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Application of GIS and GPS for Facilitating the Management in Construction Industry

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ABSTRACT

Construction work involves many uncertainties from it's starting to end. There is lot of investment in this industry all over the world. The general economy of a country has strong correlation with the rate of construction. However, success of this sector fully depends on the proper management throughout the project life cycle. GIS makes the decision of management system easier by providing spatial and attribute features together of a project. The objectives of this study were to investigate the extent of application of GIS in construction project management and find the potential areas of GIS application in that arena. In this regard, good numbers of published articles are reviewed and found that, construction progress monitoring, material procurement, construction vehicle, equipment and labor tracking, underground construction risk assessment etc. are efficiently managed by GIS. Finally, the study discover some potential research fields where GIS/GPS can also be applied for facilitating the construction management such as positioning heavy equipment (i.e. crane) at site, labor tracking during outside work at elevated level, progress monitoring by cost analysis during construction, equipment and labor productivity analysis, risk quantifying and management etc.

Table of Contents

List of Figures

1. INTRODUCTION

Geographic information system is a science of understanding the world by explaining human interaction with the Earth including analysis, modeling and prediction of future aspect in aiding decision making for proper management (Poku and Arditi 2006; and Huxhold 1991). Construction industry involves large and complex activities where huge amount of money are invested in worldwide but very prominent source of nation GDP such as 33% for Palestine, for 23% Tajikistan, 14% for UAE etc. (Faridi and Sayegh, 2006; Enshassi et al. 2008; Marat, 2009). Efficient and effective management may solve many problems of this industry specifically those have multiple projects and different types of work such as consultancy, construction and marketing. In this regard, management of basic components of construction industry such as money, manpower, material, and machine involve in individual project and overall management of the industry can facilitate by using GIS software. By developing database of the projects, progress monitoring and controlling process and proper resources management for the construction industry with the GIS software, the mentioned problem can be solved easily. In this regard, two objectives of this study are setting for sustainable, efficient and effective management system of the construction industry based on GIS are given below:

First, is GIS using for facilitating construction management? If so, what extent? The study will find the answer of the questions by reviewing the published scholarly articles from different academic journal.

Second, is there any other field of research in construction arena for effective management by using GIS? At the end of reviewing literature, the study will give some suggestions for future study of using GIS to ensure efficient management system in construction industry.

2. GIS APPLICATION IN CONSTRUCTION MANAGEMENT

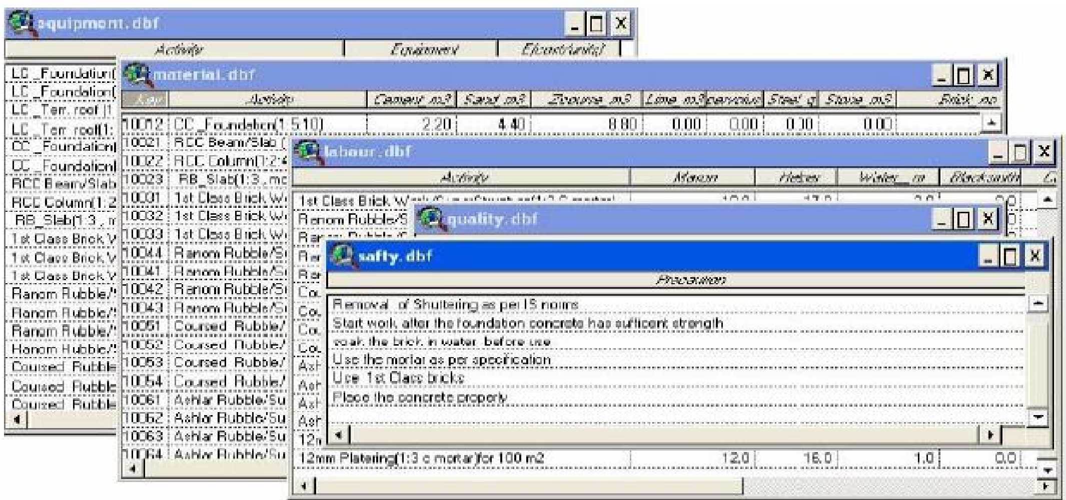
GIS is widely used in Civil engineering project such as soil investigation, construction site management, earth excavation, sub-structure, superstructure construction progress and monitoring, resources management, labor and equipment monitoring and tracking, construction safety management and monitoring of underground tunnel, pipe line, and sewage system construction etc. Oloufa et al. (1994) were used GIS for making database of soil properties for the boreholes of corresponding locations. An automatic site layout system to select suitable location for temporary structure (Cheng and O’Connor 1996) and material storage were developed (Cheng and Yang's 2001) by using GIS. In addition, GIS was used for automatic schedule monitoring system for pre-cast construction developed by Cheng and Chen (2000). GIS also used in highway construction for easy access of project personnel to the site (Udo-Inyang and Uzoije 1997) and for optimizing the road network planning to control the snow and ice effected route in Indiana Department, USA (Wright et al. 1993). Cheng et al. (2001) developed computed aided safety system in geotechnical construction with the help of GIS. Li et al. (2003) were applied GIS concept for online construction material procurement system and Li et al. (1996) also used GIS for tracking compaction process of pavement construction.

3. GIS BASED CONSTRUCTION PROJECT INFORMATION SYSTEM

GIS is a computer system for capturing, storing, quarrying, analyzing, and displaying geographic data. GIS is a special class of information system, which can be divided into four components involving a computer system, GIS software, human expert, and the data (Bansal and Pal, 2006). GIS activity can be grouped into spatial data input, attribute data management, data display, data exploration, data analysis, and GIS modeling mentioned by Clark (2001). GIS can handle both spatial and attribute data, spatial data relate to the geometry of the features, while attribute data describes the characteristics of the different features and stored in the tabular form. Each row of the table represents a feature while column represents the characteristic of features. The intersection of a column and a row show the value of particular characteristics of a feature. In the geo-relational data model, split data system is used to store spatial and attribute data in separate files and linked together by the feature Identification Descriptor (ID). These two sets of data files are synchronized so that both can be quarried, analyzed, and displayed (Chang 2002). By using the data management feature of GIS, a prototype construction project information system (CPIS) was developed in ArcViewGIS 3.2 (ArcViewGIS3.2, 1996) using a sample data set. An information system is a set of the interrelated data parts operating together to provide appropriate feedback to the decision maker in a way that entire information is available on time and when needed. The information needs of the contractor include detail of activities to be carried out, from which the types and quantities of the manpower and the amount of materials can be obtained (Paterson, 1977). Bansal and Pal (2006) developed GIS based information system where all resource data were available in tabular form. Each project in their proposed CPIS was presented in a separate table to define the activities and corresponding keys for the rate analysis purpose. Few basic features of ArcView GIS such as JOIN and LINK were also used to develop the proposed model of construction project information system. Their project systems are briefly discussed below.

3.1 Resources Database

GIS is useful software where different attribute tables can be created for storing data related to design a Construction Project Information System (CPIS). Bansal and Pal, (2006) developed CPIS for storing, maintaining, and updating resources database of construction project. Besides, separate tables were used to store the information about labor, material, equipment requirements, safety, and quality control recommendations. There is opportunity to add other information in all tables of the database to ensure expansion and update the system at later stages.



Source: Bansal and Pal, 2006

Fig-1: Resource Database Development in ArcView GIS

This option was designed in a way that only selected users such as the owner or the system developer can use it (Bansal and Pal, 2006).

3.2 Progress Monitoring and Control of Project

Before starting of construction, schedule of its different activities are prepared for achieving the target deadline of the project which is very helpful also for monitoring. It can be achieved easily with user friendly Bar chart technique developed by planner for scheduling. This bar chart can be formed by using ArcGIS guided by the activities attribute tables. In such case the activities are listed in order of construction priorities on the left hand side column, while the time scale is plotted horizontally on the bottom commented by Bansal and Pal (2006). All the cases ArcView GIS is being used for both tabular and graphical presentation. The main advantage of the ArcView's chart document over conventional bar chart is that when a bar on bar chart in ArcView is clicked, a window appears which provide the information related to that particular activity of a project (Bansal and Pal, 2006).

