A knowledge-based approach for automating construction safety management

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ABSTRACT: Concerns about the safety of construction workers have dramatically increased in the past decade. Owners and contractors are continuously working on reducing the unusually high rate of injuries and fatalities in the construction industry. Research has shown that injury reduction is only possible by improving the way safety is managed on site. Currently, managing project safety is a reactive process that is the sole responsibility of the safety manager. The safety manager’s main objective is to ensure the contractor’s compliance with OSHA regulations. This usually involves spending long hours sifting through volumes of safety regulations to determine what apply to a given project.

To improve safety management, a more proactive approach that integrates safety with other project management functions is needed. Such approach would involve more people in the safety management process, would ensure timely availability of safety information and would utilize safety knowledge in design and in the selection of construction methods. For this proactive approach to be effective, computer based systems that effectively manage safety information are needed.

Some computer-based systems have been developed to support the safety management process. The paper initially presents a discussion of these systems to illustrate their limitations. The paper then proposes an integrated knowledge-based database management system for automating safety management. The proposed system integrates safety and schedule information thereby making safety a more integral part of the overall project planning and control cycle. The proposed system ensures timely access to safety information by associating each schedule activity with required safety actions. Such association is automatically performed by the knowledge base after the user responds to questions related to the specific job conditions and the equipment utilized. Output from the system consists of daily reports that list safety actions to be performed on a given day.

1 CONSTRUCTION SAFETY

In the early 70’s, the safety condition in the construction industry was appalling. This has led Congress to enact the Occupational Safety and Health act that established the Occupational Safety and Health Administration (OSHA) in the Department of Labor. OSHA is empowered to develop and enforce detailed safety regulations for all industries including construction. A comprehensive set of safety standards that are applicable to the construction industry was developed by OSHA in order to improve safety.

Recently, many construction companies have realized the importance of safety in their projects. These companies have discovered that safety is as much a part of effective project planning and control as are costs, schedules, procurement and quality (Barrie and Paulson...
A good company safety record reduces insurance premiums resulting in a more competitive bid price. Good safety policies that are effectively implemented improve labor productivity thereby increasing profit.

Despite recent efforts to improve safety in the construction industry, statistics show that the accident and injury rate in construction is still significantly higher than most other industries. One factor contributing to such a high rate is that construction includes different activities that require different safety precautions (Oglesby et al. 1989). Although as discussed above, a comprehensive set of safety standards and regulations for most construction activities, was developed by OSHA, many of these standards are vague and ambiguous, and inconsistently categorized. Determining what regulations apply to a given project usually involves spending long hours sifting through volumes of safety regulations.

What construction managers really need is timely and quick access to specific information to protect employees from the hazards associated with materials, equipment and procedures they work with daily. Such timely and quick access to safety information can be achieved through the use of computers. For this reason, several computer-based systems have been developed to support the safety management process. The following section presents a discussion of these systems to illustrate their limitations. The paper then proposes an integrated knowledge-based database management system for automating safety management. The proposed system integrates safety and schedule information thereby making safety a more integral part of the overall project planning and control cycle. The system provides ready reference material to the field engineer for day to day operations and eliminates the need to refer to OSHA safety books for normal construction activities.

2 KBS APPLICATIONS FOR SAFETY MANAGEMENT

A Knowledge based system (KBS), also called expert system is a computer program that emulates the problem solving process used by human experts. A KBS contains the knowledge, experience, and judgment of experts and is well suited to solving problems where judgment and experience play an important role (Bell and Elzarka 1992). At the University of Cincinnati, a wide range of KBS applications have been developed to support the safety management process. Applications have been developed to assist the construction manager to plan and safely execute earthwork, reduce environmental hazards, recommend appropriate personal protective and life saving equipment, and prevent fall accidents (Kak et al. 1995, Minkarah et al. 1996). OSHA safety regulations were incorporated into these systems.

The applications mentioned above recommend safety regulations for a given project based on project specific information. However they are stand-alone applications that do not integrate safety with other project management activities. Because of this, safety recommendations produced by these applications, though complete, might not be disseminated to project participants at the right time. Also in these applications, only OSHA regulations were modeled in the knowledge base. Safety knowledge and experience gained by the company’s personnel is not utilized in an organized and efficient manner. From the above discussion, it is clear that the biggest limitations of current computerized safety management systems are the inability to provide timely access to safety information, and to retrieve safety knowledge gained in previous projects.

