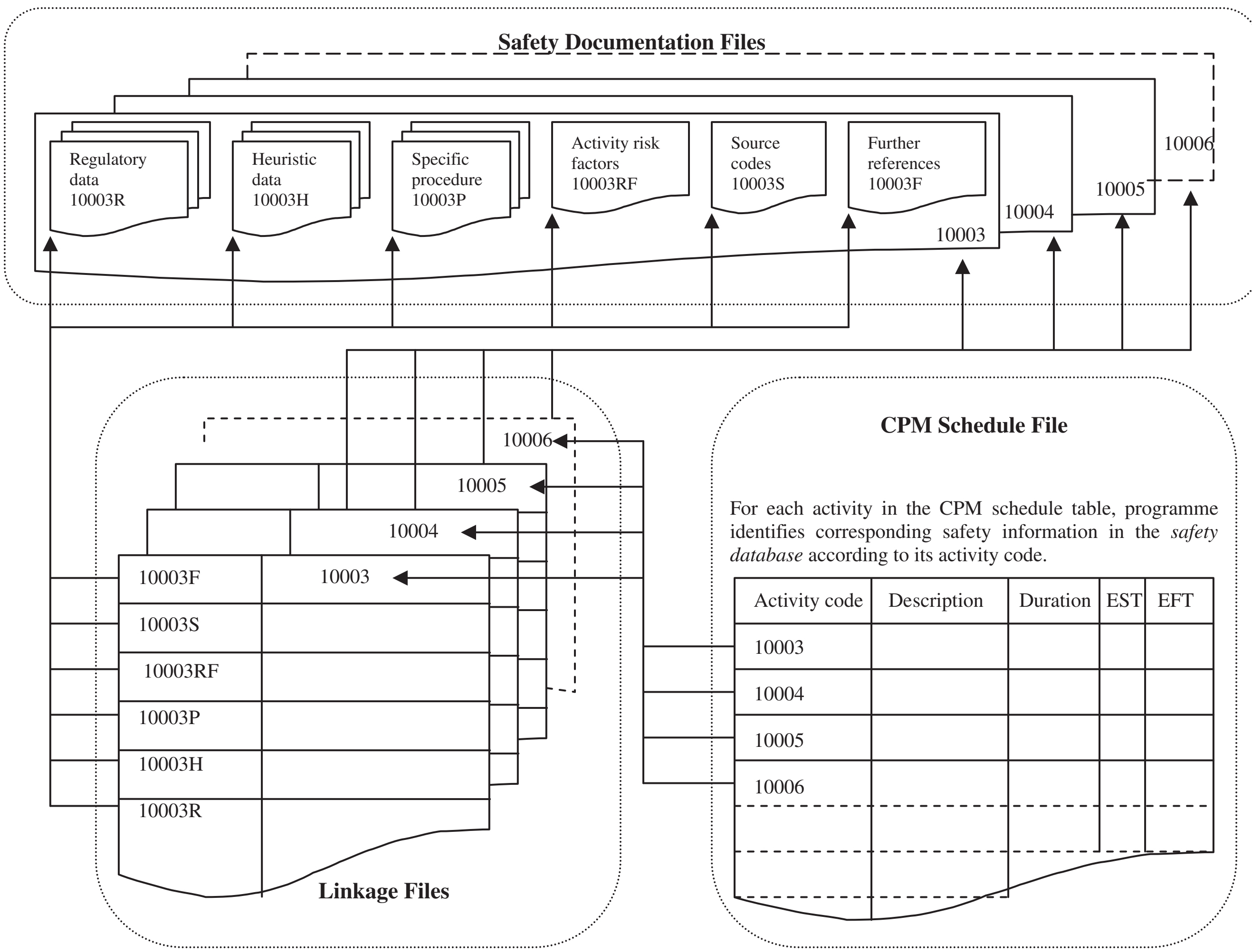

Fig. 1. Linking process and the flow of information between the CPM schedule and *safety database*.

