Generating, Evaluating, and Visualizing Construction Schedule with Geographic Information Systems

V. K. Bansal\textsuperscript{1} and Mahesh Pal\textsuperscript{2}

Abstract: Linking of the activities in a critical path method schedule with the corresponding elements of a three-dimensional (3D) model makes the project sequence easier to understand. Although some commercial tools allow the planner to build a 3D model and create graphical simulation of the construction process, it still lacks features like generation and manipulation of a 4D model within a single environment. This paper presents a geographic information systems (GIS) based methodology for scheduling as an alternative to the existing 4D computer aided design tools. A methodology to build a 3D model and link it with the construction schedule using several in-house scripts written in GIS environment is discussed. It allows the planner to understand the construction schedule quickly by linking the activities of the schedule with the corresponding 3D components as well as to visualize a buildable schedule on a computer screen. The proposed methodology utilizes the dynamic linkage between the activities in the schedule and corresponding 3D components, thus, making it possible to detect the incompleteness and logical errors in the schedule sequence. The ability of GIS to maintain spatial data (i.e., 3D components corresponding to each activity) in separate themes, which can be superimposed spatially, is utilized. The related nonspatial information (like schedule, material type and quantity, safety and quality control recommendations, etc.) are stored in the attribute tables of corresponding components, which can be extracted from the database maintained within the GIS itself.


CE Database subject headings: Geographic information systems; Scheduling; Construction management; Project management; Information systems.

Introduction

Difficulties in Detecting Problems through CPM Schedule

In most of the construction projects, critical path method (CPM) networks and bar charts are widely used to represent the schedule. Different activities of the CPM network are related to one or more components of the project under consideration. The CPM schedule provides nonspatial information which lacks in the spatial aspects of construction activities. Therefore, to have the spatial aspects of the project, the construction planner uses two-dimensional (2D) drawings and associates the components of drawings with the related activities present in the schedule (Koo and Fischer 2000; Chernen ef al. 1991). The information such as drawings, specifications, and CPM networks or bar charts required during planning are in different forms, which makes it difficult to mentally integrate them during the planning phase.

Further, there is no dynamic linkage between the CPM-based schedule and its spatial aspects in the commercially available scheduling tools. Interpreting the schedule without any link of its activities with the spatial components is cumbersome because the actual project may contain hundreds of activities. This makes the CPM schedule difficult to check for completeness. The interpretation of the nonspatial CPM schedule may vary with the experience of persons involved due to the difficulty in mentally linking each element in 2D drawing with the corresponding activities of the schedule, thus making it difficult to understand, communicate, and discuss whether a problem exists in the schedule or not (Koo and Fischer 2000).

4D CAD Modeling

The construction industry has acknowledged that its current scheduling and progress reporting practices require substantial improvements in terms of quality and efficiency (Retik and Shapiro 1999). This creates a gap in the effective communication among different project participants. The limitations of the CPM schedule forced the researchers to combine the construction schedule with a 3D computer aided design (CAD) model that leads to the development of a 4D CAD model. The 4D CAD allows a planner to visualize the construction process in the way it would actually be built. Koo and Fischer (2000) suggested that a 4D model increases the comprehensibility of the project schedule and allows users to detect potential problems such as scheduling conflicts prior to the construction. They have suggested that the planner using 4D simulation is likely to allocate resources more effectively. The use of 4D CAD also assists the planner in avoiding schedule conflicts, examining constraints, and evaluating alternative construction methods (Koo and Fischer 2000; Ak-

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\textsuperscript{1}Lecturer, Dept. of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana, 136119 India (corresponding author). E-mail: vijaybansal18@yahoo.com

\textsuperscript{2}Assistant Professor, Dept. of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana, 136119 India. E-mail: mpc_pal@yahoo.co.uk

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A study by Abeid and Arditi (2002) reported a dynamic scheduling system that links digital movies of construction activities, a CPM schedule, and progress control of construction.