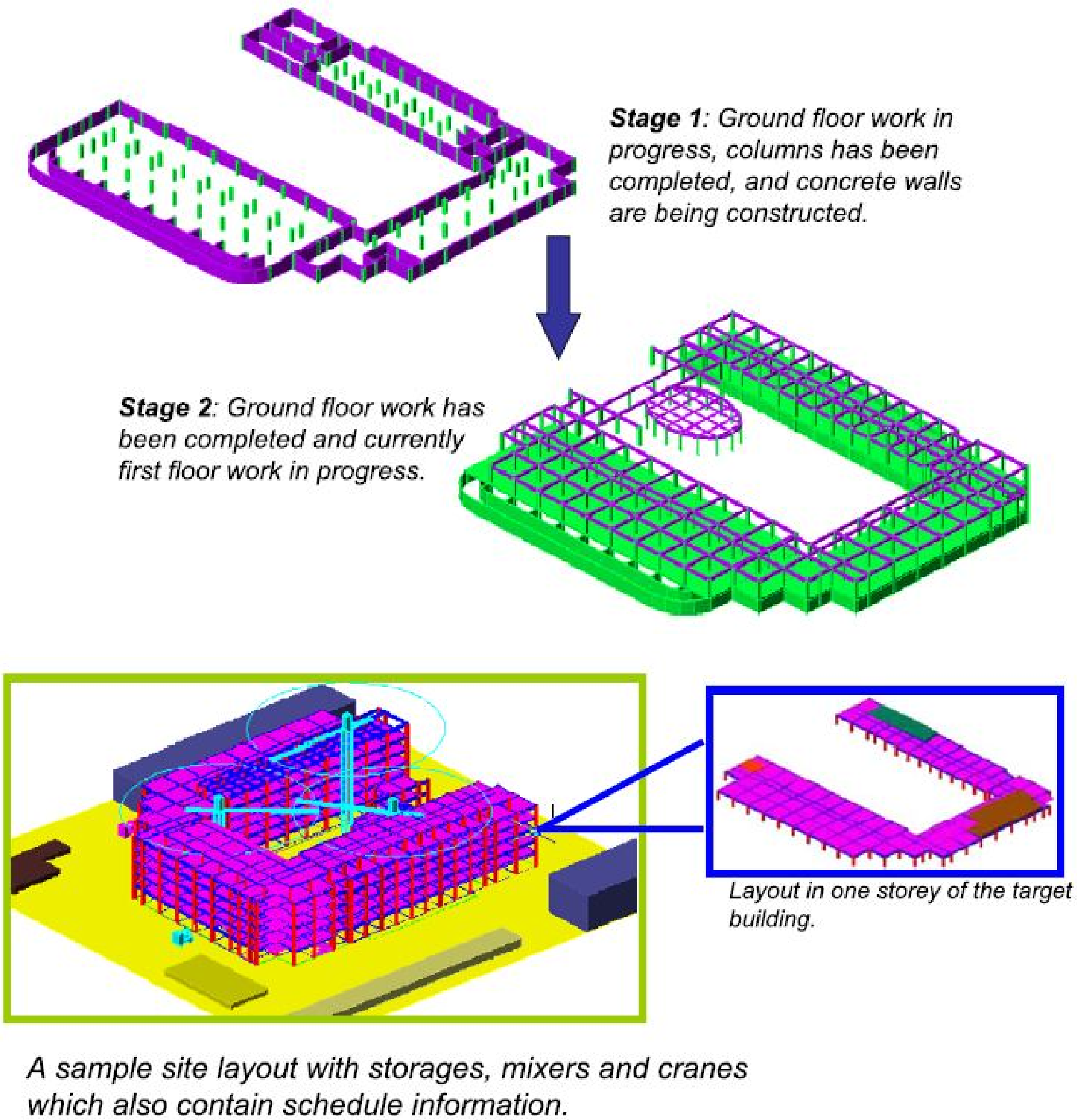
Source: Bansal and Pal, 2006

Fig-2: Schedule of Activities by Bar-chart in ArcView Chart Document

4. CONSTRUCTION SITE LAYOUT MANAGEMENT BY 4D IN GIS

4.1 4D CAD model

For large construction project, site condition is not limited in 2D static besides some equipment and materials also occupied space during construction. In addition, construction process itself is very uncertain and complicated including soil excavation, foundation, superstructure and finishing work (Zhaoyang, 2003). 3D model of a project with schedule has been proved as beneficial for construction project management which is termed as 4D management system (Cleveland, 1989). 4D planning system provides simultaneous access to design and schedule by visualization, graphical simulation of work plan and communication tool to facilitate decision making by problem identification at early stages (Williams, 1996). A construction site has space restriction for resource management like construction equipments, materials and labor. For increasing work productivity and safty in work place, efficient space management is essential which can be done by 4D management with the help of GIS. Such a 4D integrated site planning system (4D-ISPS) for construction management is developed by Zhaoyang et al. (2005). Zhaoyang et al. (2005) also mentioned that the benefits of 4D CAD system are to visualize assembling steps of construction project and simulate different scenarios before construction and help engineers for constructability analysis of design. Above figure (Fig-3) shows the 4D system of management at construction site.



Source: Zhaoyang et al. (2005)

Fig-3: 4D Site Layout Management System of a Construction Project

4.2 Limitation of 4D CAD model

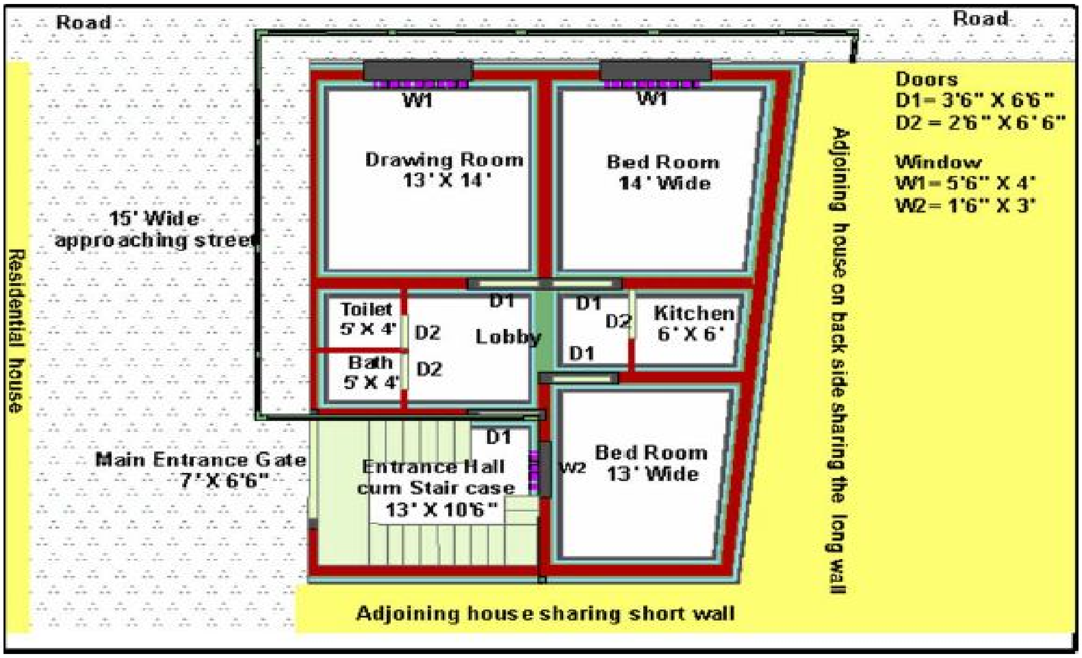
4D is a visualize tool instead of a tool for analytic use and does not support computer based analysis for cost, safety and resources management (Heesom and Mahdjoubi, 2004). It is used frequently planning, design and appraisal types of analysis rather than decision making and administering of construction process (Martinez and Halpin, 1999). 4D CAD model has single level of detail which obstructs the teamwork of subcontractor and general contractor (Poku and Arditi, 2006).

