INTEGRATING SAFETY AND HEALTH PERFORMANCE INTO CONSTRUCTION CPM

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ABSTRACT: Construction accidents cause many human tragedies, demotivate construction workers, disrupt construction processes, delay progress, and adversely affect the cost, productivity, and reputation of the construction industry. Therefore, use of effective planning and control techniques to prevent them can have a significant human, social, and financial impact. This paper develops a framework for a computerized safety and health knowledge-intensive system that has been implemented and integrated with current critical path method (CPM) scheduling software. A discussion of current industry problems is initially presented to verify the need and approach taken. The purpose and rationale for a knowledge-intensive integrated system is presented to show how the development of such a system will improve on current industry practice. Next, the design and implementation of the system called IKIS-Safety—integrated knowledge-intensive prototype system for construction safety and health performance control—is described. Finally, the paper highlights the contributions and benefits of such a prototype system.

PROBLEM

The U.S. Department of Labor, Bureau of Labor Statistics, reports an average of one death and 167 injuries per $100,000,000 of annual construction spending. Based on *Business Roundtable Report A-3* (Construction 1982), the total cost of these accidents totaled $8.9 billion or 6.5% of the $137 billion spent annually by users of industrial, utility, and commercial construction.

The construction industry is statistically one of the most hazardous occupations in this country, and ranks low in safety performance among the industrialized countries of the world. One out of every six construction workers can expect to be injured each year, at an average cost of $18,000. This staggering number translates to more than 2,000 deaths and 200,000 disabling injuries each year (Hinze 1993), a number that far exceeds many other causes of death.

Death rates today for construction workers in the United States appear to be substantially higher than in the Netherlands, Sweden, and Ontario, Canada. Since 1970, construction fatalities have been reduced by 75% in Sweden; since 1965 construction fatalities have been reduced by 83% in Ontario (Center 1993). Another statistic that indicates poor performance in construction safety is that construction employment constitutes less than 6% of the U.S. labor force but accounts for 20% of the fatalities and 11% of the disabling injuries (Hinze 1993) (see Fig. 1).

Owners, contractors, and regulatory agencies are obligated to help provide a safe work environment to minimize injuries. The owner cannot take a hands-off approach towards safety because construction activities take place on the owner's property. The owner needs an effective means by which to monitor and control safety during construction and to assess safety plans as criteria for selecting a contractor.

Contractors also need a tool by which to actively integrate safety and health measures into project planning. Construction is an industry that presents hazardous situations, but most accidents are the result of unsafe acts. Unsafe acts are the main factor in 50% of construction accidents, and a contributing factor in 85% of construction accidents (Preziosi 1989). The Occupational Safety and Health Administration (OSHA) reports 75% of all cited violations are caused from noncompliance with 25 OSHA standards. Penalties for a willful violation can range from a minimum penalty of $5,000–$70,000. These figures do not even account for multiple citations that OSHA can issue to different responsible parties for a single violation.

In addition to penalties, a current proposed modification to ANSI A10.33 has become a bill in Washington, D.C. This bill requires certain construction projects to include mandatory minimum safety and health activities and requirements. The passing of this bill will require more extensive planning, training, design, and activity sequencing to be performed by the contractor.

Project safety is a process in the construction industry, which is, for the most part, managed reactively and is the sole responsibility of the contractor (Hinze and Wiegand 1992). Schedule, cost, production, and quality control, on the other hand, are managed with well-thought-out computerized plans and controls at all levels of responsibility. "Today, safety and health professionals realize that what is really needed is "built-in," "integrated" safety, and not some artificially introduced program. Safety must be an integral part of the company's procedures" (Stanton and Willenbrock 1990).