Despite much research in 4D CAD technologies, their use is not very common in the construction industry. These tools are somewhat difficult to use and the visualization provided by them is not easy to customize (Issa et al. 2003). Existing CAD systems are unable to aggregate and distribute the information between spatial and nonspatial databases and so far there is no standard procedure for using 4D CAD technologies. The 4D CAD tools are based on object-oriented concepts and are used primarily for planning, design phase analysis, and appraisal type of analysis (Poku and Arditi 2006). Most of these tools have an ad-hoc modeling approach that makes it difficult to update and maintain these systems. Furthermore, 4D CAD models have a single level of detail, which hinders the collaboration among general contractors and subcontractors. Moreover, these models do not support computer based cost and safety analysis (Poku and Arditi 2006). Therefore, the research in the field of sharing and manipulating data on a common platform is still required for the widespread use of existing 4D CAD tools.

GIS and Its Applications in Construction

Geographic information system (GIS) is a special class of information system having a computer, GIS software, human expert, data, and handles both spatial and attribute data. The data model used in the present study stores spatial and attribute data in separate files and links them by feature ID. Spatial and nonspatial data are synchronized so that both can be queried, analyzed, and displayed. Spatial data describe the features geometry, whereas attribute data describe the characteristics of different features of a theme and are stored in tabular form. Each row of the table represents a feature, while the column represents the characteristic of that feature. The intersection of a column and row shows the value of a particular characteristic of a feature. GIS uses the vector and raster data models to represent the spatial features. The vector data model uses points with x, y, and z coordinates to construct spatial features (points, lines, and areas), where features are treated as discrete objects in the space. The raster data model uses a grid to represent the spatial variation of a feature, where each cell of a grid has a value that corresponds to the characteristic of the spatial feature at that location (Chang 2002).

Koo and Fischer (2000) have suggested that the construction industry requires a tool that can manipulate the schedule and 3D components in a single environment. GIS, which combines CAD-like spatial data with a database management system, seems to have the potential to solve this problem (Cheng and Yang 2001). Several other studies also suggest the usefulness of GIS in the construction industry to handle various construction project requirements such as data management, integrating information, visualization, cost estimation, site layout, construction planning, etc. (Bansal and Pal 2006a,b; 2007; Cheng and O’Connor 1996; Miles and Ho 1999; Varghese and O’Connor 1995; Zhong et al. 2004). GIS improves the construction planning and design efficiency by integrating the spatial and nonspatial information in a single environment (Jeljeli et al. 1993; Camp and Brown 1993; Oloufa et al. 1992, 1994). Despite several applications of GIS, the construction industry still depends on tools other than GIS for scheduling, as integrating GIS with project management tools such as Primavera Project Planner (P3) and Microsoft Project is a tedious and time-consuming process. Keeping in view the above limitations, this study explores the potential of GIS to handle CPM basic scheduling computations and links the developed schedule with a 3D model in the same environment.

Research Objective

The proposed methodology demonstrates the benefits of using GIS in construction project scheduling. The ability of GIS to maintain data in separate themes (layers) based on the same geographic referencing system, which can be superimposed spatially, is utilized in this study. The main objective of this research is to enhance the capabilities of GIS for CPM scheduling, linking the activities in the schedule with corresponding 3D components, and visualizing buildability of the schedule on a computer screen. The schedule and 3D components are synchronized in a way that can be queried, analyzed, and displayed simultaneously. The following subobjectives are also achieved:

1. Linking the resource data of each activities with corresponding 3D components; and
2. Maintaining and editing information like drawings, specifications, and schedule in a single environment. These subobjectives are achieved through the development of a database within the GIS itself. The proposed methodology also allows extracting the required information for a given activity of the project from the database. Several new scripts as well as different in-built functions of ArcView3.2 are used. Because of the limited spatial editing capabilities of the ArcView3.2, ArcGIS 9 is used to generate different 3D components of the building.