4.3 GIS application in 4D CAD model

A system called PMS-GIS (Progress Monitoring System with Geographical Information Systems) was developed by Poku and Arditi (2006) to represent construction progress not only in terms of a CPM schedule but also in terms of a graphical representation of the construction that is synchronized with the work schedule. In PMS-GIS, they executed the architectural design by using a AutoCAD, and the work schedule was generated using a project management software (P3), the design and schedule information including percent complete information were plugged into ArcViewGIS, and for every update, the system produces a CPM-generated bar chart alongside a 3D rendering of the project of the project (called 4D management) to show progress. The GIS-based system developed in that study helps to effectively communicate the schedule/progress information to the parties involved in the project, because they will be able to see in detail the spatial aspects of the project alongside the schedule. Figure-3 shows the progress monitoring system developed by Poku and Arditi (2006) where progress work of exterior wall is shown similar to that of real construction with schedule and variation of planned schedule is possible to observe for controlling the project overrun.

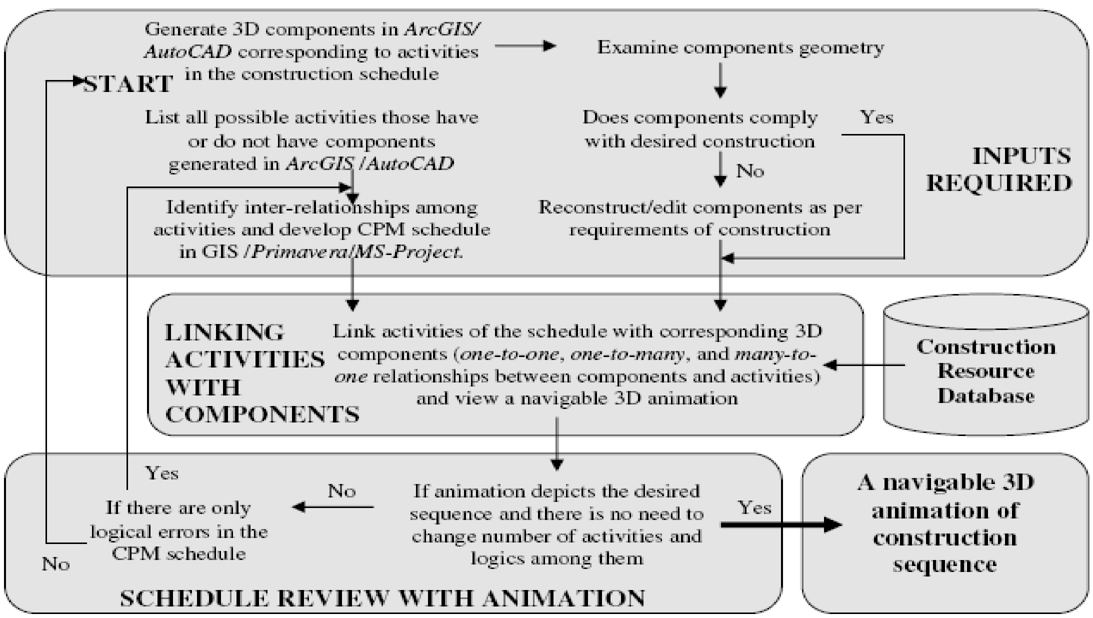
5. CONSTRUCTION SCHEDULE REVIEW BY GIS

Although integrate virtual planning was developed (Waly and Thablet, 2002) for planning the construction activities before going to real construction stages, GIS was used by Bansal and Pal (2008) for developing 3D-view of a project as well as CPM-based schedule of activities for monitoring real construction progress with its schedule which was not possible by the project management software like as *primavera.* Besides, their study created a dynamic relationship between schedule and corresponding 3D components which ensure problem detection in incompleteness or logical errors in work sequences. In this GIS based study, developed such a facility that can manage construction projects of their spatial and non-spatial data in a single platform which can only possible by introducing GIS application.



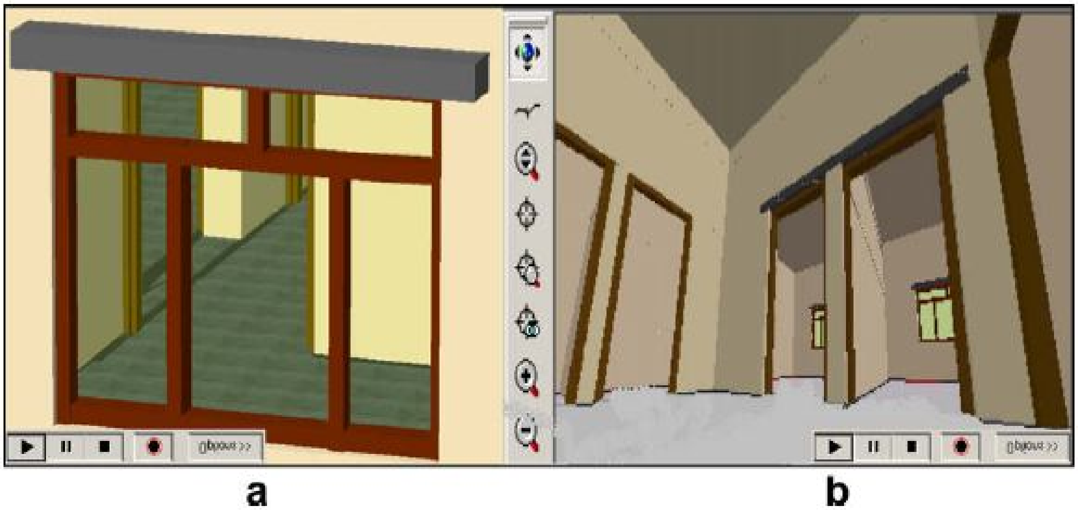
Source: Bansal and Pal (2008)

Fig-4: Floor Plan Consist of Different Data Layer in Arc GIS



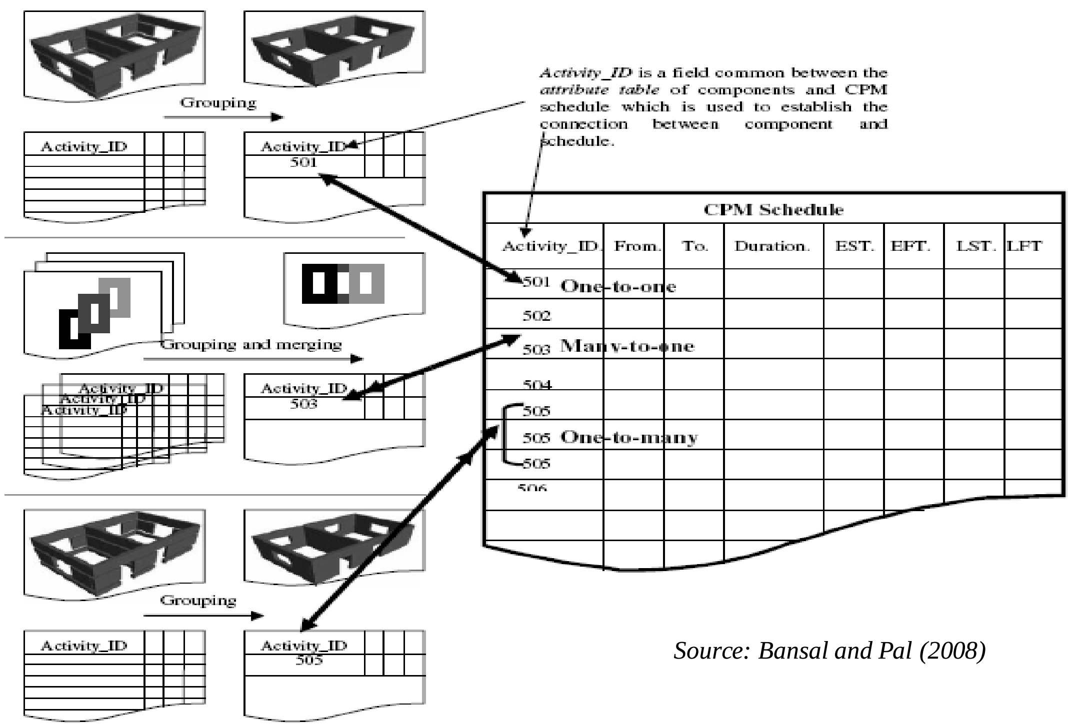
Source: Bansal and Pal (2008)