are responsible for providing their workers with a safe place to work. Studies by Hinze and Wiegan (1992) and Gambatese and Hinze (1999) state that in project development important role is played initially by the designers then by the constructors. Designer plays a strong role in reducing the incidence of injuries and fatalities among workers. They should accept their responsibility to provide each design with a safer workplace for workers. Therefore, workers safety needs to be seen in the design process that requires the involvement of experienced safety personnel in the design review. Keeping this aspect in mind an iterative construction safety planning process is designed. Fig. 2 shows an overview of this process, following steps are the parts of this:

4.1. Deciding project parameters

Deciding project parameters consists of making decision about different factors which influence workers safety. In construction design, site layouts, temporary facilities, site conditions/environment, access routes, thermal comfort, etc. influence workers safety. Among them design and site layouts are dominant factors. Therefore, designers may sometimes need to alter the design as per the suggestions from safety professionals in safety reviews process. A GIS based approach developed by Cheng and Yang (2001) may be utilised for material layout design. Cheng and Yang (2001) linked material estimate with execution schedule to calculate dynamic materials requirement, based upon the materials amount and site methodology identifies suitable locations to store different materials. GIS use may also be explored for safe temporary facilities layout design (Cheng and O'Connor, 1996). To provide thermal comfort and day lighting near working platform study by Bansal and Pal (2009b) for direct sunlight visualisation is also found helpful. For planning heavy vehicle routes, GIS based approach developed by Varghese and O'Connor (1995) may be utilised.

4.2. Development of execution sequence

Construction sequence development is a link between the execution schedule and 3D components. The project is decomposed into activities and their interrelationships

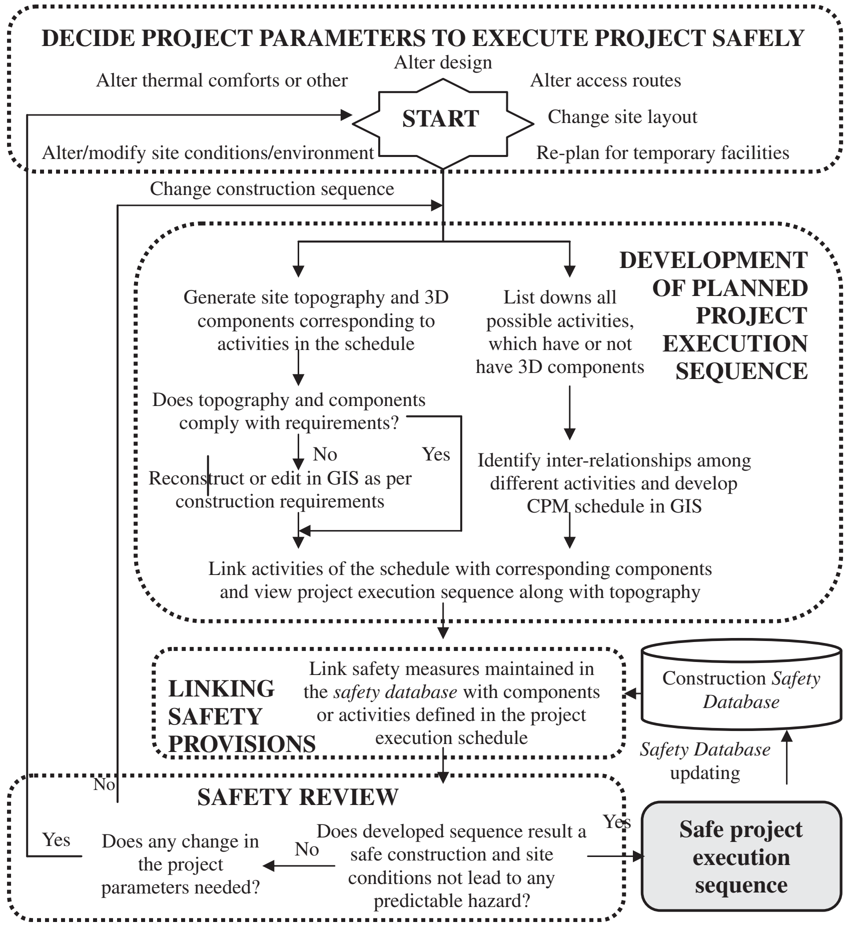

Fig. 2. Construction safety planning process and review of execution schedule for safety in the GIS environment.

