

## SPATIAL ANALYSIS BASED HEALTH AND SAFETY RISK ASSESSMENT FOR LINEAR CONSTRUCTION PROJECTS

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### ABSTRACT:

This paper describes an on-going study that aims to develop a web-based spatial decision support system model for proactive health and safety management in linear construction projects. Currently, health and safety management is usually performed reactively instead of proactive management since hazard identification and risk assessment is mostly performed on paper based documents that are not effectively used at site. This leads to accidents and fatalities at construction sites. The proposed system automatically identifies the spatial risks according to the topographic and layout map of the site, project specification and health and safety regulations by means of spatial analysis. It enables the workers and management personnel to access the possible hazards and thematic risk map of any portion of the construction site for linear projects.

Finally, the described approach provides the proposed mitigation measures for the identified hazards. The developed system is expected to raise awareness in H&S among workers and engineers, and increase participation of workers to health and safety management.

### 1. INTRODUCTION

#### 1.1 Construction Industry, Health and Safety (H&S) and Geographical Information System (GIS)

The construction industry is statistically one of the most hazardous industries in many countries (Salminen, 1995; SGK, 2007; BLS, 2009). Besides causing fatalities, construction accidents also increase costs, cause delays and damage the reputation of the contractors (Everett and Frank, 1996). British Health and Safety Executive (HSE) have been reported that cost of accidents in construction sector has become 3-6% of total project cost (HSE, 2009).

Construction safety is one of great concern for construction industry because of ranked low in the safety standards. Failure of managing construction safety may results in injuries, financial loss, human conflicts, and penalties. Thus, construction industry needs a tool that may help them to actively integrate safety and health measure into project planning. Therefore there is a need of development of a database, which solicits project specific data from the user and provides, as output, applicable safety control recommendations (Kartam, 1997).

Complex and vast amount of information available for a construction project requires a coordinated system that may help in integrating whole information together. With the advances in the field of information technologies, construction industry has started taking the advantages of some of these developments. GIS is a relatively new branch of such technologies for managing the spatial and non-spatial data. Database is the essential part of any information system employed for construction management so the usefulness of geographical information system need to be explored (Bansal and Pal, 2005).

GIS is a computer system for capturing, storing, quarrying, analysing, 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 (Lo and Yeung, 2002). GIS activity can be grouped into spatial data input, attribute data management, data display, data exploration, data analysis, and GIS modelling (Clark, 2001).

Health and Safety (H&S) management is especially important for linear projects (e.g., pipeline or highway projects) due spatially dispersed nature of horizontally linear projects. In linear projects, the project site is not at a fixed location and multiple crews and sub-contractors perform jobs at various scattered points along a route which might be hundreds kilometres. Thus, it is a challenging task for site engineers and superintendents to follow up production closely and to identify H&S risks. There is a need for identifying H&S risks automatically at the job sites of such projects for proactive H&S management and planning.

#### 1.2 Motivation

In many construction companies, H&S departments operate on a reactive business management model due to a number of factors including minimal staff, limited budgets and an inadequate corporate safety culture (Mohamed, 2003). Lack of resources and support lead to H&S departments that can only react to unmanaged hazards/risks rather than being proactive by assessing and mitigating risks before a problem or an accident occurs.

To develop a proactive H&S management system, Saurin et al. devised a model to integrate safety into three hierarchical levels (i.e., long-term, medium-term, and short-term) of production planning (Saurin et al., 2004). In another research is a framework for a computerized safety and health knowledge

intensive system that was integrated with current critical-path-method (CPM) scheduling software (Kartam, 1997). In this framework, extensive safety data and knowledge were coded and stored in a database system which was linked to other construction management files. However, in these studies, the H&S data is hardcoded in the system and they do not dynamically use any geographic information from the site and represent it visually to the user.