Fig-5: Animation-base Construction Schedule Review and Correction



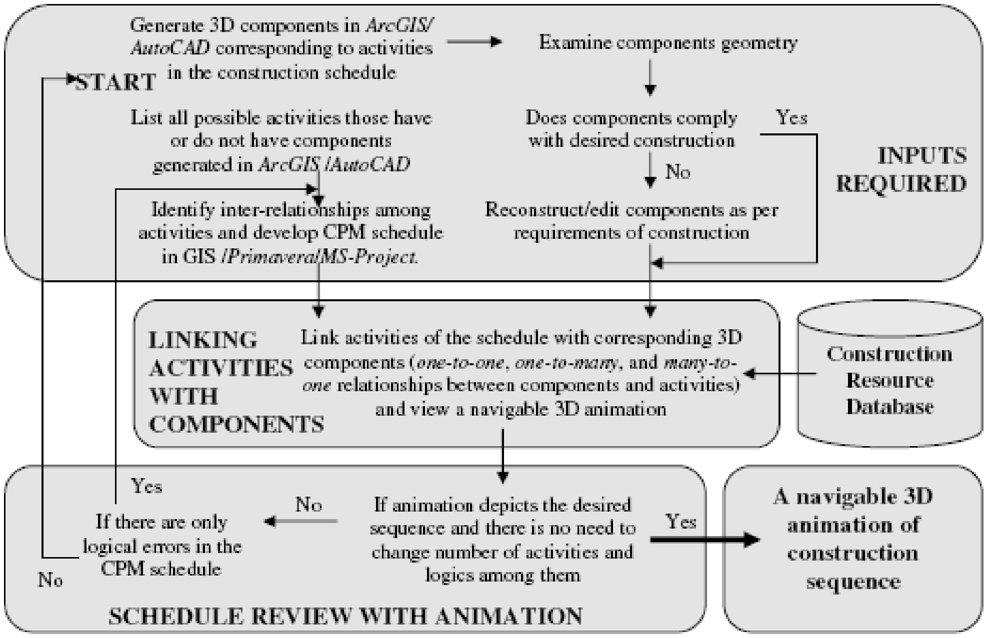
Source: Bansal and Pal (2008)

Fig-6: 3D Modeling Developed by ArcGIS



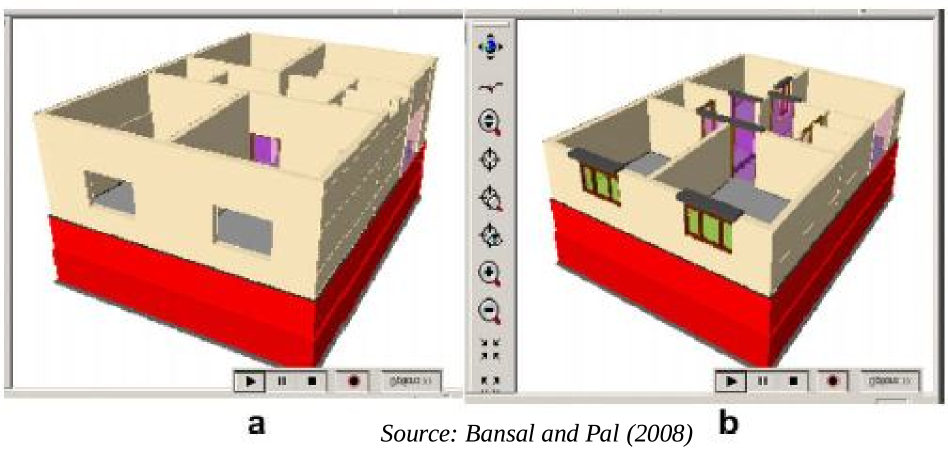
Source: Bansal and Pal (2008)

Fig-7: Relationships between Components of a 3D Model and CPM Schedule Connected Through Field Named Activity_ID.



Source: Bansal and Pal (2008)

Fig-8: Animation Based Construction Schedule Review and Correction Process.

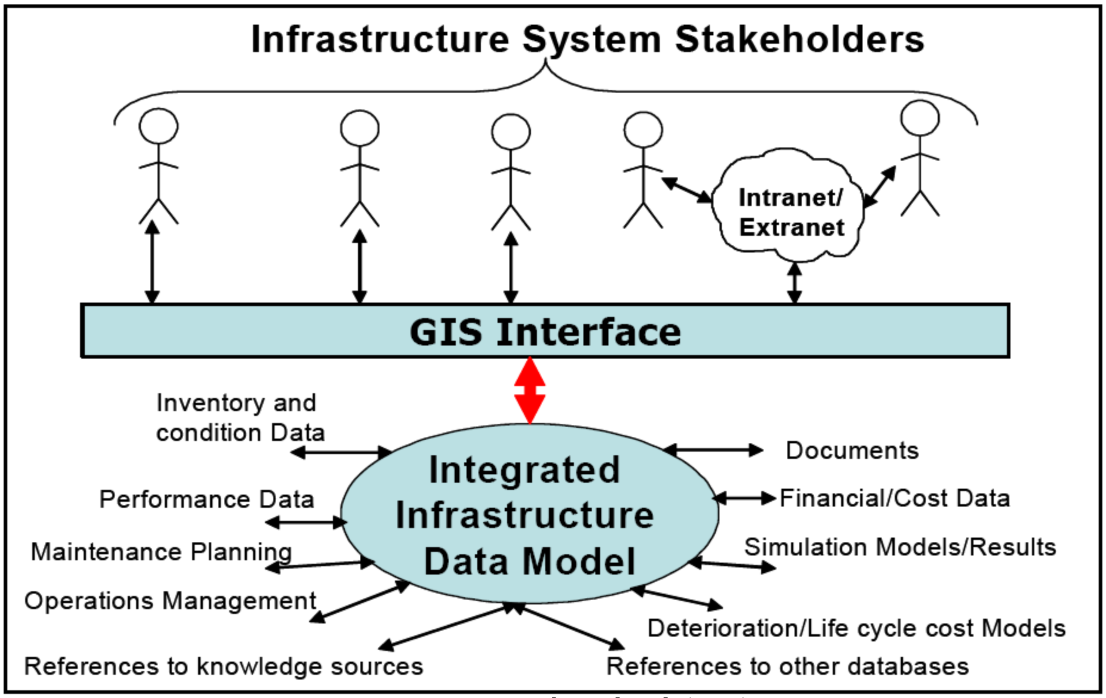


Source: Bansal and Pal (2008)

Fig-9: Complexity capturing of the CPM schedule, (a) screenshot of animation without sufficient degree of details, (b) corrected with sufficient degree of details.