and time durations are estimated to develop the schedule. 3D modelling in GIS is done into two parts: building interior modelling and modelling of terrain around the building (landscaping). Building interior modelling depicts floor level detail whereas digital terrain represents topographical condition. The components corresponding to activities of the CPM schedule are generated in GIS and maintained as vector data model in different layers. The number of layers used to represent each activity depends upon the degree of detail to be provided in an animation. The factors which influence the time taken to develop 3D components includes: correctness and completeness of components, skill of modellers, level of details required in an animation and type of relationship between activities and components. The modelling of landscaping stores 2.5D surfaces as raster or Triangulated Irregular Network (TIN) model. The surfaces are taken as continuous and each surface location (x, y coordinate) has only one elevation or z value.

In order to generate execution sequence, 3D components are linked with schedule based on either earliest or latest start time. After the association of activities with corresponding 3D components resulting 4D model is viewed for safety check. The degree of detail in an animation depends upon the detail in the schedule; therefore, it is better to use full work breakdown structure. Details in the schedule and division of a 3D model into components have serious implication on the time spent. For more detail about 4D modelling in GIS readers are directed to the earlier studies made by Bansal and Pal (2008, 2009a).

4.3. Linking safety recommendations

4.3.1. Safety recommendations with CPM

If safety planning is viewed as an integral part of the execution planning from beginning, link between safety recommendations and the execution schedule is very important (Kartam, 1997; Saurin et al., 2004). After establishing this link, CPM schedule has the ability to display the requested safety information when needed by avoiding too much of information being explicitly displayed. This link reduces information overloading and provides an effective safety data management tool. This process is also found suitable in linking company's specific procedures with the corresponding activities to handle project specific operations. The primary role of linking procedures and safety measures with corresponding activity is to ensure compliance with safety regulations and get help in deciding safe methods during construction.

The CPM schedule consists of many fields including activity code, description, duration, early start time, early finish time, late start time, late finish time, total float, free float, resource requirement and remarks. The field activity code is used to establish the connection between activity and linkage file. The linkage file corresponding to each activity in the safety database is stored with the name as that of its activity code (Fig. 1). With the help of a linkage file, programme links selected activity with its six safety documentation files in the safety database. A user-friendly dialogue box as shown in Fig. 3 was designed that allows the interaction between user and the safety database. Selecting an activity in the dialogue box immediately corresponds to its linkage file. It connects activity to any file out of six safety documentation files. Fig. 1 illustrates the linking process and the flow of information between the schedule and safety database.

4.3.2. Safety recommendations with components

The components of a 3D building model are linked with the *safety database*. In this process three types (*one-to-one*, *many-to-one* and *one-to-many*) of relationships between components and *linkage* files are used (Fig. 4). In *one-to-one* link, programme connects a component of building model with a single *linkage* file. The linked *linkage* file then connects component with corresponding six *safety documentation* files in the *safety database*. Several components may also correspond to a single *linkage* file of the *safety database* (for example, two columns related to a reinforced cement concrete (RCC) work corresponds to a single activity); therefore, *many-to-one* link is used in such cases. The *linkage* file then connects components with six *safety documentation* files. In *one-to-many* link, a single component corresponds to number of *linkage* files in the *safety database* (for example, excavation operation includes safety recommendations related to excavation as well as blasting also). Each component of the building model corresponds to one or more activities in the *safety database* depending upon the type of relationship. Fig. 4 illustrates the flow of information between building components and the *safety database*. In this way the developed system provides a user-friendly method to retrieve safety measures for each component of the building model. It is not necessary to have a component corresponding to each activity defined in the schedule. For example, building used in this study, activities like marking and curing of concrete do not have related components, in such cases safety measures may be extracted by linking the schedule with the *safety database*.

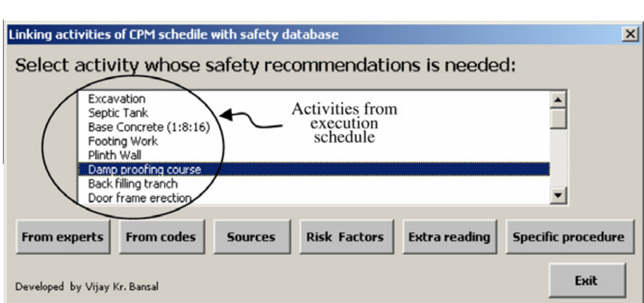

Fig. 3. Dialogue box designed to facilitate the linking between the CPM schedule and the *safety database* in *ArcGIS*.