GIS as Modeling Tool for Scheduling

GIS-Based Spatial Operations

This study makes use of the vector data model (nontopological) represented by simple graphical objects such as: point, line, and polygon to represent the spatial features. In the spatial geographic database, feature classes are logically organized as themes, where each theme is allowed to have only one type of graphical element (point, line, or polygon). The ArcGIS used to create spatial data has to some extent CAD like tools/commands to create 2D or 3D building models (ArcGIS 2004). The functions such as delete, move, cut, and paste available in ArcGIS can be applied to one or more selected features like point, line, or polygon. For reshaping the lines and polygons, the vertex edit tool can be used. Each point, line, or polygon theme in the spatial database is stored as shapefile, where shapefile is the nontopological format for storing the geometric location and attribute information of geographic features in ArcView or ArcGIS. The main functionalities/features of GIS used in this study are discussed below:

Grouping of Features

The merge function in ArcGIS or union features in ArcView groups the features of a theme into one feature. These tools combine features by removing the boundaries or nodes between adjacent polygons or lines. For example, Fig. 1 contains five walls (polygon features), all of which are dissolved into one using merge. These tools also join nonadjacent features to create one feature. For example, three nonadjacent columns (square polygons) in same theme (Fig. 1) are also merged to create a multipart polygon feature.
Extrusion
The 2D themes do not have base height and feature height information, where base height is the elevation value and feature height is the height of features of a theme in 3D space. To display the 3D perspective view, all features of a 2D theme must be assigned base height and feature height from the fields of its own attribute table. The extrusion tool (in ArcView/ArcGIS) changes the points into vertical lines, lines into vertical walls, and polygons into 3D blocks. Fig. 2(a) shows a 2D theme, whereas Fig. 2(b) shows the theme in a space at required orientation. Fig. 2(c) shows the feature of a theme in a space at an elevation value equal to its base height, and is extruded upward to make it 3D by value equal to its feature height, as shown in Fig. 2(d).

Merging of Themes Together
Merging is used to create a new theme by piecing together two or more themes of the same geometry type (e.g., points, lines, or polygons). The merging themes together tool of the GeoProcessing extension available in ArcView is used to merge the themes. It generates one output theme that contains features of two or more input themes. The output theme encloses the fields from one of the input themes. If the remaining input themes have the same fields, then all cells in the output theme’s attribute table populate. Otherwise, if any of the remaining input themes have additional fields that will not be included in the attribute table of the output theme (ArcView GIS 3.2 1996). Fig. 3(a) shows three 2D input themes; and in Fig. 3(b), three themes are merged to one using the tool merging themes together. In Fig. 3(c) different features of a theme are shown in a space at the elevation value equal to their base height, whereas in Fig. 3(d) all features are extruded upwards by the value equal to their feature height.

GIS-Based Nonspatial Operations
The characteristics of the spatial features are represented by nonspatial data stored in the feature attribute table of the theme in ArcView. Each row of the table represents a feature, whereas each column represents the characteristic of the respective feature. Sometimes storing the entire attribute information in a single attribute table makes it difficult to maintain and update. An alternative to this is to store the attribute data in separate tables called database tables. These database tables can be managed by a database management system. The proposed methodology maintains construction resource data in such tables, so as to link them with the activities in the construction schedule.

Critical Path Method Programmed in GIS
Several tools such as P3 and Microsoft Project are used by the construction industry for scheduling purposes. The integration of these scheduling tools with GIS may be difficult due to the requirement of coding within different programming environments. As the construction progresses, the network needs to be updated frequently and the scheduling computations are carried out many times on the modified data, which is a time consuming process. Therefore, the proposed methodology uses GIS to carry out various scheduling computations in tabular form (Moder et al. 1983) by using in-house scripts written in Avenue (programming language of ArcView).

The proposed approach for scheduling in GIS generates an empty table with a fixed number of columns. The number of rows in the table depends on the number of activities in the network. The script requires activity (activity description), from node (predecessor event number, i), to node (successor event number, j) and duration (activity time estimate) as inputs for each activity through a multi-input dialog box. The multi-input dialog box inserts a row corresponding to each activity in the empty table. Finally, the output table provides start and finish times, floats, and criticality of the different activities of the network.