In construction safety, some computer-based systems have been developed with a limited focus on the owner attempting to evaluate a contractor safety performance or a firm safety program (Levitt and Kartam 1990). Such programs have been

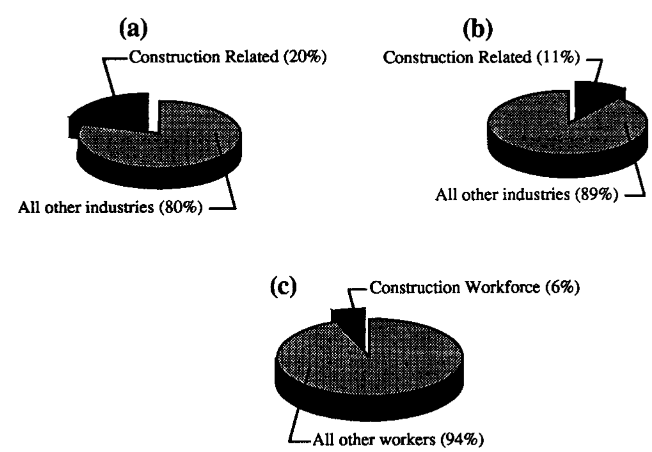

FIG. 1. Construction Industry—Percent of: (1) Fatalities (Compared to other U.S. Industries); Disabling Injuries (Compared to Total Injuries); (c) Workforce (Compared to Total U.S. Workforce)

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Note. Discussion open until November 1, 1997. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on October 26, 1995. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 123, No. 2, June, 1997. ©ASCE, ISSN 0733-9364/97/0002-0121–0126/$4.00 + $.50 per page. Paper No. 7244.

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implemented as simple decision-making tools using expert system shells running on PC-based computers.

RESEARCH OBJECTIVES

This paper presents IKIS-Safety—integrated knowledge-intensive system for construction safety and health performance control—a proactive safety environment that integrates safety and health issues into all phases of a construction project from design and planning through construction and start-up, and finally operation and maintenance. The system is based on the three E's of safety: (1) engineering, by specifying actions such as substituting less hazardous materials, using warning devices, and prescribing protective equipment; (2) education, by using the system as a teaching and training tool; and (3) enforcement, by following federal, state, and local laws and regulations, especially OSHA requirements. The objectives are to: (1) provide contractors with a tool to plan the safety and health measures and integrate safety and health concerns in the construction process; and (2) provide owners with a means to review a contractor's safety plan and monitor performance during construction.

The achievement of these objectives is being accomplished mainly through: (1) the development of a database management system that solicits project-specific data from the user and provides, as output, applicable safety and health standards and recommendations; and (2) integration of the safety and health information into critical path method (CPM) project files.

RESEARCH RATIONALE AND APPROACH

The foundation of IKIS-Safety is built on the four common principles of management: planning, organizing, controlling, and leading (Ivancevich et al. 1989), as shown in Fig. 2. The basic steps in quality management apply to any and all aspects of a project, including safety and health.

Incidents involving poor safety and health performance can be categorized as physical and behavioral (Barrie and Paulson 1992). Physical incidents are those that pose a hazardous condition and behavioral incidents are those caused by unsafe acts. Establishing quantified safety objectives is crucial to monitoring and measuring safety against minimum performance standards. By setting objectives and a means of monitoring and measuring safety performance, responsibility for attaining objectives can be delegated to competent personnel who can be held accountable for them.

How could costs be controlled if there were no budget? How could deadlines be met if there were no schedule? The same reasoning applies to safety. Posters stating "Work Safe!" on the jobsite may promote awareness but do not establish objectives or provide an effective way to manage safety.

With objectives identified and accountability established, management can focus on methods of statistical analysis to take corrective action when variations from objectives occur. In such an environment, safety and health become proactive rather than reactive, i.e., the common practice of correcting mistakes is changed to correcting factors that lead to mistakes. Reactive planning, which often incorporates corrective action after an accident or unsafe situation occurs, may be an acceptable means of control when risk and related costs are low. Unfortunately, this is not the case with safety and health, yet reactive planning is still widely practiced to manage safety today.