4.4. Construction sequence review

Concurrent activities in the schedule sometimes lead to congestion, delay and unsafe working environment; therefore, such situations must be avoided by correcting the schedule before construction. Sometime, only one or more project parameter in the original scenario may require modification to make construction safe. Therefore, generated sequence needs to be analysed by the safety professionals. In safety review process if planned sequence does not appear safe, alternative construction sequence need to be explored by re-sequencing the project activities or by changing the construction methods. In safety review process if activities in the schedule need addition/deletion and editing in components' geometry then entire procedure need to be repeated again.

After the implementation of desired changes, schedule again needs to be associated with the corresponding components for safety review and verification. It is an iterative process until safety professionals are fully satisfied. The sequence will be finally accepted if safety professionals approve it. This process entirely depends upon the creativity of sequence planners and safety professionals in making the construction safe.

4.5. Safety database update

Sometime, few safeties related problems remain in the construction sequence which is accepted in the last step. Such problems must be corrected further by the site personals on the jobsite. Such information must be communicated to the concerned professional responsible for updating the *safety database* to prevent repeat occurrences. Also if there are some changes in the project specific procedures to improve safety conditions those may also be communicated for database update. The database is kept safe and made available to one who updates it.

Visualisation of the construction sequence and physical conditions on project site in GIS help in identifying *when* and *where* safety hazards occur and *what* safety measures are needed. Similar jobs accomplished at different site conditions need different safety measures. During construction much emphasis is given on critical activities, therefore, safety aspects of such activities are of great concern. To determine the number of safety reviews required to improve safety conditions is an iterative process.

5. Implementation

The developed approach was implemented in the construction of first floor of MBA-block building at National

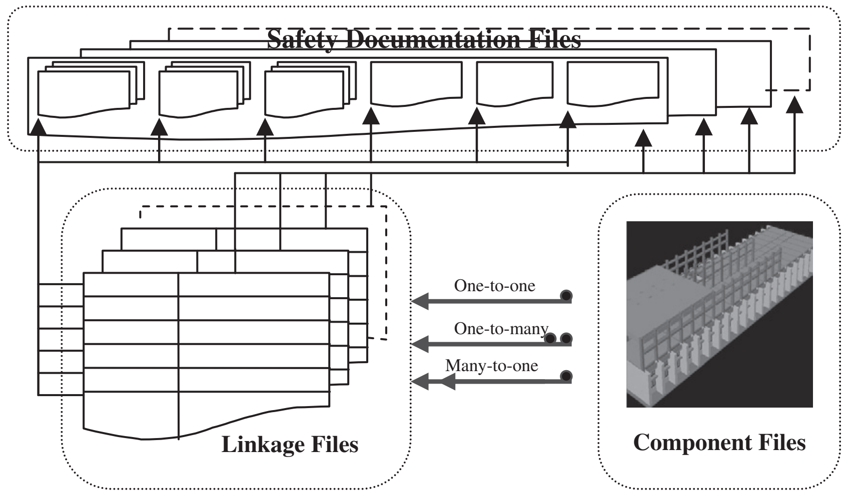

Fig. 4. Information flow between components of building model and the developed *safety database*.

Institute of Technology, Kurukshetra, Haryana, India. As compare to the developed countries, construction safety in India is still in its infancy, mainly due to the safety laws enforcement issue. *European Union*, for example, has a far better record of accomplishment of enforcing safety laws than India. Although, India has no scarcity of laws like *The Building and other Construction Workers Safety and Welfare Act of 1996* and *The Indian Explosives Act*, very little of these are put into practice. *National Building Code* of India is a national instrument providing guidelines for regulating building construction activities across the country. Even then, workers safety in Indian construction is frequently pushed to the bottom rung of priorities by the builders, contractors and engineers. *Construction Safety Manual* is evolved in the Indian industry now, which is made a part of decision-making criteria generally submitted along with the standard tender document by the bidders and enforced by the supervising agencies.