6. CIVIL INFRASTRUCTURE MANAGEMENT BY GIS

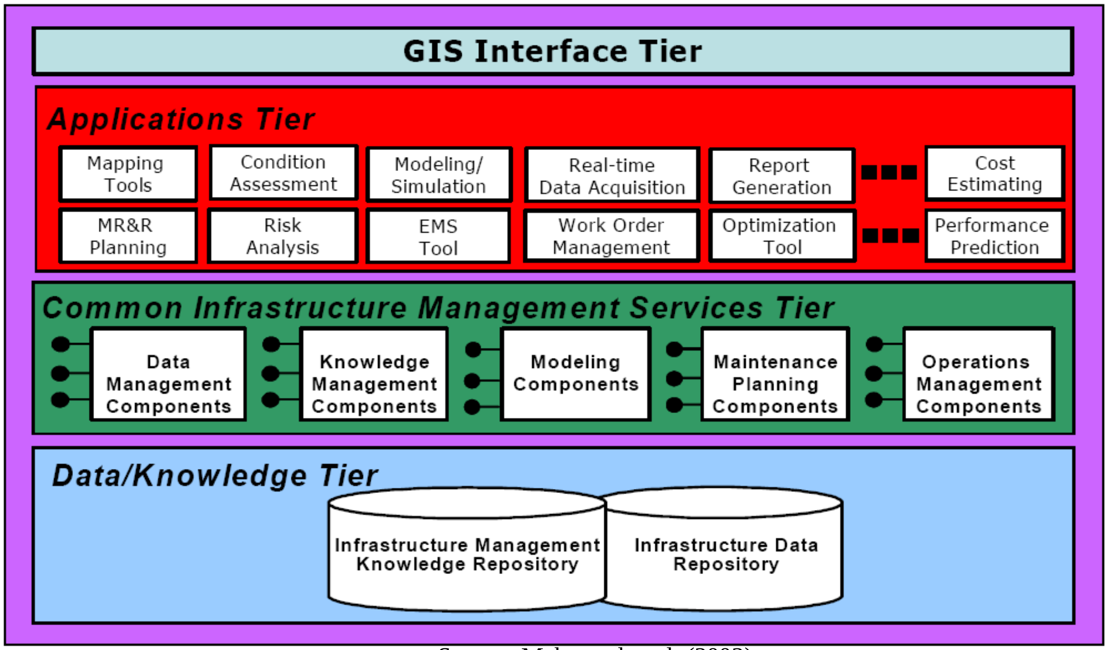
Infrastructure management to maintain acceptable performance with minimum cost is a great challenge for the infrastructure management agencies. Mahmoud et al. (2002) developed a cost effective integrated component-based framework that is enable to implement the knowledge-intensive GIS-based infrastructure management systems. The framework has four tiers such as GIS interface, applications, infrastructure management components and the data respiratory tier. The model-based management has many facilities such as it can store inventory and condition data, performance characteristics, maintenance planning, operations, cost etc. with inspection reports, maintenance records, drawing files, etc. with the help of features attributes in GIS. It provides a single point access to all infrastructure relevant information for improving communication among stakeholders mentioned by Mahmoud et al. (2002). GIS interface tier includes five main components: (1) Data management component; (2) Knowledge management component; (3) Modeling component; (4) Maintenance planning component; and (5) Operations management component. The components are show in the figure below (Mahmoud et al. 2002). The framework is shown below:



Source: Mahmoud et al. (2002)

Fig-10: Model-based Approach to Infrastructure Management

Multi-tier component-based framework is suitable to manage the complexity and variety of scope of a specific functional project (Szyperski, 1998). According to Mahmoud et al. (2002), the flow of information across various disciplines and activities for improving the availability, reliability, and consistency of infrastructure information, resulting in timely and more efficient decisions can be achieved by integrated infrastructure management systems.

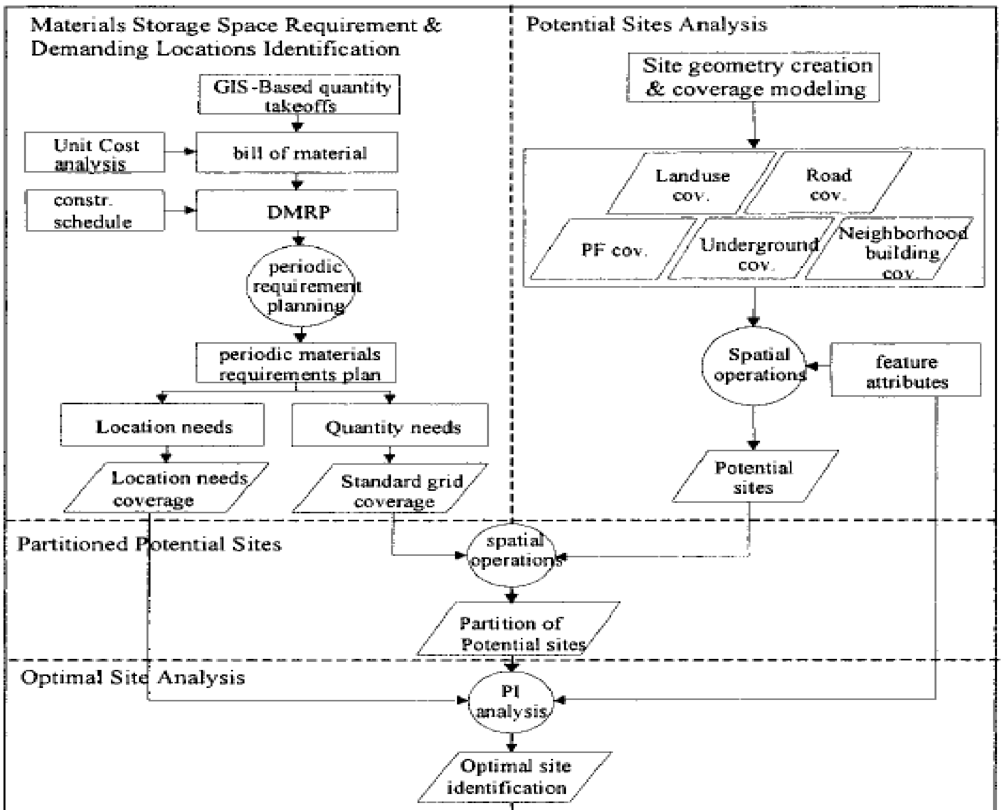


Source: Mahmoud et al. (2002)

Fig-11: Component-based Framework for Integrated Infrastructure Management

7. GIS BASED COST ESTIMATION

Cost estimation is very much essential part of construction management which require in whole life of the project from feasibility study to the end of the construction period. The success of the project fully depends on the accuracy and proper management of the project cost. GIS became helpful software to estimate the cost of a project by selecting cost effective place for material storage at construction site, such a study was done by Cheng and Yeng (2001). They used the basic concepts of GIS like spatial and attribute features to select the suitable location regarding cost for example, how much material can be stored in a parcel of location for what cost were the matter of facts in this regard. Not only that, suitable location for material storage also influence the labor productivity and hence minimize the cost of the project. Besides, Cheng and Yang (2001) developed proximity index for optimal site selection to manage cost effective space for the material storage and for this purpose they introduced MaterialPlan tool in GIS which facilitates the construction planning and schedule design. This study changed the manual process of cost estimating to automatic computer-aided process by taking quantity of material using GIS and developed dynamic material requirements plan (DMRP) which means requirements of material with respect to construction schedule progress by this way they merged quantity takeoff with schedule plan. The algorithm of the study is shown below.

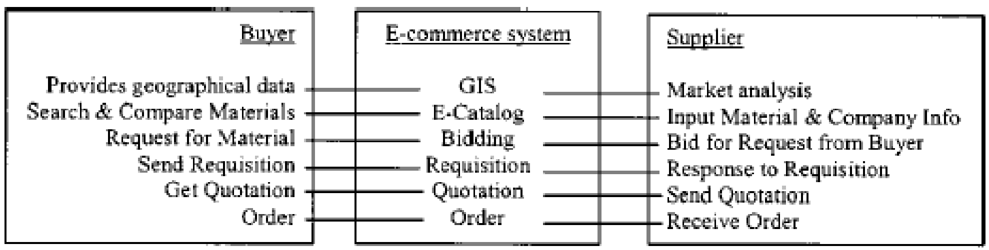


Source: Chang and Yang (2001)

