© Nottingham University Press
Proceedings of the International Conference on
Computing in Civil and Building Engineering
W Tizani (Editor)

GIS based decision support system for health and safety management in linear projects

H Atay , E Ergen & G Toz
Istanbul Technical University, Turkey

Abstract

This paper describes an ongoing study that aims to develop a web-based spatial decision support system 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. 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.

Keywords: health and safety, risk map, pipeline, linear project, GIS

1 Introduction

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). 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.

Geographic information system (GIS) has a potential for identifying and highlighting geography-related H&S risks at linear construction projects. GIS is capable of linking and integrating textual and numeric data with geographic data and visually representing horizontally distributed information on a map. Different data sets from maps or lists can be extracted and analysed to automatically identify H&S risks by reasoning about geographic information such as topographic land forms and regional geology. These advantages provide great flexibility for rapidly creating maps with necessary H&S risk information for superintendents, engineers and workers at site. Recent research studies demonstrate that GIS can effectively be used for other purposes in linear projects such as for route selection, progress monitoring, etc.. However, there are not any research studies that used GIS for automatically identifying H&S risks in construction industry.

This paper describes an ongoing study that aims to develop a decision support system for proactive H&S management in linear projects. It is estimated that nearly 232.000 km. of new pipeline projects are in various stages of planning, design, engineering and construction worldwide at a cost of more than 30 billion US dollars a year (Tubb, 2009). Therefore, the paper specifically focuses on developing an H&S management approach for oil and gas pipeline construction projects. The specific goal is to assist construction engineers and superintendents in automatically identifying geography-related H&S risks at pipeline projects by using a GIS based approach.

2 Background

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.

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.

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, 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 modeling 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.

3 Proposed system

The IDEF0 model of the proposed system 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.

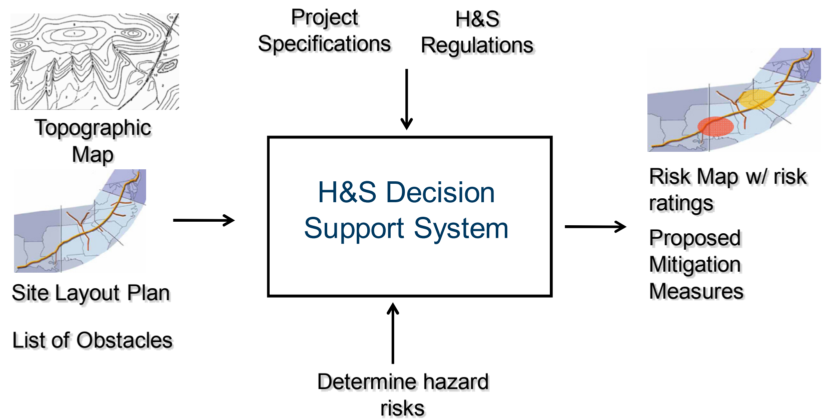

Figure 1. IDEF0 model of the proposed H&S decision support system

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

Table 1. Probability, consequence and risk rate values used in the risk matrix

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

Table 2. An example of risk rating performed for trenching activity based on the H&S standards

Hazards	Associated risks	Risk rate	Mitigation measures
Unsafe access and 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

In the proposed system, the hazards were extracted from a H&S regulation, formalized and stored in the GIS system together with associated risks and mitigation measures. 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, that are independent of spatial characteristics.

Risk assessment for the hazards that 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.

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 kms) 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.

4 Representation of spatial information

There are two fundamental approaches for representation of spatial information; vector model and raster model. 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.`

5 System development and architecture

The spatially based decision support system was developed for the 17 km section of a pipeline project which is 200 kilometres long. The steel pipe that is used in the project had a diameter of 102 cm and buried under one meter of soil. The pipeline had 30 meters working strip and was located at mountainous terrain. The risk map for this project was generated for clearing and grading, trenching, stringing, bending, welding, coating, lowering, back filling, testing and reinstatement activities.

The formalized H&S requirements were extracted from project specification and British Health and Safety at Work Act and Construction (Health, Safety and Welfare) Regulations, which are Health and Safety at Work etc Act 1974 (HASAW) and Management of Health and Safety at Work (MHSW) regulations 1999. HASAW is the main piece of legislation on occupational health and safety and MHSW was created in addition to the duties included in HASAW in the UK.

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. Three tier model was 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.