In addition to this, another script to generate single calendar date option (7-, 6-, and 5-day weeks) is used. This provides output in the form of day and date (e.g., Monday May 11, 2005). The in-built chart document functionality in ArcView is used to gen-

Fig. 2. (a) 2D theme; (b) 2D theme at a suitable orientation; (c) feature of a theme in the space at elevation value equal to its base height; and (d) feature is extruded upward by value equal to its height

Fig. 1. Grouping of the selected features of a theme, which removes the boundaries between adjacent polygon features and nonadjacent features together to form a multipart polygon feature
many-to-one are used to join/link different tables together. To explain these relationships, one needs to define the source and the destination one record in the destination table may be related to one record in the source table, whereas the source table remains unchanged. The contents of the destination table change to include the joined attribute from the source table, whereas the source table.

The function Link establishes a one-to-many relationship between the destination table and the source table. Unlike joining tables, linking tables define the relationship between two tables rather than appending the attributes of the source table to those of the destination table. After Link is established, selecting a record in the destination table will automatically select the record or records related to it in the source table.

Data Integration
Three types of relationships i.e., one-to-one, one-to-many, and many-to-one are used to join/link different tables together. To explain these relationships, one needs to define the source (from) and the destination (to) tables. For example, if the purpose is to add data from the database table to the estimate table, then the estimate table is the destination table and the database table is the source table. In Fig. 4, one-to-one relationship means that one and only one record in the destination table is related to one and only one record in the source table. The one-to-many relationship means that one record in the destination table may be related to more than one record in the source table. In the many-to-one relationship two or more records in the destination table may be related to one record in the source table (Chang 2002).

The Join function of ArcView is used to establish a one-to-one or many-to-one relationship between the destination table and the source table (ArcView GIS 3.2 1996). Two tables are joined on the basis of a field called Activity_ID available in both tables. The name of the field does not need to be the same in both tables, but the data type (number to number or string to string) must be the same. The contents of the destination table change to include the joined attribute from the source table, whereas the source table remains unchanged.

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Maintaining Construction Resource Data in GIS
The methodology utilizes GIS to maintain the construction resource data in tabular form and integrate these data with the corresponding activities of the project using the relationships discussed in an earlier section. The database tables store the information related to construction materials, laborers, equipment, etc. Additional information can also be incorporated into all database tables to ensure expansion and updating of the system at later stages. The database management capabilities of GIS to maintain the construction database and its utilization for rate analysis are discussed by Bansal and Pal (2006b). Their approach replaces the manual method to extract the information from the database tables and allows easy updating, as entire information is
in digital form. For safety and quality control recommendations two separate tables are maintained in the database. The information available within these tables can be linked with relevant activities in the schedule. A study by Chin et al. (2005) also reported a non-GIS based daily reporting system for a construction project to collect as-built information regarding the project progress.

**Case Study**

Being in the research stage, the proposed methodology is implemented on a single-storied residential house (Fig. 5). The 2D drawing of the building consists of three living rooms, a single lobby, bathroom, toilet, and kitchen. Stairs are located in front of the main entrance of the building, and are not covered with the roof (with the possibility of adding more stories in the future). The entire work was divided into four parts to manage the project effectively. The first part involved substructure, i.e., activities related to trench excavation for foundation, foundation concrete, foundation brickwork, backfilling, and damp proofing course. The second part involved the superstructure, activities related to exterior walls, interior partition, erection of door and window frames, and flooring, whereas the third part involved activities pertaining to roof slab and parapet wall construction. Electrical fitting, wooden, and plumbing work were included in the fourth part of the construction.

**Evaluation and Visualization of Construction Schedule**

Bansal and Pal (2007) discussed the procedure to develop 3D components corresponding to the activities in the schedule. They utilized AutoCAD to create the data themes, whereas the present methodology replaces the CAD system with ArcGIS. Fig. 6 represents a detailed procedure to evaluate and visualize the construction schedule within the GIS. Various steps involved to evaluate and visualize the construction schedule within GIS are discussed below:

**Step 1. Construction schedule.** Schedule is a timetable for execution of various project activities, and acts as a roadmap for the successful implementation of the methodology. This step involves identification of all possible activities of the project and recognition of their inter-relationships to arrange them in proper sequence. Therefore, the building construction project is decomposed into different activities and the time duration for each is estimated. A script written for CPM calculations receives the identified activities, their inter-relationships, and durations. It computes the project duration using a CPM algorithm. The output table provides start/finish times, floats, and criticality of each activity of the project. The calendar dates or timescale that provide the quick overview of start and completion dates of individual activities can also be generated. The components corresponding to each activity of the project are linked with the CPM schedule based on the earliest start time or latest start time.