Recently, GIS technology is being effectively used for route selection, feasibility studies, progress monitoring, asset management, and operation and maintenance management for linear projects (Luettinger and Thayne, 2005; Prest, et al. 2007; Zheng, 2008). Furthermore, hazard map preparation is a very common use of GIS in risk assessment in natural catastrophes such as earthquake risk assessment, hurricane impact risk assessment and environmental risk assessments such as oil spilling at the sea and fire risk assessment modelling at forestry (Sala and Vighi, 2008; Zhang et al. 2009). However, a GIS based system was not developed for use in health and safety risk assessment as a part of daily working plans in linear construction projects.

### 1.3 Problem

Currently, the H&S personnel performs risk assessment for each construction method and keeps this information attached to the method of statement that is submitted to the owner at the beginning of the project. However, usually site workers and superintendents do not use this risk assessment information at site since it is recorded on based documents which are kept in the office. Also this information is only associated with method of statement, not related with daily individual activities. This results in low awareness in H&S among workers and engineers and leads to hazards and fatalities at construction sites.

The primary objective of the paper is to develop a GIS based system for H&S planning as a part of daily work plans and effectively integrating various types of document based H&S data used in the risk assessment in GIS environment.

The following sub objectives were also achieved in developing this system by means of GIS functionality: (1) Development of the H&S database in relation with GIS environment, (2) To replace the manual methods to extract the information from the available database and (3) Integrate H&S risk assessment data with spatial data.

## 2. MATERIAL AND METHODS

### 2.1 Proposed System Model

In the first step of system design, end users need was assessed and information products were described. The information a GIS based DSS generates was described and end users need to be interviewed in order to determine what their job involve and what information they need to perform their tasks.

In the second step the scope of the system was defined and system designed. This phase was performed in three step; conceptual, logical and physical modelling. After that data design was created. In this step spatial and H&S database design were actualized. Following the data design stage system requirements determining was realized. In this stage examine the system functions and user interface needed along with the hardware and software requirements.

Briefly, users need was assessed, system scope was defined, data design was created, and system requirements were determined in design phase.

The IDEF0 model of the proposed decision support system (DSS) is given Figure 1. To create a risk map of the area, main inputs are the topographic map, site layout plan and the major obstacles identified in the project's construction site such as, other pipelines, power lines. These maps and obstacle information will be integrated to determine potential hazards and health and safety risks according to the H&S regulations and the project specifications. The final outputs of the system are the risk map that highlights the risk factors and their ratings and proposed mitigation measures to be taken at those high-risk locations (Atay et al. 2010).

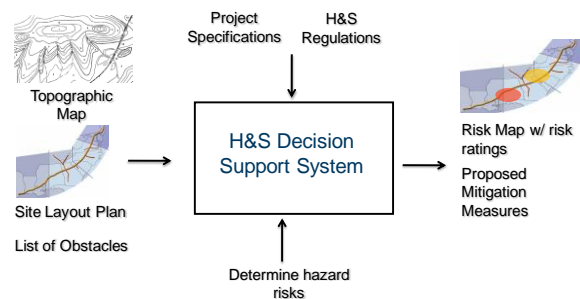


Figure1. IDEF0 model of the proposed H&S DSS

Currently most commercial Web-based decision support systems are designed around a three or higher tiered architecture. (Yeung and Hall, 2007). Therefore, GIS based H&S decision support system was developed based on n-tier web based system architecture that is shown in Figure 2.

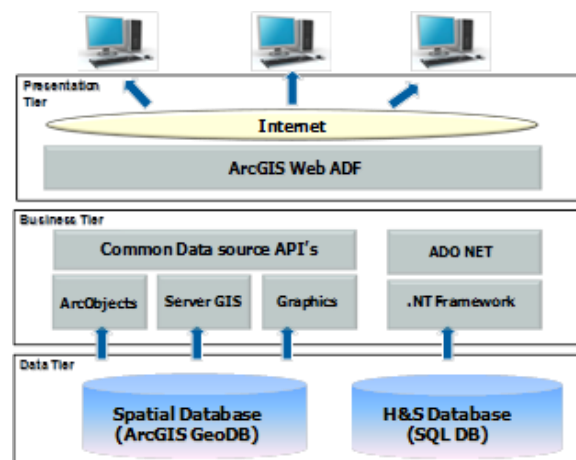


Figure2. System Architecture

Three tier models were chosen for the application which has data tier, business tier and presentation tier (Figure 2). The processes of information storing and retrieving from a database or a file system are executed at data tier. Business tier coordinates the applications, processes commands, implements reasoning mechanisms, makes logical decisions and evaluations and perform calculations. Finally, the main function of presentation tier is to visually present the results to the user.