Figure 12: System Design and Development Algorithm for Cost Estimation

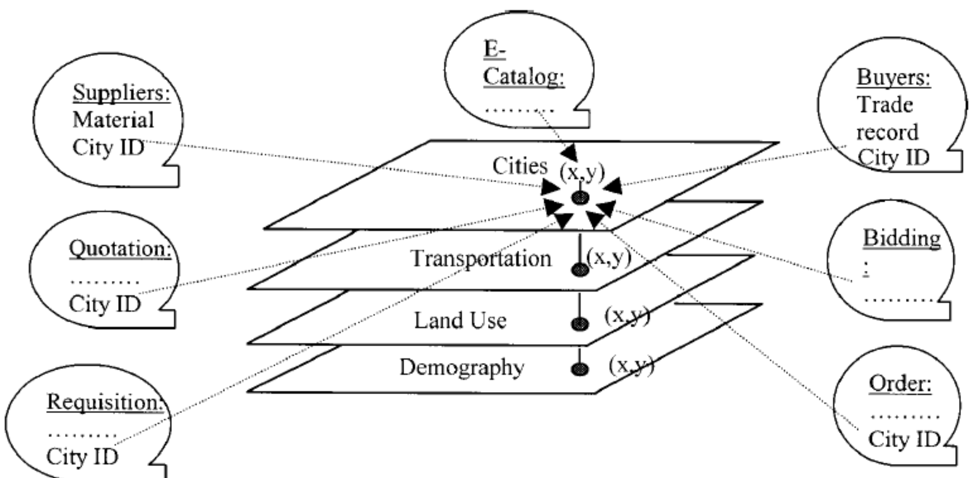
8. INTERNET GIS FOR CONSTRUCTION MATERIAL PROCUREMENT

Now-a-days GIS is proved as very important tool for e-commerce in material procurement. Cost control of any project is important and since construction project has great importance of material quantity and subsequent price, cost efficient material procurement is a great challenge for the management to make the project successful. Li et al. (2003) used GIS in E-business for construction material procurement and introduced new dimension of management. They apply internet based GIS for location based queries, business area analysis and transport facilities analysis for finding economic procurement of materials. Yang et al. (2000) found that internet based business provide the business related information in addition with effective way of goods supply. Regarding cost, finding economic way of vehicle transport for goods distribution is very important. There are four types of internet based business found by Liang and Huang (2000) such as online order and supply, off line order and supply, online order offline supply and offline order online supply. Among these Li et al. (2003) commented that offline order and supply as well as online order and offline supply are suitable for purchasing construction materials and they used Electronic Data Interchange (EDI) for making linkage between buyers and suppliers for convey order, exchange material and money electronically. This study made link of EDI with "channel partners" reduced processing and cycle time, improve accuracy and create strategic value found by Mukhopadhyay (1998). Basic e-commerce system and data integration developed by Li et al. (2003) are show below.



Source: Li et al. (2003)

Figure 13: Basic E-commerce System for Construction Material Procurement

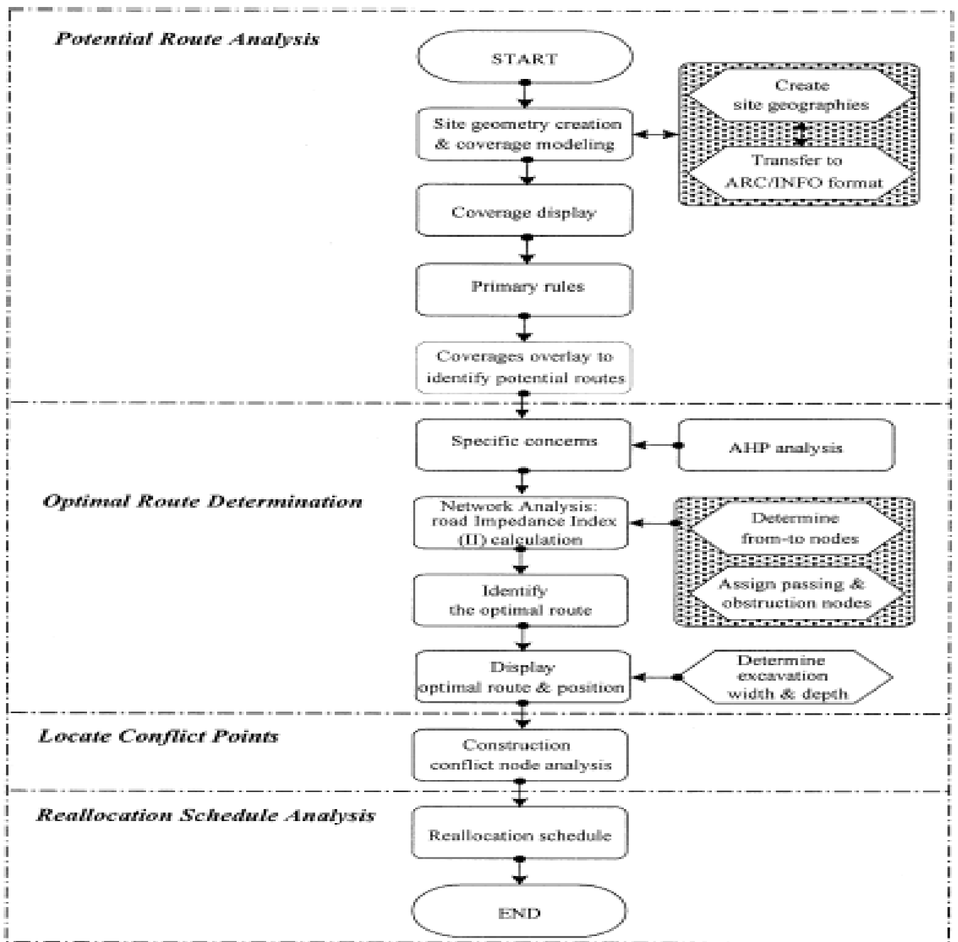


Source: Li et al. (2003)

Figure 14: Data Integration by Using GIS for Material Procurement

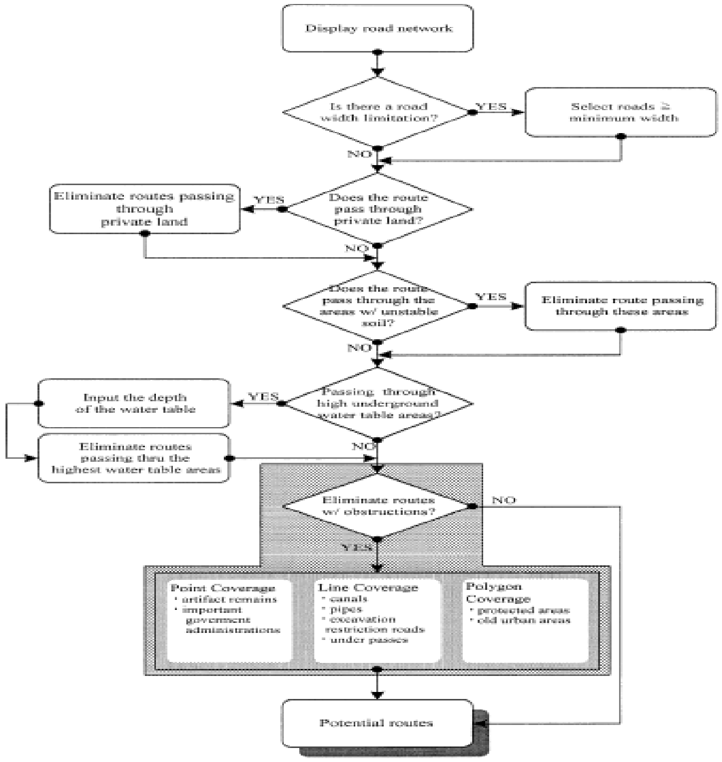
9. GIS FOR UNDERGROUND UTILITY ROUTE DESIGN AND PLANNING

It is a big challenge for engineer to find out appropriate route for minimizing construction cost and avoiding constraints in trench construction. Cheng and Chang (2001) developed GIS based automatic route selection process and facilitated utility construction. They used network analysis for optimal paths determination to select best route. Since so many existing utilities such as water supply, gas distributing, telephone, sewerage etc. are constructed in underground routes further facility construction like electric supply always create problems and damage the existing structure eventually delay the construction work. This situation creates basically, for the lack of spatial information as well as superimposing different layers manually to solve the conflicting points which is very difficult (Cheng and Chang 2001). However, GIS can provide spatial and attributes features of the locations and so many layers can be solved by GIS. The suitable route selection algorithm used by Cheng and Chang (2001) is shown below.