**Step 2. 3D components.** Spatial information of different activities available in the schedule is maintained in the data themes, which form the basis of GIS based visualization. It is not necessary to have a 3D component corresponding to each activity in the schedule. For example, in the schedule of the sample building, activities like clearing and leveling of construction site, marking of the site, and curing of the concrete do not have related 3D components. However there should be an activity in the schedule corresponding to each 3D component. The number of themes created corresponding to each activity (representing its spatial
aspects) will depend upon the degree of detail to be provided in the resulting model. For example, in Fig. 3 brickwork can be shown with three subactivities in different themes by providing different start/finish times for each. Another possibility is to merge the subactivities represented by three different themes to make a single theme (a single 3D component). The number of themes to be constructed for each activity may also depend upon the shape, openings, and thickness at different levels of the height.

For example, in the sample building, one theme will be enough to represent concreting in the foundation. The thickness of brickwork in the foundation wall changes twice across the height, therefore, two different themes representing these changes in height are created and merged into one to represent the brickwork in the foundation. Similarly five different themes for brickwork in superstructure are created at different levels of height to consider openings in different walls. The themes corresponding to the activities in the schedule can be reviewed by viewing them in 2D/3D. The components are linked with the schedule if they comply with the requirements, otherwise they are reshaped.

Fig. 6. Procedure for evaluation and visualization of the construction schedule

Sometimes different themes may be merged together (or split) depending on the activities defined in the CPM schedule generated in Step 1. For example, in Fig. 3, brickwork is shown in three different themes. If the entire brickwork is included in a single activity of the CPM schedule, three themes may be merged into a single theme. The components in a theme that belongs to the same activity but are located at different positions in the 3D space may also be grouped together. For example, the lintels over the doors and windows are not adjacent to each other but can be grouped into a single component, corresponding to an activity of the schedule.

After creating the spatial aspects corresponding to an activity in the CPM schedule, spatial information is reviewed by viewing the resulting 3D components. If it complies with the requirements, then the next step is followed, otherwise the components are edited.

Step 3. Linking activities with corresponding 3D components. Linking activities with 3D components implies connecting spatial aspects generated in Step 2 with the corresponding activities of the CPM schedule obtained in Step 1. The linkage between a component and an activity of the CPM schedule may not always be one to one (one component corresponding to an activity of the schedule). However, a relationship like many to one may exist in which many components corresponds to an activity in the schedule. In such a relationship, components are merged together and thereafter linked with the corresponding activity. The one to many linking is also possible if there is a single component corresponding to many activities (Fig. 4).

Linking involves adding a field called Activity_ID to the CPM schedule and the attribute table of each component either manually or by using a script. The field Activity_ID that is common between the two tables (i.e., CPM schedule and attribute tables of different components) is used to establish connections between the components and the corresponding activity. All entries in the field Activity_ID are to be entered manually and should be unique in both the tables. Thus, the attribute required to associate the components with the corresponding activities in the schedule are the entries in the field Activity_ID of the attribute table of each
component and the schedule table. A script is used to associate activities in the schedule to the corresponding 3D components. This script also informs the user about those activities in the schedule that do not have corresponding 3D components and also provides a list of 3D components without corresponding activities in the schedule. After the association of activities in the schedule to the corresponding 3D components, the resulting 4D model can be viewed for its correctness.

Step 4. Schedule evaluation. This step involves evaluating the schedule to verify the construction sequence. A script that generates the lists of all the dates (i.e., starting times) in construction of the schedule is added to the ArcView. By clicking on a date in the list, activities that are planned to be in operation on and before that date will be graphically visible in 3D on the computer screen. The schedule for different dates can be evaluated by visualizing it in 3D through animations. The planners can have a series of images to depict the state of the construction on a particular date. This step may be a time consuming process but it provides the opportunity to explore the alternate construction sequence also.