In the developed system, data tier is composed of H&S Database and Geo-database. H&S data is stored on a MS SQL

server 2008. Furthermore, spatial data is stored as Geo-database file on ArcGIS Server 9.3.1. Spatial queries are executed by using Arc-Object API meanwhile queries that related to H&S, are performed via ADO.NET. Geo-processing, mapping, geometry and geo-data applications are realized via the arc object API at the business layer. Presentation interface is designed by using Asp.NET 3.5 on the Visual Studio 2008 development platform with ArcGIS Web ADF tools and full AJAX solutions.

## 2.2 Database Modelling

H&S and spatial databases were used independently in solution architecture of system in order to provide integration with other construction management information system.

**2.2.1 H&S Data:** It contains activity based risk assessment data. Risk assessment is an essential part of the planning stage of any H&S management system. It basically evaluates the risks involved in the execution of activities to provide the managers with information necessary to address intervention measures to comply with associated regulations.

Various risk assessment methods, which can be classified as qualitative, quantitative and semi quantitative, may be used depending on the type of risk that is being considered and availability of data about the risk (Grassi et al., 2009; Huges and Ferret, 2007; Rowlinson and Lingard, 2005). In this research study, qualitative method was selected since it is a commonly used for risk assessment in pipeline projects. This method is appropriate where the level of risk does not correspond to the cost involved in applying a more detailed analysis.

To perform a qualitative risk analysis, risk matrix method was used. In risk matrix, risks are rated according to the probability of their occurrence and their possible consequences (Table 1). Ratings can have a scale of three or five while the former is more commonly used. Probability and consequence are rated using verbal descriptors (e.g., medium-frequent probability and major severity) and cross referenced to establish the position of a risk in the matrix (e.g., 1 for low-seldom and 3 for major). These positions indicate the magnitude of the risk (e.g., 2 x 3 = 6, high priority action), which can then be used to guide the selection of appropriate risk control methods and to establish priorities for the implementation of these controls. The greater the magnitude of the risk, the more effort should be put in its control, and the more urgently risk control actions should be implemented.

Probability / Likelihood	Consequences / Severity	Risk Rate
1 - Low (seldom)	1- Slight (off work for < 3 days)	1 - No action
2 - Medium (frequently)	2 - Serious (off work for > 3 days)	2 - Low priority action
3 - High (certain or near certain)	3 - Major (death/major harm)	3-4- medium priority action
		6 - High priority action
		9 - Urgent action

Table1. Probability, consequence and risk rate values used in the risk matrix

An example of risk rating and mitigation measures is given for trenching activity in Table 2.

Hazards	Associated Risks	Risk Rate	Mitigation Measures
Unsafe access, egress and falling into excavation	Injury to personnel	4	- Ladders to be secured at the top and extended at least one meter over the top of the trench - Foreman checks the ladders and barriers at each shift. - Barrier excavations > 4 m with appropriate fencing

Table2. An example of risk rating performed for trenching activity based on the H&S standards

In the proposed system, the hazards were extracted from H&S regulations, formalized and stored in database as interoperable with the GIS system. During the formalization of the hazard data, it was identified that there are two types of hazards: (1) Hazards which have risk ratings that are independent of projects, for example, a hazard that is related to breaking down of a stone crusher has a fixed risk rating, regardless of the project and location, (2) Hazards which have risk ratings that change based on project characteristics. Hazards that are dependent on the project characteristics are also grouped into two categories: (1) Spatial hazards, which can occur if some spatial characteristics exist, (2) non-spatial hazards, which are independent of spatial characteristics.