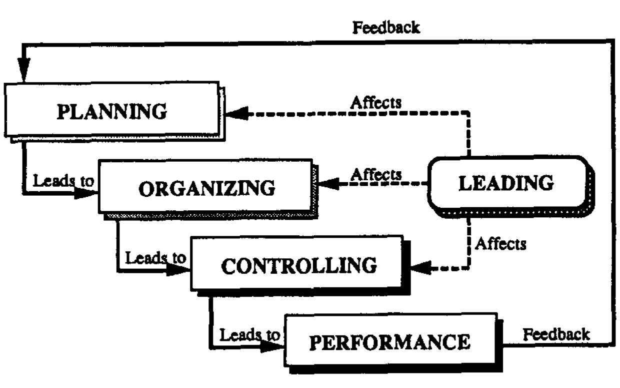

FIG. 2. Principles of Management

IKIS-Safety adopts a total quality management (TQM) approach to construction safety and health by integrating safety and health activities within the projects own CPM network. A very important feature is the early involvement of safety and health in the project. During the planning stages of a project the safety engineer would be responsible for providing the data, schedule, financial or budget requirements, and other criteria such as training requirements. When the job is gets under way and the CPM documents are published, each party in the construction project will be aware of the safety requirements, as well as its own tasks. Communication has always been a weak link in the construction process. On many jobs, fall protection, guardrails, personal protective equipment, medical services, etc. are left to the responsibility of the safety office. In a reactive sense, the safety representative would tour the job, note the deficiencies, and issue notices to correct hazardous conditions. This process would not be eliminated, but there will be many fewer correction notices in a proactive CPM-safety network environment.

Typically, CPM programs are effectively used in scheduling of work activities, ordering and delivery of construction materials, and project management information systems data collection. An important benefit is tracking performance and costs, particularly when claims are presented for delays and lack of performance.

Safety and health concerns in the construction industry may be managed quite effectively within the concepts of a CPM program. The added feature is that incorporation within the CPM schedule places the requirements for safety and health performance in full view of all concerned parties. Construction managers, when reviewing the CPM schedule, will be alerted to the safety requirements.

Construction schedules may deal with the type of work but the safety and health requirements may be unknown to the craft specialists. Conversely, the requirements may be common knowledge but since ordering documents for materials are expected to be complete, it is possible that materials for safety performance may be left out (i.e., materials to shore trenches, personal protective equipment, etc.). Combining these activities in CPM project files provides a way to proactively manage safety and health performance.

To ensure efficient design and implementation of the system, an advisory board of industry professionals was formed. This Safety Advisory Board (see "Acknowledgments" section for members) serves as the backbone for data and knowledge acquisition, as well as system implementation and validation. The advisory board provides the assurance that development of the system is practical and sensitive to actual industry needs.

IKIS-SAFETY—DESIGN AND IMPLEMENTATION

IKIS-Safety was developed by the writer in cooperation with industry experts and professionals. IKIS-Safety is an integrated system in the following ways:

1. It has been integrated with existing computerized packages for CPM scheduling, cost, and production. Presently, there are a multitude of software applications mar-

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keted and being used to effectively manage these items. Current CPM usage is extremely complex, with many networks containing literally thousands of activities. To superimpose every safety and health concern on the network would only create a worse problem than the one it was intended to correct and, in all likelihood, make the CPM network unusable. To overcome this problem, IKIS-Safety has utilized implied links to the CPM network. In this way the network has the ability to display user-requested information when needed and avoid too much information being explicitly displayed in the project's schedule. Also, the information can be accessed independently of the CPM network by the use of a "menu selection" and user query.
2. It is suited for integration with existing company procedures for managing site operations specific to individual projects. In other words, IKIS-Safety will reduce information overload and provide timely safety and health objectives for effective project management.

Data and Knowledge Acquisition

To achieve the project's objectives, construction safety and health data, information, and knowledge have been collected from many sources. Sources include safety and health professionals, field investigations, and current databases and regulatory standards such as OSHA, National Institute for Occupational Safety and Health (NIOSH), National Fire Protection Association (NFPA), American National Standards Institute (ANSI), American Concrete Institute (ACI), Bureau of Labor Statistics (BLS), NSC, and Architecture and Engineering Performance Information Center (AEPIC). [The AEPIC database has approximately 10,000 cases involving claims against design professionals (Loss 1988), of which 25% involve bodily injury at the construction site. AEPIC's files have been reviewed in this project.] Currently, the system's focus is on construction safety and health performance as related to concrete, masonry, and site works in building construction.