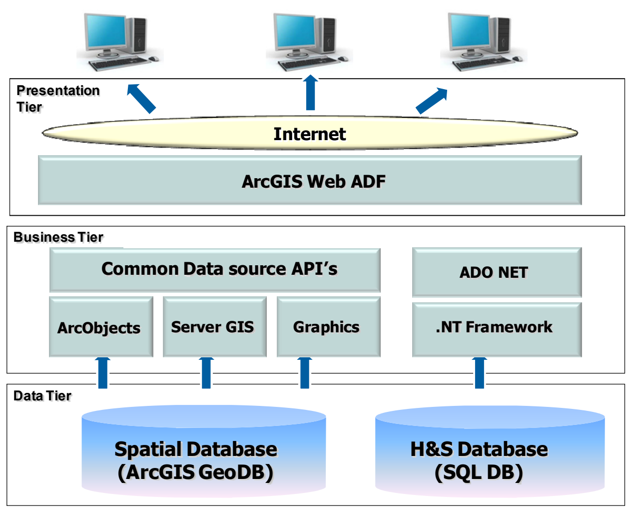

Figure 2. System architecture

In the developed system, data tier is composed of H&S Database and Geodatabase. H&S data is stored on a MS SQL server 2008. Furthermore, spatial data is stored as geodatabase file on ArcGIS Server 9.3.1. Spatial queries are executed by using arcObject 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. The system has been implemented and it is in the testing and validation stage.

6 Conclusions

This paper describes an ongoing 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 neccessary 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.

Acknowledgements

The authors would like to thank Burak Şentekin for his contributions and support.

References

BLS, U.S. Bureau of Labor Statistics, 2009. *U.S. Department of Labor*, Washington D.C, Available online: www.bls.gov, *Last accessed: December 2009*

EVERETT, J.G., FRANK, P.B., 1996. Cost of accidents and injuries to the construction industry, *J. Constr. Eng. Manag.,* ASCE 122 (2), 158–164.

GRASSI, A., GAMBERINI, R., MORA, C., RIMINI, B., 2009. A fuzzy multi-attribute model for risk evaluation in workplaces, *Safety Science Journal*, Vol.47, pp.707–716

HUGES, P., FERRET, E., 2007. *Introduction to health and safety in construction*, Butterworth Heinemann Publications, UK

KARTAM, N.A., 1997. Integrating safety and health performance into construction CPM, *J. Constr. Eng. Manag.,* ASCE 123 (2),121–126.

LUETTINGER, J., and THAYNE C., 2005. Geographic Information System-based Pipeline Route Selection Process, J. of Water Resour. Plng. and Mgmt., Volume 131, Issue 3, pp. 193-200

MOHAMED, S. 2003. Scorecard Approach to Benchmarking Organizational Safety Culture in Construction, *J. Constr. Eng. Manag.,* 129(1): 80-87.

POWER, D. J., KAPARTHI, S. 2002. Building web based spatial decision support systems, *Studies in Informatics and Control,* Vol.11, No.4, pp.291-302

PREST, R., DANIELL, T., and OSTENDORF, B., 2007 Using GIS to evaluate the impact of exclusion zones on the connection cost of wave energy to the electricity grid, Energy Policy, Vol. 35, Issue 9, pp. 4516-4528

ROWLINSON, S., LINGARD, H., 2005. *Occupational health and safety in construction project management*, Spon Press, United Kingdom.

SALA, S., VIGHI M., 2008. GIS-based procedure for site-specific risk assessment of pesticides for aquatic ecosystems, Ecotoxicology and Environmental Safety Volume 69, Issue 1, pp. 1-12

SALMINEN, S., 1995. Serious occupational accidents in the construction industry, *Constr. Manag. Econ.* 13, 299– 306.

SAURIN, T.A., FORMOSO, C.T., GUIMARAES, L.B.M., 2004. Safety and production: an integrated planning and control model, *Constr. Manag. Econ.* 22, 159– 169.

SGK, 2007. Occupational Accidents in 2006 (in Turkey), *Social Security Institution*, Ankara, Turkey.

TUBB, R., 2009. P&GJ's worldwide pipeline construction report: picture looks clear for pipeline construction through 2010, *Pipeline & Gas Journal* , January 2009, USA.

YEUNG, K.W.A., HALL, G. B., 2007. *Spatial database systems, design, implementation and project management*, Springer, Netherlands

ZHANG, J., LIANG, J., LIU, X. P., TONG, Z. H.,2009. GIS-Based Risk Assessment of Ecological Disasters in Jilin Province, Northeast China, Human and Ecological Risk Assessment: An International J., Vol.15, Issue , pp. 727 -745

ZHENG, M. B., CHEN, GUO-HUA J., GONGCHENG, S., 2008. Study on 3D simulation of gas-pipelines applying ArcGIS, Computer Engineering and Design Journal, Vol. 29, no. 7, pp. 1824-1827.