The system visually communicates the house construction according to the schedule. If the construction sequence complies with the desired output and does not require any change in the number of activities and logsics, the CPM schedule will finally be accepted and no alteration is allowed afterwards (Fig. 6). This step suggests the usefulness of the GIS based approach in identifying the problems in the schedule.

Step 5. Schedule corrections. In the resulting model, the GIS based approach displays at what time components are to be built and where they will be in the space. It facilitates understanding a 3D model and the topological relationship between different components in many ways like zooming, pan, fly forward or backward, etc. After analyzing the model, if it does not comply with the required construction sequence and needs some changes in the logic (interrelationship among the activities), the CPM schedule is changed again as per the requirements. All activities that are not in the sequence need to be rearranged in the CPM schedule. All relationships among the activities in the CPM schedule that constitute a physical impossibility or can cause major disruption or delay at the construction site need to be corrected at this stage.

After implementation of the desired changes, the schedule is again associated with the related components for evaluation and sequence verification. It is finally accepted if no change in the logic and number of activities is required. If the numbers of activities in the schedule need addition/deletion or if some editing is further required in the corresponding components, the entire procedure needs to be repeated again.

Degree of Details in Model

By implementing the proposed methodology in the construction of a residential house, incompleteness of the original schedule was detected and corrections were made. These are not discussed due to the manuscript size restrictions. If some of the activities in the schedule are with limited detail, the developed model does not communicate the construction process in a desired sequential manner even if the schedule is correct. For example, the activity brickwork in superstructure is shown in Fig. 7(a), but by that time only doorframes were erected and no window frame was fixed on the place. Thus, the brickwork shown in Fig. 7(a) should not appear complete unless all the door and window frames are fixed. Similarly lintels over the door and window should also appear before the complete appearance of brickwork. Therefore, the current level of detail for this activity is not sufficient to describe the sequence correctly. The brickwork that appears on a computer screen at a single time, as represented in Fig. 7(a), lacks in the degree of detail. In order to have a sequential visualization the schedule should have a sufficient degree of detail for its activities.

The schedule should have activities to properly represent the hierarchy of work breakdown. Some activities of the schedule may encompass a set of subactivities that represent each activity in more detail. This helps in understanding the logics in a much better way. To discuss this issue in detail, the activity brickwork in the superstructure [Fig. 7(a)] is divided into five subactivities at different levels of height and each subactivity is treated as the main activity. Fig. 7(b) represents the sequence of the construction in a desired manner. In Fig. 7(a), the door frames are shown erected before the start of brickwork (for load bearing walls), and the brickwork is shown up to the sill level. Subsequently, the window frames appear erected and the brickwork appears extended up to the lintel level. The lintels and the rest of the brickwork appear afterwards.

When actual construction of the house started, the as-built schedule representing the actual progress of the work is recorded. The as-built schedule is also linked with the components (after some editing) to compare it with the planned schedule. Fig. 7(c)
shows the model of the sample building according to the as-built schedule, for the same date as in the planned schedule represented in Fig. 7(b). Thus, Fig. 7 presents a comparison between the schedule without sufficient degree of detail [Fig. 7(a)], corrected planned schedule [Fig. 7(b)], and as-built schedule [Fig. 7(c)] on a single date.

Advantages of System

Despite much research in 4D CAD technology, its use is not very common in the construction industry (Issa et al. 2003). Many existing 4D CAD systems are unable to aggregate and distribute the information between spatial and nonspatial databases (Heesom and Mahdjoubi 2004). On the other hand, the GIS based developments suggested in this study eliminate this limitation by maintaining and editing the spatial and nonspatial data on a common platform. Most of the developed 4D CAD technologies do not have the project management capabilities and they are used primarily for planning and design phases of the project. The GIS based methodology suggested in this paper can be used at different stages of the project and allows the user to utilize the database management capability of GIS to maintain and update the construction database. Therefore, the suggested GIS based approach not only provides a visualization tool but it may also be used as a project management tool.