The knowledge source has been mainly guided by OSHA codes at the initial stages and supplemented with recommended practices identified by practitioners of construction safety and health. The experts' recommendations specifically cover code regulations that are ambiguous or simply unresponsive to today's technology and industry needs (e.g., outdated codes that are suspended in lengthy bureaucratic revisions). Additionally, since this system is not considered a mandatory "standard," it identifies hazardous activities and provides performance suggestions offered by experts, thereby not limiting it to a simple computer version of safety and health standards.

The analysis of the data and knowledge, which have been collected, established two types of safety and health objectives. Namely, those required by law (regulatory) and those practiced by knowledgeable safety and health professionals (heuristic). Regulatory data were collected from the sources identified earlier under the guidance of safety experts. Heuristic knowledge can be best thought of as the expert's experience in identifying problems and incorporating effective safety techniques. Extracting expert knowledge from subject matter, or domain experts, is perhaps the most difficult step in the development of any knowledge base. Experience in knowledge engineering has shown that personal interviews, rather than pure questionnaires, are the most effective method of knowledge acquisition. Heuristics, or rules of thumb, are plentiful in construction safety but difficult to articulate.

Interviews, with the main focus on safety work practices in concrete and site works in building construction, were conducted with more than 30 construction experts, including safety directors of major construction firms in the Washington–Baltimore area, project executives, project managers, estimators, superintendents, field engineers, and foremen. Once the appropriate level of knowledge was decided upon, the process of collecting, classifying, and organizing the information became essential.

System Structure

Safety and health information have been analyzed and classified according to the 16 divisions of the *MASTERFORMAT* system (Construction 1983), the most widely used coding system in building construction. The use of a common coding system improves consistency and information flow between IKIS-Safety and other computer-based construction systems allowing for better integration of organizational efforts. With such a standard coding system, basic computer operations such as information storage and retrieval became much more efficient. Code extensions can be added to the basic Construction Specifications Institute (CSI) codes to indicate more specific information such as location of work or responsible organization.

Although the CSI system is the main coding and classification system, alternative means of information access are available, e.g., safety topic, construction activity, structural component, and OSHA codes. Fig. 3 illustrates this multiclassification feature of the safety database. The main database structure consists of three types of files: safety records file, link files, and access files.

The safety records file is the main source of safety and health information. In this prototype stage, this file contains more than 100 safety records mostly from CSI Division 3 "concrete" and Division 2 "sitework." Each record includes a set of attributes necessary to sufficiently describe the safety standards and recommendations; the conditions under which it is applied; the source and context from which the information is collected; and a relevant sketch or reference to other documented information. The access files allow the user to retrieve safety information according to many classification options, including the 24 OSHA subparts, CSI, keyword, component, source, etc. The linkage between the access files and the safety records file is achieved through the linkage files. Each linkage file simply consists of two data fields: one from the safety records file, the other from the access files.

System Implementation

The IKIS-Safety was developed using a relational database management system (SuperBase) and hypermedia techniques running on the IBM-PC class of computers. Combining the capabilities of database with hypermedia techniques allows alternative means of accessing information as well as potential integration with other computer-based construction systems. Also, most database management systems such as SuperBase can be linked to scheduling software such as Primavera, making it possible to automatically transfer safety information to specific project activities in a CPM schedule based on the CSI coding system. Thus, the IKIS-Safety functions in a standalone manner and can be downloaded into a CPM program.

Hypermedia techniques permit dynamic linkage of separate text or graphic files or other forms of computer data. These techniques reduce the scope of interest to a manageable size, allowing the user to concentrate on a reasonable amount of information at a time. As a result, the IKIS-Safety allows the developer to encode knowledge efficiently and users to navigate through the sea of expertise interactively.