Source: Cheng and Chang (2001)

Figure 15: System Design and Development Algorithm

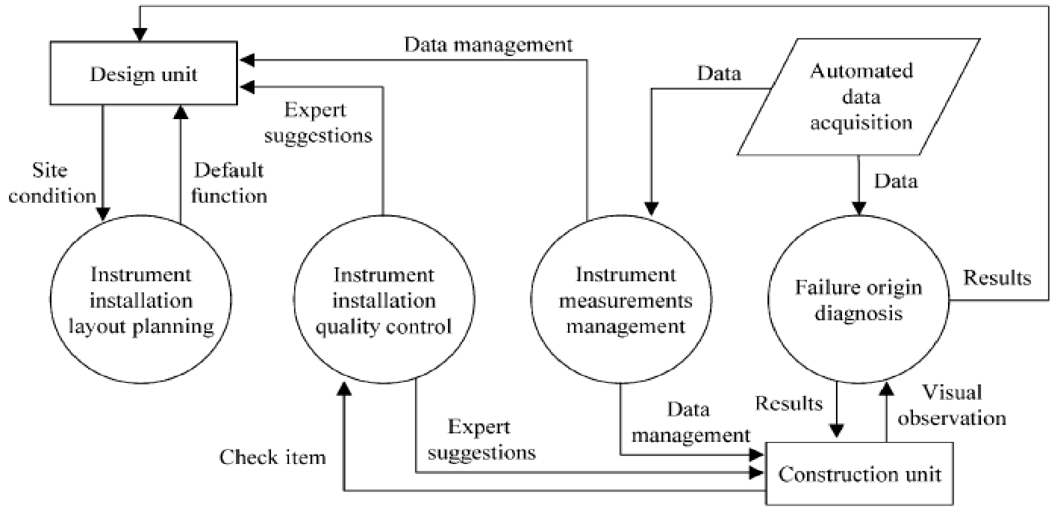


Source: Cheng and Chang (2001)

Figure 16: Potential Route Analysis

10. GIS BASED CONSTRUCTION SAFETY MONITORING

In geotechnical construction, accident control and hazard minimization is a big challenge. For deep excavation continuous monitoring is essential specifically at the sites where neighboring structure exists and the soil condition is poor. Cheng et al. (2002) developed automatic decision support system to monitor the construction progress with the help of GIS by fuzzy model for identifying adverse situations. In this study, they used automatic data transmission technology which collected from sites. Different layers in GIS showed the site layout, attribute characteristics and instruments position, then the data integrated and analysis the vulnerability to quantify the risk for protecting accident in geotechnical construction. Figure below shows the application model of failure monitoring based on GIS.

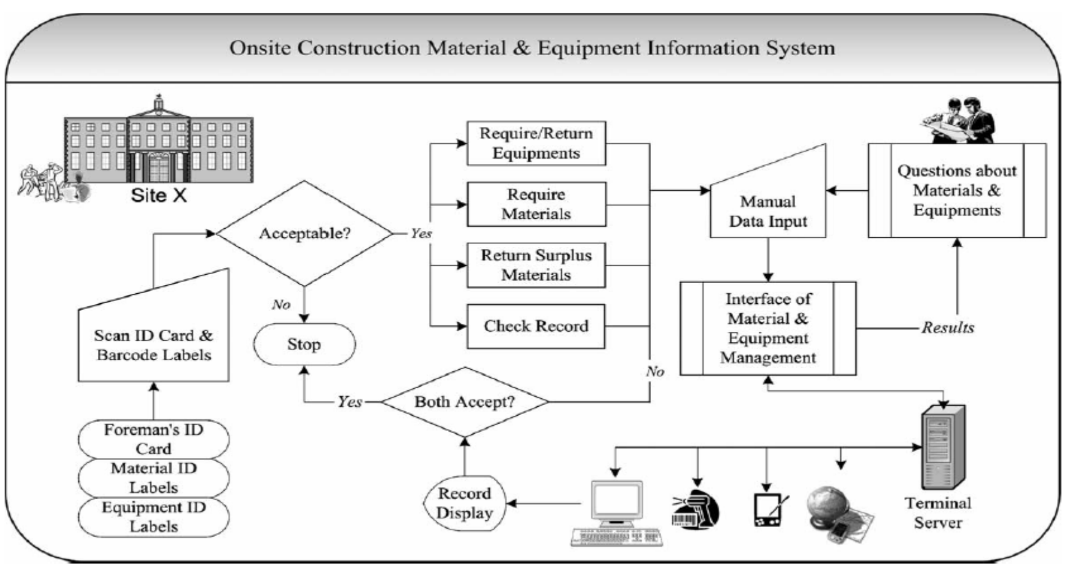


Source: Cheng et al. (2002)

Figure 17: Application Model for Instrumentation Monitoring

11. GPS AND GIS FOR INCREASING CONSTRUCTION PRODUCTIVITY

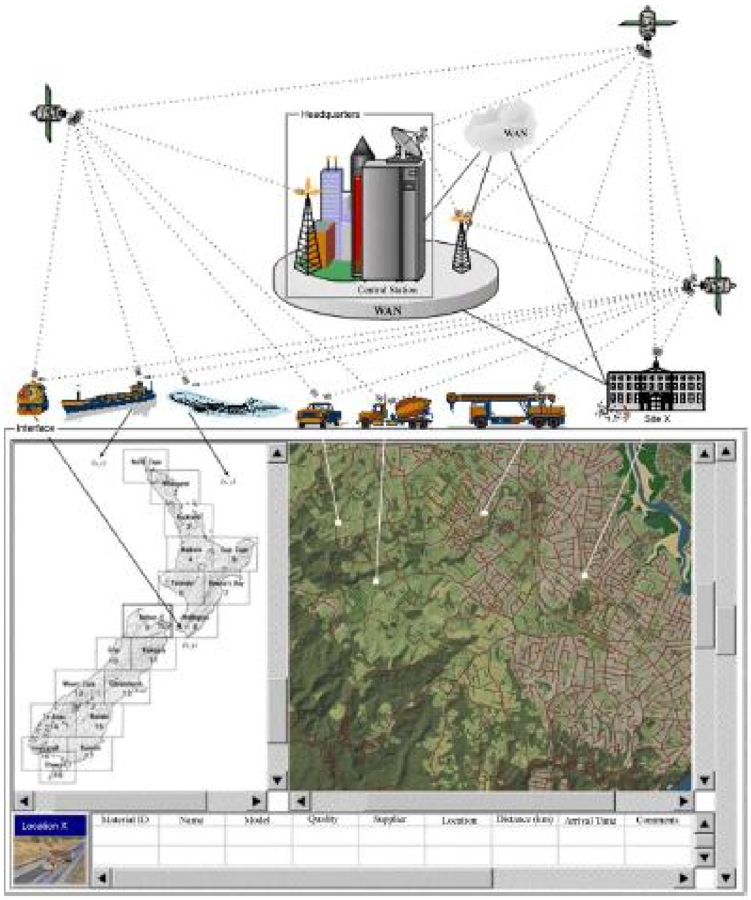
Integrated application of Global Position System (GPS) and GIS was proved as efficient automatic system for material and equipment management at construction site for reducing waste and thus increasing construction productivity by facilitating management system (Li et al. 2005). For this system, bar coding is used for tracking the equipment and vehicle enter into the site for transporting material. Following figure shows the material and equipment information system at construction site.



Source: Li et al. (2005)

Figure 18: A Conceptual Model for the Crew IRP-based Barcode System

Chen et al. (2002) developed Incentive Reward Program model for the crew by using barcode monitoring system for worker at site to reduce waste by them and giving reward for this work. However, this crew IRP was developed by worker motivation theory of Maslow et al. (1998).