2.1 Timely access to safety information

Timely access to safety information is an important part of the safety management process; Construction managers (CM) need to know what safety precautions are required before the start of construction activities. Early access to data will enable the CM to make informed decisions when it has the most benefit. Thus, the safety management system should not only provide a mechanism for retrieving safety regulation, but should also ensure that the data are
retrieved when actually needed. If safety regulations are not disseminated when required, dangerous and fatal accidents can occur.

Timely access to safety information can be ensured by integrating safety management with the construction schedule. Such integration will provide the construction manager with a scheduled list of safety actions that need to be performed on a given date without overwhelming him/her with massive quantities of safety information required for the entire project.

2.2 Learning from previous experiences

Although all construction projects are unique, many operations and processes are common to every project, and require the same safety regulations. An effective safety management system should recognize this and should enable its users to share knowledge among projects. Sharing of knowledge and experience from past projects will improve the performance of the management system through continuous learning.

For the continuous learning to occur, a safety management system should be capable of storing the safety data and knowledge gained in previous projects for future access. This will create a knowledge base of all company projects in a central location and will facilitate the transfer of knowledge from old projects to current ones. Such a system also makes the implementation of company rules and regulations uniform across all construction projects of the firm.

The discussion above illustrates that the effectiveness of safety management systems can be improved by ensuring timely access to safety information and enhancing the learning mode of the safety knowledge base. To demonstrate the importance of these attributes, an integrated construction safety schedule (CSS) knowledge-based system was developed. CSS captures safety knowledge from previous projects into the knowledge base and enables the generation of daily reports of required safety regulations that can be printed out and distributed to managers and foremen. The safety management process is greatly simplified and the time that the safety manager spends on sifting through OSHA regulations is greatly reduced allowing him/her to focus more on the important task of ensuring compliance with these regulations.

3 SELECTION OF SOFTWARE DEVELOPMENT TOOLS

CSS consists of two main components: an executable file and a database. The executable file was developed using Microsoft Visual Basic. The database was created using Microsoft Access and is stored separately from the executable file.

Microsoft Visual Basic was selected as the software development tool because it is a mature product that can be used to rapidly develop Windows-based applications. Microsoft Visual Basic is an object-oriented visual development programming environment that makes extensive use of intuitive visual objects, instead of code, to speed development. It has several graphical form capabilities. These forms collect user input through a variety of mechanisms including fields, graphical controls, and scrollable lists. Visual Basic applies several object-oriented techniques to its visual objects. Each object has a set of attributes that control the appearance of the object during the program execution. Examples of these attributes include location, size, font and data type (i.e. string, number, etc.) of the objects.

Each object has its own script that contains a code defining all events associated with the object and the actions to be performed when an event occurs. For example, a script for a field object may contain a code associated with the “Click Field” event. This code is executed when the user clicks on a field. The code can contain either functions that control the graphical user interface (GUI) or control access to the database. GUI functions are used to perform various tasks such as displaying a message, drawing a control, and/or activating a new form.
The Visual Basic event-driven development environment facilitates creating a well-structured application and makes debugging the application much easier. It is more convenient to go directly to the code that is associated with a particular event (Elzarka and Bell 1997).

4 SYSTEM DESCRIPTION

As illustrated in Figure 1, the integrated safety scheduling management process starts with a construction schedule generated by a scheduling software. The schedule should contain the description of all activities, their start dates and end dates. The schedule can be either entered using one of CSS screens (Figure 2) or can be read directly from a file.

Figure 1 also shows that the knowledge base is the central repository of all safety knowledge and is created using Microsoft Access. The knowledge base is divided into two main components: OSHA knowledge base, and company knowledge base.

The OSHA knowledge base contains OSHA safety regulations. The “Occupational Safety and Health Standards for the Construction Industry (29 CFR Part 1926)” promulgated by the Occupational Safety and Health Administration (OSHA) was the basic source for knowledge acquisition. Safety regulations in the OSHA knowledge base are organized by construction
activity (i.e. excavation, steel erection, etc.). Each regulation is presented in a long format and a short format. The long format exactly matches OSHA wordings, while the short format is a one line summary of required safety actions. At the end of the knowledge base consultation, the user is capable of printing the recommended safety actions report in either the short or long format. This capability adds more flexibility for the construction manager in case he/she wants to print safety reports in simpler, easier to understand language. An example of a typical OSHA safety regulation for an excavation with close proximity to existing structures is given in Figure 3.