India is just at the starting of safety laws enforcement, not only abundance of laws, new safety equipment and services are being launched. Safety professionals are providing training and consultancy services to the construction workers. Besides explaining precautions related to dangers such as physical injury, falling hazards, fire, short circuiting, safety professionals in Indian construction sector are also showing workers how to handle new equipments safely. India is also catching up with the developed countries in terms of improving working conditions of its workers.

Indian construction industry is highly labour-intensive, unskilled and semi-skilled labour are cheap, unorganised, being unaware of their rights, Indian builders find it convenient and profitable to use such manpower. When it comes to the actual implementation of safety laws on workers who are unaware of their rights, many Indian construction companies not adhere to the code provisions. In such situations, it is very important to introduce virtual environment or IT advancements such as 4D CAD and BIM for the demonstration of construction process, hazards identifications and accordingly safety planning. Moreover, India is exploring its hydroelectric potential fully. Topography plays a major role in the construction sequence simulation and visualisation of hydroelectric projects (such as gravity dams) for safety planning, therefore, Indian construction industry also needs to explore the GIS capabilities for topography modelling and geospatial analysis capabilities.

The case study building consists of a store, a server room, two lobbies, two toilets and fourteen two-size classrooms. There are two stair cases; one is located on left side while other inside the building. The entire construction work was divided into three parts. In first part activities related to RCC work like construction of beams, columns, lintels and roof slabs were included, whereas in second part activities related to exterior walls, interior partition walls, parapet wall, fixing of door and window frames, plastering and flooring were included. The activities related to electrical fitting, wooden work and plumbing were included in the third part of construction.

The 3D components corresponding to different activities and the CPM schedule were generated and linked in *ArcGIS* to develop the execution sequence. Virtual 3D model of features like buildings already existing around the site, roads network and other permanent objects were also generated in *ArcGIS*. Building model was geo-referenced to see the construction sequence along with its surrounding. In Fig. 5, 3D view from the front side of building is shown. The link between the *safety database* and schedule/components was established and found helpful in accessing the safety measures.

During the construction of first floor, ground floor of the building was used to conduct regular classes. Therefore, to execute construction smoothly and safely without interrupting the regular classes it was decided in first review to change the access of construction workers from the front side so that department personals/students could use the building from its front side. It was decided to approach the building from backside during the construction period;

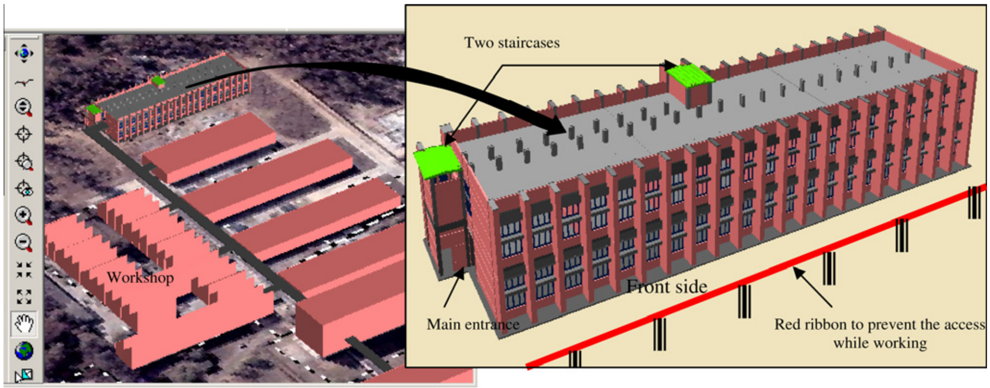

Fig. 5. 3D model of MBA building along with its surrounding developed in *ArcGIS*.

therefore, access was made available form backside by cutting the back wall (to approach the staircase that is located outside the building). The members of construction team were made fully committed to protect the environment from dust, maintain safe and healthy conditions for regular classes and safe workplace.

By providing access from backside, professionals were also able to utilise entire freely available area. In this way contractor was able to store materials and equipment, develop working platforms, site offices, labour huts, etc. on backside (Fig. 6a). It was also decided to change the access road of vehicles coming to site from the front side. The entry in area of about 3–4 m in front of the face wall was restricted to avoid any hazard because of falling objects during the construction period. This was done by erecting few vertical posts and tying red ribbon with those (Fig. 5).