Poku and Arditi (2006) used AutoCAD and P3 to generate the construction design and schedule, respectively, and both were linked in ArcView. The major limitation of study was the manual transfer of the information from P3 and AutoCAD to ArcView. However, in the suggested methodology the drawing generated by using AutoCAD can also be utilized. In addition to this, the system is made more user friendly by utilizing the drafting capabilities of GIS itself. The major advantage of the editing capabilities of GIS is that, if during the schedule evaluation stage the constructed 3D components do not comply with the desired construction, the editing can be done in GIS itself. The proposed methodology can also read the schedule generated in P3 but if the resulting 4D model does not comply with the actual construction sequence, the schedule generated in P3 cannot be corrected in GIS (Poku and Arditi 2006). To get rid of this problem an in-house script to develop the CPM schedule within the GIS environment is used in the proposed methodology. In addition to this, the proposed methodology may also overcome the shortcomings of the construction schedule generated by commercially available tools like P3 and Microsoft Project described in the following sections.

Omission of Activities

It becomes quite difficult to determine whether the schedule is complete or not by just viewing the CPM network. Further, to confirm that all components of the project have related activities is a time consuming process because of the large number of activities in the network. To ensure this, the proposed methodology uses a script to prepare the list of activities in the schedule without spatial information. This script also lists all components that do not have scheduling information. In addition to this, a visual check of the schedule is also possible by viewing it graphically in 3D, which may help in preventing omission of the activities.

Construction Sequence Visualization and Evaluation

Activities with mutual dependencies may be located in different parts of the schedule. Multiple participants individually conceptualize the sequence in their minds by associating activities with the corresponding components in the drawings. This interpretation may vary according to the level of experience, knowledge, and individual perspective of the participants. These inconsistencies in the interpretation may lead to the miscommunication among the project participants. This paper presents the GIS based approach to display the components to be built at “what time” and “where” in the space. This is achieved by using a script to prepare the list of dates from the construction schedule. The components that are scheduled or planned to be in operation on and before a date will graphically be displayed in a 3D space by clicking on a particular date in the list. This allows checking of the schedule for each date. The GIS based approach also facilitates the understanding of a 3D model and the topological relationship between different components in many ways (like zooming, pan, fly forward or backward, navigation, etc.). Fig. 8 shows a 3D view of the example building in which the roof slab is set transparent to display the internal details more clearly. Any component can be set transparent to make visualizations of the model much easier. The users also have the option of rotating 3D components around the x, y, or z axis to observe the developed 3D models from any direction and angle.

Spatial and Nonspatial Data Integration

Failure or success of a building contract depends upon the quality and timing of the information available to the contractors from the database, thus requiring an automated system to get the desired information without delay. The proposed methodology allows understanding of the construction process by integrating spatial and nonspatial information together. The nonspatial data include construction resource data, specification for quality control, and safety recommendations. When a 3D component corresponding to an activity is clicked, a window appears on the computer screen that informs the user about the various times, floats, and resource information of an activity by extracting it from the attribute table.

Anticipating Safety Hazard

All construction projects are unique in nature, therefore many accidents occur due to unforeseen human error. Hazards at the construction site are the main cause of additional cost. Many construction companies consider workers safety to be the prime objective. A navigable 3D animation in the suggested GIS based approach allows the project manager to detect accident-prone areas and execute preventive measures (such as place warning signs, restrict access, provide safety guards etc.). Following this approach a project manager can view the time and location of the work, and inform the respective workers about the possible hazards.

Data Interoperability

The paper presents a methodology that uses ArcGIS, which provides varieties of interoperability modes including file conversion, entity translation, and direct read/write mode. ArcGIS has the ability to read a variety of CAD data formats without conversion, including DWG, DXF, and DNG. It can also export selected
GIS features (points, lines, polygons, and annotation) directly to CAD (ESRI 2007). ArcGIS also includes an improved bidirectional CAD-GIS translator that can move the data from the CAD system to GIS and vice versa which facilitate data sharing. Bansal and Pal (2007) discussed a GIS-based procedure for quantity takeoffs using data themes generated in AutoCAD. Some products from ESRI also allow the users to edit simple features stored in GIS using their CAD application.