The IKIS-Safety provides user-friendly "Pop-up Menu" selections where the user can access or input data regarding general and specific information by choice. Although the menu selection has greater flexibility in the base program the proper

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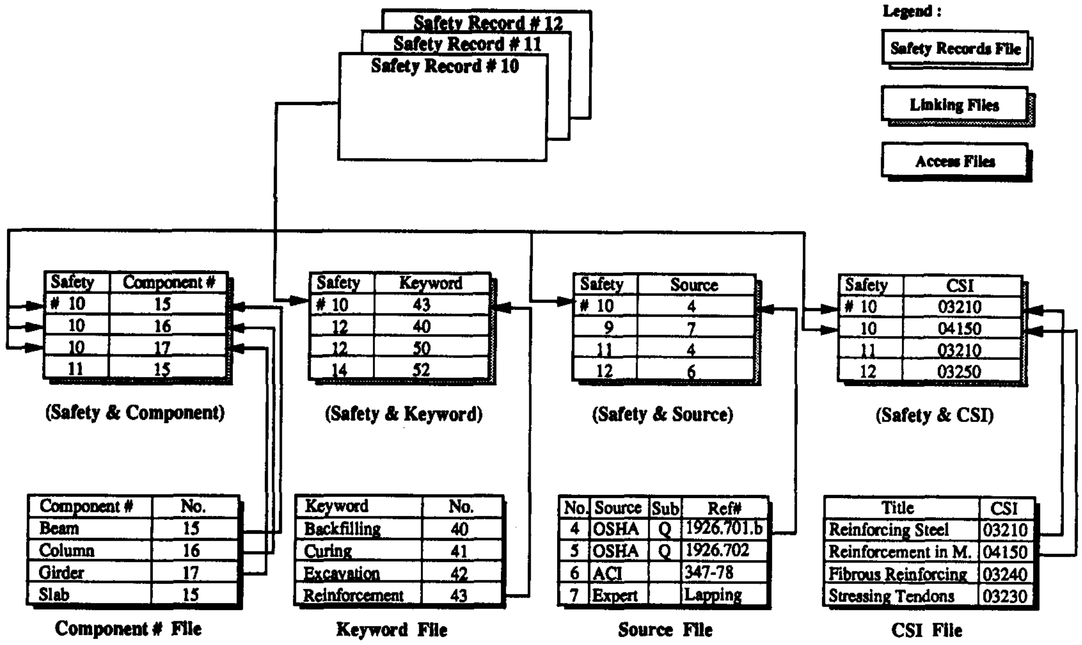

FIG. 3. Structure of Safety Database System

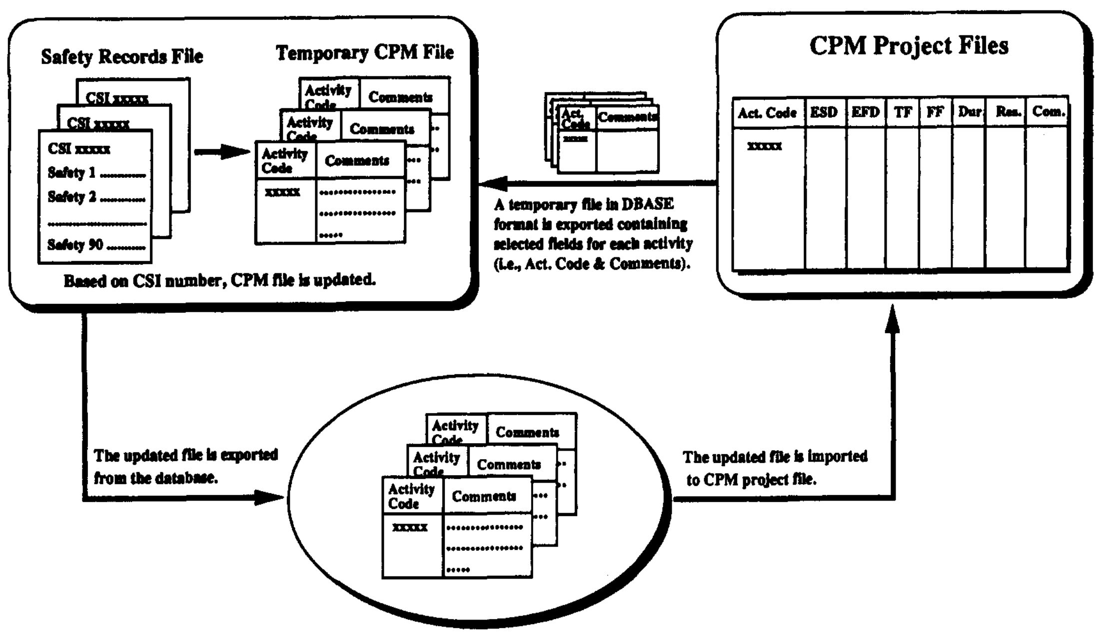

FIG. 4. Flow of Safety Information between Safety Database System and CPM Project Network

use of data selection allows for structuring the program to be downloaded into the CPM environment.