The staircase located outside the building was planned to be used by the workers to approach the first floor. GIS based animation was used to simulate the direct sunlight visualisation in the safety review process no adequate lighting was found inside the staircase. Therefore, to receive adequate natural light throughout the access route it was decided to remove temporary roof covering of staircase during the construction period. At the end of construction period same roof covering was planned to be reinstalled again.

By viewing the times and locations of different tasks, it was possible to recognise how workers affect one another and create dangerous situations. Demonstration of construction sequence to workers has informed them better of their and other's work related responsibilities. With the help of execution sequence animation in safety review the positions and time periods to install barricade, handrail, guardrail, warning sign board and fall protection measures to protect workers time to time were decided. All safety measures decided in review were inserted as safety related activities in the revised schedule or linked with the related activities defined earlier in the schedule.

Execution schedule in safety review process was modified in such a way that different activities related to RCC works were rescheduled for construction earliest. Immediately after RCC work permanent stairway located inside the building was scheduled for construction so that the use of temporary access to approach the first floor roof could be minimised because roof slab was planned to be laid in three stages.

Few findings from the animation were incorporated in the schedule by re-sequencing concurrent activities into subsequent activities and by adding activities that represent the installation of safety measures. The rushed activities are likely to be unsafe; therefore, starting of few activities in the schedule were also rescheduled to ensure the availability of safe working area during construction. Immediately

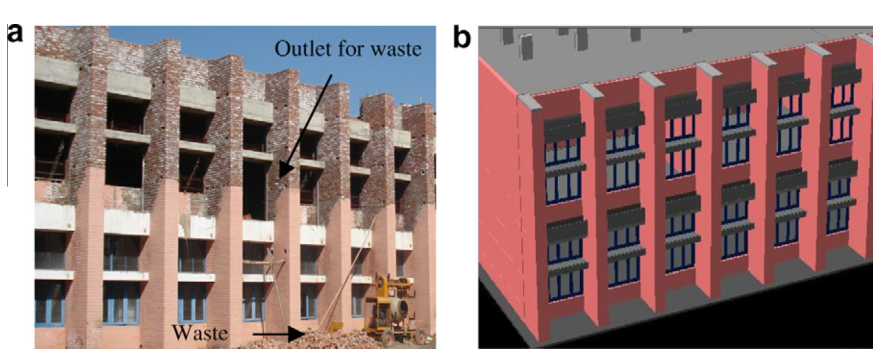

Fig. 6. (a) Suitable passage that was kept to bring out the waste and (b) animation does not show such opening because it was not planned earlier.

after RCC work exterior walls were scheduled for construction in order to minimise the chance of falling down from height. The schedule was also altered to construct a parapet wall immediately after the construction of roof slab to avoid any falling hazard.

During the safety planning process few activities were marked as hazardous to construct, for example, construction of drain-cum-sunshades was identified as hazardous activity which was also observed during the construction (Fig. 7a). Another hazardous activity which includes the possibility of falling hazards was the construction of short side external wall as shown in Fig. 7b. Therefore, during construction of such activities extra care was exercised. It was also ensured during construction that all scaffoldings must be installed in such a manner so that workers may work at their chest height, no one perform over the heads of other or leave tools overhead.

Few tasks like removal of all waste materials from inside were not in the schedule. Also there were no safety measures corresponding to such activities in the *safety database*. Fig. 6a shows a suitable outlet that was kept in the wall to bring out waste when construction was over. Fig. 6b shows an animation screenshot that does not depict such opening; therefore, *safety database* was updated for such cases.

6. Potential benefits and limitations

This work facilitates 4D modelling and geospatial analysis in the development of safe construction execution sequence. Safety planner may detect accident-prone areas and execute the preventive measures (such as placing warning signs, restricting access, providing safety guards, providing guardrails). They may also inform to the respective workers about the possible hazards by viewing the times and locations in the animation. *ArcGIS* provides the in-built module for fly through animation to demonstrate site condition, surrounding topography, transportation route, etc. During the safety review process, if planned schedule leads to hazardous situations, it can be changed in the GIS environment itself. The proposed approach can also use the schedule generated in *Primavera/MS Project* and components created in *AutoCAD*.