The company historical knowledge base contains safety actions that have been successfully implemented on previous projects. This portion of the knowledge base allows the construction manager to use the successful experience of other managers from the company that might not necessarily be part of the OSHA regulations. The information in this knowledge base is proprietary in nature and contains the collective experience of all personnel of the company. The use of a central knowledge-base enables the transfer of safety recommendations from old projects to new ones.

![CSS Project scheduling screen](image)

Figure 2- CSS Project scheduling screen

The knowledge in both knowledge bases is modeled in the form of production rules that are expressed in an IF-THEN format. An example of a CSS consultation screen is illustrated in Figure 4. During the consultation, the user is asked to enter project specific information. In Figure 4, for example, the user is prompted to answer several questions regarding the excavation activity. If the user thinks that the excavation activity of the current project is similar to that of a previous project, he/she can press the “Suggest” button located at the bottom of the screen. This will list all previous projects stored in the company’s historical knowledge base. The user can then select a comparable project and all safety actions performed on this project will be recommended for the new project.

At the end of the consultation, as illustrated in Figure 5, the user can enter a specific date for which a safety action report is to be generated. CSS compares the user provided date with the start date of all project activities to determine which safety actions need to be performed right away. These actions are listed in the “To Do” list (the middle box of Figure 5). The construction manager should review all listed safety actions in the “To Do” list. If some of these actions have already been implemented, he/she can change the status of these actions to “Done” by simply double clicking on the action. This will send the action to the “Done” list.
(the upper box of Figure 5). The system also informs the user of any actions that need to occur in the near future. Those are listed in the “Future” List box (the lower box of Figure 5). The text contained in any of these boxes can be copied to any windows based word-processing software where it can be reformatted (if necessary) and printed.

SAFETY ACTIONS NEEDED FOR AN EXCAVATION WITH CLOSE PROXIMITY TO EXISTING STRUCTURES.

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(1) Where the stability of adjoining buildings, walls, or other structures is endangered by excavation operations, support systems such as shoring, bracing, or underpinning shall be provided to ensure the stability of such structures for the protection of employees.

(2) Excavation below the level of the base or footing of any foundation or retaining wall that could be reasonably expected to pose a hazard to employees shall not be permitted except when:

(i) A support system, such as underpinning, is provided to ensure the safety of employees and the stability of the structure; or
(ii) The excavation is in stable rock; or
(iii) A registered professional engineer has approved the determination that the structure is sufficiently removed from the excavation so as to be unaffected by the excavation activity; or
(iv) A registered professional engineer has approved the determination that such excavation work will not pose a hazard to employees.

(3) Sidewalks, pavements and appurtenant structure shall not be undermined unless a support system or another method of protection is provided to protect employees from the possible collapse of such structures.

Figure 3. Example of safety recommendations included in the knowledge base

Figure 4. CSS Consultation screen
5 CSS EVALUATION AND FUTURE WORK

CSS was tested and evaluated at two construction sites for the purpose of obtaining subjective information on the benefits associated with the development of an integrated safety and schedule knowledge based system. Feedback from the reviewers indicated that the integrated approach has potential when applied to safety management. Integration of safety and schedule simplifies the safety management process by making safety information accessible when needed and utilizing safety knowledge from historical projects. The reviewers have indicated that the importance of safety and schedule integration becomes more obvious in complex and unique projects where construction managers are not very familiar with required safety precautions.

In its current form, CSS is a stand-alone application that runs on a Pentium personal computer. The personal computer was chosen because of its widespread use and relatively low cost. CSS can be easily expanded in the future. One of the important benefits of using production rules in knowledge representation is that it can be easily expanded and modified. It is easy to add more rules to handle situations not originally contemplated and to modify the knowledge to account for changes in OSHA and/or company safety requirements (Elzarka et al. 1995). This evolutionary improvement is characteristic of knowledge based systems. If many domain experts contribute their knowledge to the system, the knowledge base over time may become more knowledgeable and capable of problem solving than any one of the experts who contributed to its development.

Figure 5. CSS Output screen

6 CONCLUSIONS

Current computerized safety management systems can be enhanced by creating interface links to scheduling systems and by adding knowledge based modules that capture safety knowledge
and experience gained from previous projects. This paper discussed several capabilities that can enhance computerized safety management systems. The paper also presented a prototype system CSS that was developed to establish the feasibility of incorporating the above mentioned capabilities in current systems. Evaluation of CSS has indicated that the system is an inexpensive tool to improve the existing safety program of any construction organization, provide timely safety standards/regulations, and promote safety awareness among workers. The CSS development process has also illustrated that current Windows software development tools are sufficiently advanced to rapidly create integrated construction management systems.

REFERENCES