Fig. 4 illustrates the integration process and the flow of information between the safety database and CPM project files. The integration process is activated when the user selects the integration option from the main window of the Safety Database System. A subroutine that performs certain steps is executed. First, the user selects a specific CPM project file from the available set of projects' files within the CPM program. A given CPM project file consists of many fields including the Construction Specification Institute (CSI) activity code, early start date, early finish date, duration, total float, free float, resource requirement, comments, etc. Then, a temporary file is generated from the CPM project file and transferred to the database management environment. This temporary file consists of only three data fields: (1) the activity identification (ID); (2) the CSI activity code; and (3) the comment field. It is assumed that activity codes are based on CSI's broad, medium, and narrow scope approach to classifying construction activities. This field constitutes the common field for integration between this CPM file and the safety records file. Next, safety information can be inserted into the comment field according to each activity's CSI code. If the comment field has existing remarks, then safety information will be appended starting in a new line in the comment field. Finally, this temporary file is transferred back to the CPM environment and linked to the existing CPM project file.

The integration of the safety and health management information system with the scheduling software incorporates explicit and implicit links. Those safety and health activities, which are determined to require a high degree of visibility, are represented as safety activities on the project CPM schedule. The bulk of the database information is implied. To access any activity safety information from the database, the user only needs to click an activity or make a menu selection to activate a ''pop-up'' window. The window contains general to specific

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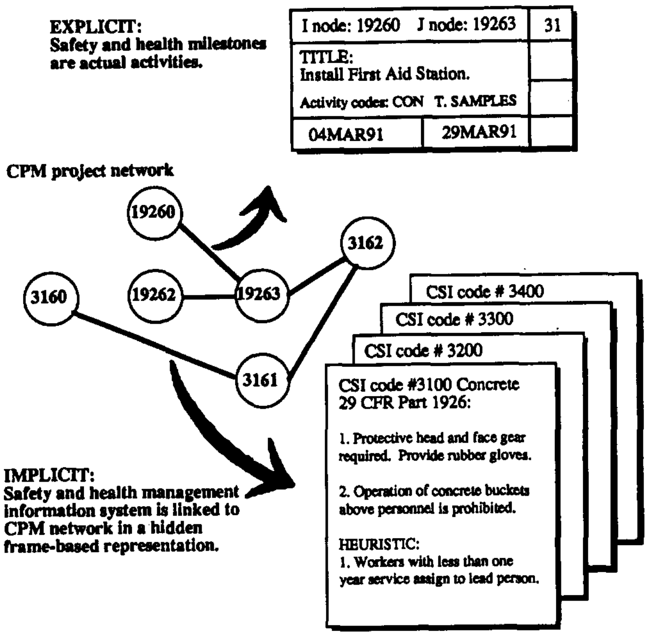

FIG. 5. Safety Information within CPM Project Files

safety and health issues for the particular activity. Fig. 5 shows how the conceptual database is accessed from the project's CPM schedule and how critical safety activities are explicitly shown within the scheduling network.

An important feature of this integrated system is that for those activities which are updated with safety information, the user will be able to see a message "flag" in the activity safety code field of the CPM project file. This flag indicates the availability of implicit safety standards and recommendations applicable to this activity. In addition, based on the sorting-selecting feature of CPM programs, the user will be able to sort out all the activities of the project that contain safety information for a given period. This is a fruitful planning tool for safety requirements in the heat of managing projects.

An interactive menu-driven capability is available to incorporate additional safety and health information to ensure the continuous expansion and update of the system. This option is available via password to selected users, e.g., the owner or contractor firm's safety director or system developer. Work in progress includes: (1) exploring other divisions in the CSI system; and (2) field testing, which will consist of interviews and on-site test applications at major construction project sites.