The accident prevention also depends upon the quality and timing of the information available to the safety professionals from the *safety database*. Therefore, in the developed approach by clicking on component or activity the relevant safety information will be retrieved from the *safety database*. If users intend to link more detailed information such scanned blueprints and reports, *hotlink* function available in *ArcGIS* is found helpful.

GIS is still a field which is not generally associated with the construction industry, therefore, author found GIS technology little difficult to implement immediately in the Indian construction industry. Commonly used tools in the Indian construction industry are *AutoCAD* and *Primavera/MS Project*, even some operational groups are using blueprints. Professionals using *AutoCAD* to develop 3D visualisation found GIS difficult to employ because 3D modelling capabilities available in GIS are not as user-friendly as they are in *AutoCAD*. In author viewpoint 3D GIS is not mature enough like 3D CAD. However, developed methodology uses *ArcGIS*, which provides *Data Interoperability* extension to directly read/write or translate more than 70 different spatial data formats including GML, XML, Autodesk® DWG/DXF™, MicroStation Design DGN, MapInfo® NID/MIF and TAB, Oracle® Spatial, Intergraph GeoMedia® Warehouse, etc. *ArcGIS* has the ability to import a variety of popular 3D model formats like SketchUp (.skp), 3D Studio (.3ds), OpenFlight (.flt) and VRML (.wrl). Therefore, suggested approach may also use the spatial information generated in different tools (ESRI, 2007). Literature (Ekberg, 2007) suggests that most of the commercially available 3D GIS tools are still in its initial phase, need of further research in 3D GIS technologies.

The construction schedule generated in *Primavera/MS Project* can be used in the developed methodology but cannot be corrected or updated. Therefore, 4D GIS was used, at the current stage, author was unable to bring the scheduling part of it comparable to the commercially available scheduling tools. Author also feels the need of operational

Fig. 7. (a) Drain-cum-sunshades construction was identified as hazardous activity and (b) wall construction which includes the possibility of falling hazards.

level visualisation in GIS to fully explore the possible hazards for safety planning. To visualise construction at operational level it is necessary to show equipments, workers, materials and temporary structures in addition to the physical components and viewing the interaction among them. Therefore, we need more research on 3D GIS and construction operation simulation for its successful implementations in safety planning. Age, computer understanding, experience and education level of the professionals have relationships with the implementation of such new technologies was another observation revealed from the field implementation. Therefore, we also need to educate and train the industry professionals about GIS technology.

7. Conclusion

This study uses GIS based navigable 3D animation in safety planning process that facilitates easier understanding of construction sequence and predicts places and activities which have higher potential for accidents. Editing 3D components, generation and update of CPM schedule, geospatial analysis capabilities and visualisation of surrounding topography in a single environment improves the effectiveness of safety planning. The developed GIS based approach allows project planner and safety planner to manipulate the schedule, components and sequence on a single platform, which in turn facilitates the rapid generation of safe construction sequence and promotes the interaction and collaboration between the members from various fields.

This approach integrates safety code provisions and expert's recommendations with components or activities which makes safety planning more realistic. The rapid retrievals of information from the *safety database* were found useful for professionals responsible in planning construction activities and developing worksite safety programmes. GIS together with the *safety database* helps in identifying the safety hazards and picking up the relevant information. The developed approach was found useful in analyzing *what* safety measures are needed *when*, *where* and *why*.

Study proves that decisions of designer and project planner have direct impact on workers safety. Designer and project planner must consider workers safety as a part of design and planning processes, therefore, their interaction with safety professionals need to be encouraged to make them more responsible for workers safety. They must be made aware of various means by which their design and decisions improve the site safety conditions. Both must know the fact that construction safety is not solitary the responsibility of contractor or employer. Therefore, safety planning process was designed in such a way that safety could be addressed right from the design stage.

At last, GIS based safety planning along with geospatial analysis capabilities has its own strength where construction may be perceived together with its surroundings. GIS not only provides a tool for construction safety planning but it may also be utilised to fulfil different project requirement in various stages (Bansal, 2007).

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