**2.2.2 Spatial Data:** There are two fundamental approaches for representation of spatial data; vector model and raster model. In this paper study spatial analysis based H&S risk assessment study is addressed. The vector model allows us to represent specific spatial locations explicitly and provides the precise position of features in space. Based on analytical geometry, a vector model builds a complex representation using primitive objects such as points, lines and areas. The raster data model quantizes or divides space as a series of packets or units, each of which represents a limited, but defined amount of earth's surface. The raster model divides the earth into rectangular building blocks as grid cells or pixels that are filled with the measured attribute values. The location of each cell or pixel is defined by its row and column numbers. If the reasoning mechanism for identifying a spatial hazard is based on geographic objects represented by points, lines and polygons on the map (e.g., roads, underground cables), related hazard was represented in a vector model. The hazards that needs to be defined based on slope and altitude were represented in a raster model since they are associated with heights which is represented in raster data format in GIS.

In the study geometric data was generated from 1:5.000 scaled topographical maps and 1:5.000 scaled pipeline layouts which are two fundamental resources for pipeline construction projects. These data resources are shown on Figure 3. and Figure 4. With respect to HS risks, relevant to terrain, are determined by spatial terrain analysis. Therefore it is based on raster data and its derived forms like height and slope data. Derived raster data and its source shown on Figure 6.

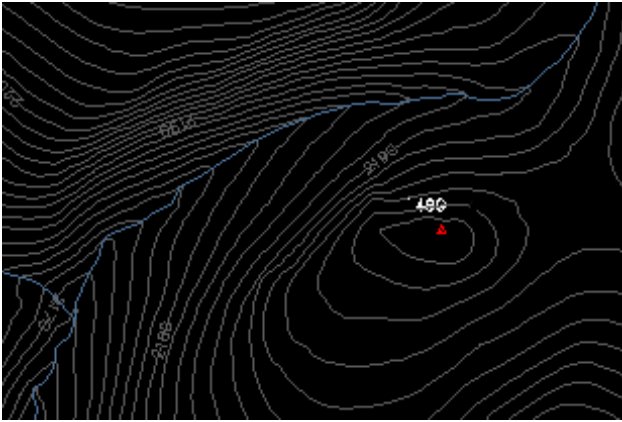


Figure3. 1:5.000 Scaled Topographical Map

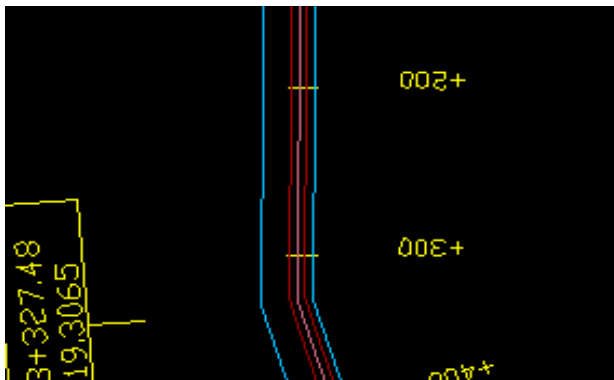


Figure4. 1:5.000 Scaled Pipeline Layouts

Obstacle lists of pipeline prepare at design stage of projects and contain information regarding spatial objects that has intersection with pipeline axis like overhead power line and underground cables. These lists have coordinates of objects, owners' information and material etc. In this research pipeline obstacle list has been used as attribute table of spatial data and is given Figure 5.

Name	KP	Easting	Northing	Elevation	Owner	Material	Type	Radius	Clearance	Voltage
NG4-014	<Null>	4090.891	8103.154	160.648	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
NG5-903	3517.16	564160.2	4602.487	129.577	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
SKG4-906	2253.5	4112.692	5855.087	196.151	DSI	BETON	Trapez	<Null>	<Null>	<Null>
NG4-015	4343.37	4451.789	3839.945	78.216	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
NG4-176	8639.48	7140.691	560.195	999.279	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
SKG4-951	13370.14	7914.221	6168.444	810.251	DSI	BETON	Trapez	<Null>	<Null>	<Null>
NG3-951	13423.95	7888.142	6121.762	809.624	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
NG2-016	13458.71	7871.51	6091.233	809.752	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
NG3-071	14698.16	7341.892	5003.781	810.968	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
NG3-952	14819.01	7371.65	4887.829	810.246	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
YBG1-001	9419.04	7531.991	9892.927	997.139	TEDAS	<Null>	<Null>	40	<Null>	<Null>
YG5-244	73.28	4149.472	7943.489	185.393	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG4-015	1149.93	4328.361	6829.714	240.688	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG4-017	2019.7	4124.534	6096.965	210.365	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG5-904	1598.5	4222.82	6495.058	242.529	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG6-905	4913.37	4712.756	3451.499	59.717	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG4-018	5030.58	4833.715	3271.469	49.301	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG6-019	5082.39	4863.535	3229.094	49.598	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>
YG6-906	7593.48	6615.043	1457.028	24.563	KHGM	<Null>	<Null>	<Null>	<Null>	<Null>