POTENTIAL BENEFITS

The IKIS-Safety program provides professionals involved in early stages of project development with access to relevant safety and health concerns so that preventive action or design modifications can be made to alleviate unnecessary risks. Such a knowledge-intensive construction safety and health performance system has the potential to benefit owners, designers, estimators, managers, and of course workers.

Designers can use the system in constructability review so that safety is built into the project's design. Conceptual alternatives can be assessed based on relative safety risk potential. Also, specifications that clearly identify appropriate accident prevention requirements can be written into the contract.

Estimators will be aided in identifying appropriate safety and health requirements so that responsible bids are prepared to account for safety and health project costs. Bids can be reviewed by owners to assess the appropriate budget for accident prevention. The owner is motivated to do this because of the large number of third-party lawsuits filed against project owners by injured employees of the contractor or his or her subcontractors. Estimates with proper budget items for safety and health issues are less likely to cause contractors to take safety risks in order to make up for budget items that were missed.

Project managers can use the system to identify and delegate appropriate safety performance standards during project execution. The system can also help identify unanticipated requirements when conditions and/or methods change. This can often occur when planned equipment is unavailable or unusable, site conditions are different, or the owner issues change orders.

The system also provides a cost-effective and affordable tool for any project manager. Time spent sifting through volumes of safety regulations will be eliminated by the hypermedia environment, which is easily accessible and specific to the individual task. The system provides a user-friendly method of identifying safety and health objectives for each of the activities on the CPM schedule. With a well-managed safety program, the project manager can expect significant cost savings as safety performance improves.

Another added benefit is the increased ability to land negotiated work, since owners are increasingly using safety records as criteria for selecting contractors. Subcontractors also appreciate a well organized and safe jobsite. The benefit to the contractor who manages safety well will be lower bid prices, greater cooperation from subcontractors, and greater acceptance by owners.

Finally, the greatest benefit will be in the fewer physical disfigurements and fewer lost lives.

CONCLUSIONS

Workers in the construction industry are exposed to a wide variety of hazards and face a greater risk of work-related fatality or injury than do workers in any other industry. Although protecting workers at a construction site often poses a greater challenge than protecting workers in other sectors, there are a variety of controls designed specifically to abate construction accidents. The safety system described in this paper serves as a major resource to complement other recent initiatives aimed at reducing the unusually high rate of injuries and fatalities in the construction industry (Center 1993). The information disseminated through such an integrated database/CPM safety system will be particularly useful to construction industry personnel responsible for planning construction activities and developing worksite safety programs. It would also be useful to NIOSH and OSHA personnel, persons responsible for training programs, union representatives, members of trade and professional associations, researchers, and others.

Since safety has been expressed as having been managed with reactive means, most safety and health professionals agree that a proactive approach is needed to improve safety performance. Simply stated, safety needs to be looked at and treated with the same kind of thoughtful project planning that goes into other project aspects. At the earliest stages of project development, construction and design professionals must be aware of relevant safety and health issues. IKIS-Safety provides the responsive and responsible means of identifying safety and health concerns for those who have control over modifying the design and construction methods to make the project less hazardous to construct.

This paper presented an effective tool for identifying the problem, picking the relevant data, selecting the appropriate objectives, and evaluating alternative courses of action when objective variances occur. Of major importance, quantified and measurable objectives can be delegated so that accountability of safety and health concerns are established.

By effectively managing safety and health, dramatic improvements can be accomplished within the construction in-

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dustry. Project managers can plan, organize, and control safety and health objectives on construction sites. Thus safety is proactively integrated along with cost, production, quality, and the project schedule.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the financial support for this research from NIOSH and the Center to Protect Workers' Rights. The writer also acknowledges the guidance and input this research project received from Ernest Jorgensen, Tim Palmer, and Magen Lyons of Professional Safety Consultants Inc.; from George Patton of the Project Management Service Bureau Inc., and Charles Martin, Carlo Colella, Jimmie Hinze, Victor Samuel, and Osama Shaheen. Many thanks for the feedback and review received from Keith DeCoster of The Poole and Kent; Jim Lapping of the Building and Construction Trades Department AFL-CIO; Pete Stafford of the Center to Protect Workers' Rights; James Sprague of Hyman; Stanley Manvell of Davis Construction Company; and Nicholas Fiore of National Constructors Association.

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