The proposed methodology uses ArcGIS that 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). In this way the suggested approach can use spatial information generated in different tools (ESRI 2007).

Miscellaneous

The spatial data generated for the purpose of visualization in GIS can also be utilized for the quantity takeoffs using the procedure suggested by Bansal and Pal (2007). It may be helpful for increasing the productivity in quantity estimation by reducing the manual work required in quantity takeoffs. Therefore, this work also provides the link between the cost and schedule. Queries such as, activities starting on the particular date and activities starting between the particular intervals of time can be made from the CPM schedule generated in GIS. The project activities can easily be stored and listed in a variety of useful ways, such as sorting the schedule in ascending or descending order in any field (floats, early, or late start time) in the table, and selected records could be displayed in the same table by promoting them to the top.

Limitations and Suggestion for Future Work

In spite of all suggested outcomes, some improvements are still required in the proposed methodology. Although the system explores the drafting capabilities of GIS, these are not comparable to the existing drafting tools like AutoCAD. However, the drawing generated in AutoCAD can be utilized/modified in the GIS environment, thus providing a practical solution for the drafting part. The schedule generated in P3 cannot be corrected/updated in a GIS environment. Therefore, the proposed methodology uses its own script for scheduling within the GIS environment. The writers at the current stage are unable to bring the scheduling part of the methodology comparable to the existing scheduling tools. Therefore, it requires more functionality like those available within P3 and Microsoft Project.

At present, the system is developed on a single-user desktop. For multiple participants working on a large project, one needs to use a server or web-based GIS (Wu et al. 2002). The future work involves testing the proposed methodology on a server-based GIS. At present, the scripts written in Avenue are being transferred to an ArcGIS programming environment to completely exclude the ArcView from the methodology developed. Future work also involves implementing the proposed methodology for multistoried buildings to judge the usefulness of the GIS based approach to generate, evaluate, and visualize the construction schedule.

A number of research papers in the conference proceedings and construction journals indicate that GIS is being widely used to meet different project requirements. GIS mainly focuses on geographic (land-based) information and analyzes that information as a basis for the design and assessment of civil infrastructure. Many of the earlier studies have used land-based capabilities of GIS, for example, network analysis for routing (Cheng and Chang 2001; Varghese and O’Connor 1995), construction site layout planning (Cheng and O’Connor 1996), and sewer/water system design (Greene et al. 1999). This study does not focus on the land-based information of the GIS but utilizes its ability to maintain spatial and nonspatial data on a common platform to make the scheduling more realistic.

Conclusions

This paper presents a GIS based methodology to represent and integrate spatial and nonspatial information, like drawing, specifications, resources, and construction schedule in a single environment. The various spatial operations on graphics and nonspatial operation on the attribute data in a GIS environment may improve and speed up the construction planning as well as ensure data integrity and accuracy. The proposed methodology integrates the construction schedule with corresponding spatial details to make the project sequence easy to understand. GIS allows the user to manipulate the schedule and 3D components in a single environment, which in turn facilitates the rapid generation of alternatives. The schedule in GIS allows easier understanding of the project as well as helps to detect possible problems in it. By integrating and displaying specification/recommendation and construction resource information, the schedule in GIS promotes interaction and collaboration among the project team members from different fields. GIS allows users to use its database management capabilities to maintain and update the construction database. Most of the 4D CAD technologies do not have the project management capabilities and are used mainly for the planning and
design phase of the project. On the other hand GIS based developments can be used at any stage of the projects.

The proposed methodology supports additional studies like rate analysis, cost estimates, and allows integrating safety recommendation with critical activities, thus making the schedule more realistic. This study concludes that GIS can be a useful alternative to project scheduling tools like P3 and Microsoft Project. It allows even an inexperienced user to identify unseen problems in the CPM schedule. Nonspatial schedules can only convey what is built “when”, whereas the schedule in GIS conveys what is being built “when and where.” The major conclusion drawn from this research is that GIS based developments not only provide a construction schedule visualization tool but can also be used as a project management tool at any stage of the project in which the schedule and the 3D components can be manipulated in a single environment.

References