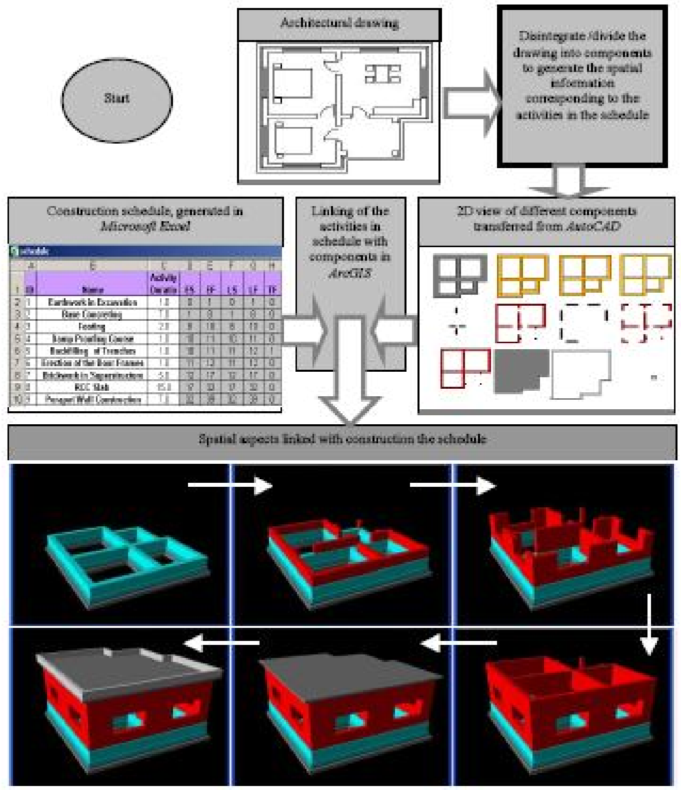


Source: Li et al. (2005)

Figure 19: A Conceptual Model of GPS-GIS based M&E Management System

12. GIS FOR TIME AND SPACE MANAGEMENT IN CONSTRUCTION

Construction schedule which is the important way of successful execution of a construction project developed by Microsoft Excel is possible to transfer into ArcGIS (Aggarwall and Bansal, 2007). Since GIS has opportunity to address both attribute and spatial features together as well as it can work together with Microsoft Excel and AutoCad by making those files as its shape files, Bansal (2007) developed a project and showing the construction progress with schedule and corresponding 3D construction for visualizing the reality to make easier for the management to understand what are happing in the site. The following figure shows the time and space relationship in construction project.

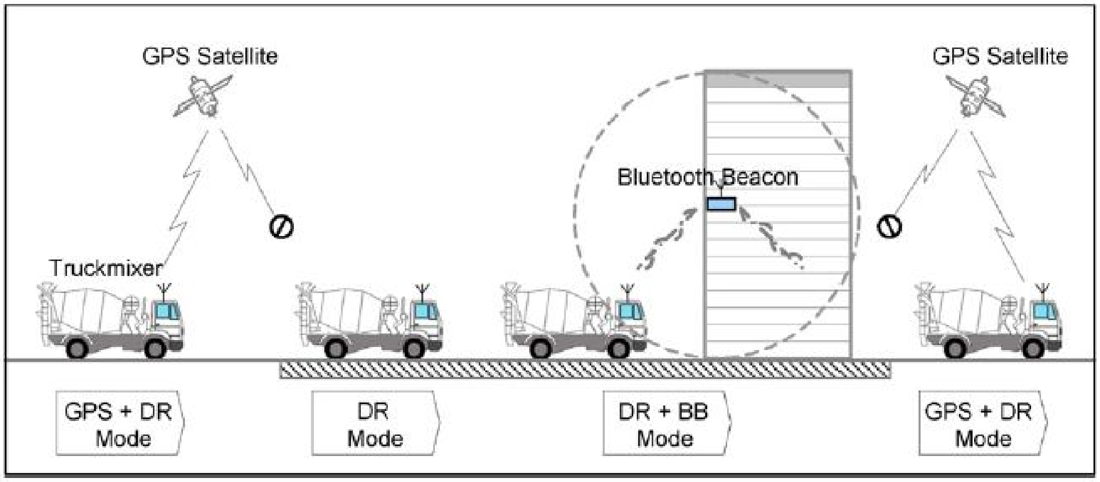


Source: Bansal (2007)

Figure 20: Linking the Time with Spatial Activities in Construction Site

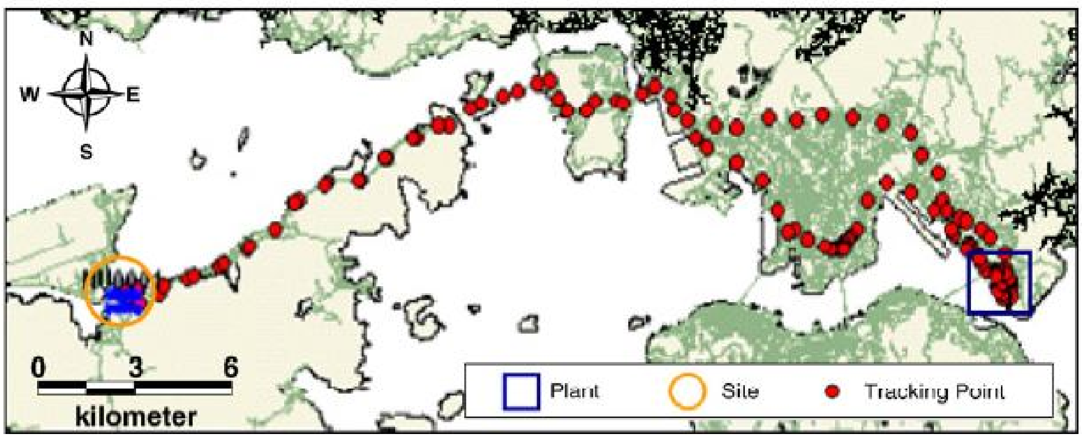
13. GPS IN POSITIONING AND TRACKING CONSTRUCTION VEHICLES

At densely populated and heavy loaded traffic conditions with other constraints like neighbor buildings and adjacent road way make serious difficulties for supplying and placing ready mix concrete by maintain its quality. Plant management need to know the travel time, vehicles productivity to concrete deliver regarding site constraints and respective urban area attributes. For concrete plant operation, concrete placing productivity is very much important. Lu et al. (2003) provided a simulation result for planning concrete production at plant and later on, quantitative analysis for concrete placing rates with its quality control was first done by Lu and Anson (2004) for facilitating the batch plant management. Anyway, arrival of concrete at right place at just time while maintaining its quality is very much important (Akintoye, 1995) that is why tracking and monitoring concrete transport vehicle obviously important task for the planner. Although GPS can collect data automatically, it has some drawback regarding accuracy at place of highly dense structured (Lu et al. 2007) area as well as tracking moving vehicle at heavy traffic loaded roadway (Mattos, 2003). This limitation little bit solved by GPS with wireless communication for tracking vehicle in open space (Oloufa et al. 2003). Lu et al. (2007) developed an integrated process of GPS, Dead Reckoning (DR), and Bluetooth Beacon for tracking and positioning construction vehicle with respect to time. Following, figure shows the integration process in details.



Source: Lu et al.. (2007)

Figure 21: Linking the Time with Spatial Activities in Construction Site



Source: Lu et al.. (2007)

Figure 22: Linking the Time with Spatial Activities in Construction Site

14. CONCLUSION AND RECOMMENDATION

From the above literature review, the study found that GIS are using in almost all areas of construction engineering and management. It makes the life of engineers and planner easier by saving time, money with ensuring quality of project and also safe the human resource from hazard. Most noticeable areas such as, 4D planning, construction space management, labor, equipment and vehicle tracking, e-commerce for material procurement which is found very efficient by GIS based management system. Besides, Radio Frequency based management (Remote Sensing GIS or GPS) are becoming prominent for ensuring position and safety management in construction industry. Although it seems to be costly, researchers have to verdict the pros and cons before extensive use of this technology in this sector.

Although there is so many applications of GIS found in construction engineering and management sector, some others application can be studied in future to accelerate the management system and subsequent success of project as the end product. For progress monitoring and controlling of the project, another method such as earn value approach can be developed with the help of GIS in incorporating with the activities and like bar chart, both tabular and graphical present would be developed for visualizing the project status i.e. how much work has been performed on the basis of what was budgeted for the work that has actually been completed. Some others potential application of GIS are resource constrains management, labor and equipment productivity, construction risk management, labor tracking at elevated work for controlling construction hazard, parties conflicts and dispute resolution etc.

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