Figure5. Pipeline Obstacle List Sample

### 2.3 Reasoning Mechanism

The reasoning mechanism developed for identification of hazards automatically by the system by using project topography and layout maps, is based on automatically execution of spatial queries and spatial analysis. Furthermore reasoning mechanism for identifying a spatial hazard is based

on geographic objects represented by points, lines and polygons on the map (e.g., roads, underground cables); related hazard was represented in a vector model.

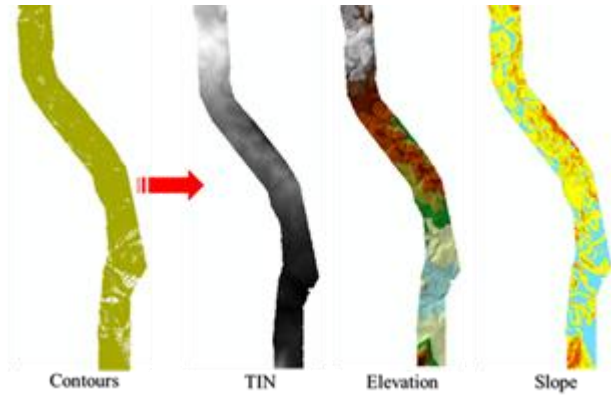


Figure6. Derived Raster Data

The hazards that needs to be defined based on slope and altitude were represented in a raster model since they are associated with heights which is represented in raster data format in GIS. Derived data shown in Figure6 is used to determine hazards relevant to terrain. Moreover used analysis methods are given below Table2.

Spatial Analysis	Functions
Linear Referencing Dynamic Segmentation	- to define working interval on pipeline,
Height Analysis	- to determine and model hazards relevant to heights (i.e. working and travelling to height etc.)
Slope Analysis	- to determine and model hazards relevant to slope (i.e. equipment using on steep slopes etc.)
Buffer Analysis	- to determine and model hazards relevant to centerline (i.e. access egress to trench etc.)

Table2. Spatial analysis and functions to be used

Regarding hazard risk assessments', whose data are stored in the system, is performed in three steps: (1) The risks ratings for project-independent hazards are entered by the system developer/H&S personnel only once as default values, and these ratings are used for all pipeline projects, (2) The risk ratings for non-spatial and project dependent hazards are entered by the H&S personnel at the beginning of each project, (3) the risk ratings for project dependent and spatial hazards are automatically identified by the system by using project topography and layout maps and presented to the user.

According to H&S DSS work flow as shown in Figure 7., once the risk ratings are created, a worker or a project engineer, can enter the location of the activity in the system (e.g., between 10-15 km) and enter the type of activity that s/he will perform in that area (e.g., trenching). The system will provide a thematic risk map where different risk ratings are shown as colour-coded areas along with the proposed mitigation measures. For instance

working near rivers and water deeper than 3 meters has drowning risks. In order to eliminate this risk, it is necessary to monitor heavy sudden rainfall that can cause sudden increase of river level and some precautions are taken near the river. System finds and highlights the rivers and water resources which are deeper than 3m on the map, and pinpoints the associated risks of hazard and mitigation measures. By using the proposed system, managers, superintendents and workers will become aware of the risks; participate in H&S activities by taking necessary measures based on the risk ratings.

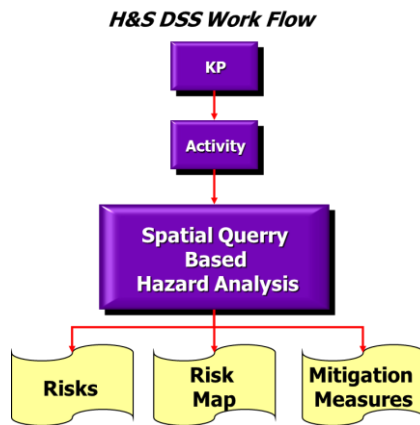


Figure7. H&S DSS Work Flow

## 2.4 Implementation

Case study was focused on 17 km of a pipeline project. It was formed by steel pipe, has 30 meters working strip and located at mountainous terrain. System was developed to produce risk map for each activity that has been performed in pipeline construction such as clearing and grading, trenching, stringing etc. H&S regulations was used in the system for implementing H&S DB these are Health and Safety at Work etc Act 1974 and Management of Health and Safety at Work regulations 1999

User selects the activity and enters working area beginning point and end point from user interface as shown on Figure8.

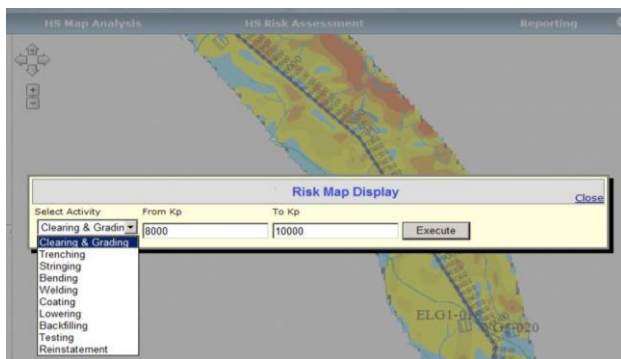


Figure8. User Interface for Information Entry

Execute the button, risk map will be shown. For example on this map hazard are highlighted by this system, based on the risk score (Figure9.).

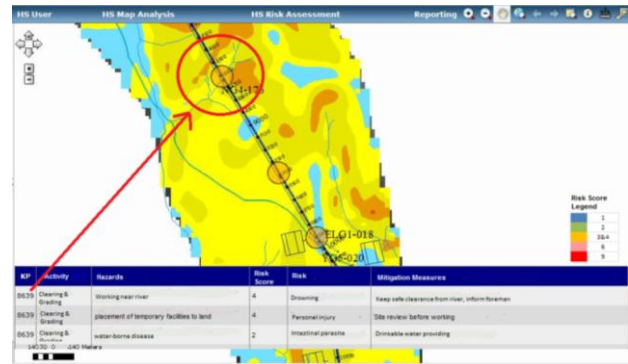


Figure9. User Interface Viewing the Hazards & Risk Map

## 3. CONCLUSION

This paper describes an on-going study that focuses on design and development of a web-based health and safety decision support system integrated with GIS for oil and gas pipeline construction projects. H&S DSS can be used for detecting potential hazards and risks, more importantly, as a warning sign for the construction activities that require immediate corrective action for mitigation. It allows the user access the H&S data efficiently for effective decision making and proactive H&S management.

The proposed system provides integration of spatial and thematic information in a single environment. Spatial data was retrieved from construction layout plans and topographic maps of the project. Geography-related hazardous work activities and mitigation measures were extracted from British Health and Safety at Work Act and Construction (Health, Safety and Welfare) Regulations and formalized. This formalized H&S data was entered to a database in GIS and represented in several data layers. Once the user input is collected for non-spatial risks, the database was queried for potential hazards and the work areas that had hazard potential and safety risks were identified. Moreover information about mitigation measures was retrieved to take necessary actions for preventing construction accidents. Besides, pinpointing potential hazards and their locations at construction site it also offers mitigation measures.

It is anticipated that the system can facilitate an effective H&S management with high level participation of employees. Since it is a web-based system, it enables remote access and control, which is important for linear projects that have a scattered nature. In the future, the developed H&S system can be integrated with construction management software.

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