Conceptual Framework for Computer-Based Construction Safety Control

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Abstract: The construction industry's endemically poor accident record and accelerating rate increases in workers' compensation insurance are warnings that the industry needs stronger safety control measures. Safety checklists, training methods, safety awards, and other motivational approaches are insufficient. The writers propose developing a computerized safety management information system (MIS) based on the same universal management control principles used to achieve schedule, cost, production, and quality objectives. The safety MIS would furnish project managers and supervisors with the timely and complete information they need to respond to safety and health problems and hazards as they occur. This paper is concerned with the first step in the development of such a control system—the establishment of a conceptual framework consisting of fundamental safety and health, management controlling, and management-information-system concepts. The framework serves as the analytical basis for determining what to measure in the safety control system and how to adapt the control system to the computer.

Introduction

Accident statistics show construction to be an industry in grievous shape. Data compiled by the Bureau of Labor Statistics in 1985 indicated that construction was the most dangerous industry in the United States, with an injury rate of 15.2 cases per 100 workers. The injury rate was well above the 10.4 cases in manufacturing and the 7.9 cases in private sector industries overall ("Construction Tops" 1986). Construction is also the most deadly industry in this country. A survey by the National Institute of Occupational Safety and Health (NIOSH), which was based on death certificates collected between 1980 and 1984, showed that construction employees incurred 20.4% of all work-related fatalities (Construction is deadly 1987) even though they account for only 6% of the total labor force (Barrie and Paulson 1984).

Workers' compensation costs, as a result, are out of control. *Engineering News Record* recently reported that the national average workers' compensation rate for three key trades, general carpentry, masonry, and structural steel erection, increased 14.1% in 1986, 17.8% in 1987, and 13.8% in 1988 to \$19.22 per \$100 of payroll. Future rate increases requested by the insurance industry indicate that large hikes are again in store for 1989 (Grogan 1988). Coupled with these costs are hidden costs that also must be considered—reduced productivity, delays, damage to equipment and material, administrative time, etc. A study made by Stanford University 1979–80 estimated that the average ratio of hidden costs to direct costs could be as much as four to one or higher (Levitt and Samelson 1987).

Avoiding Responsibility for Reform

Construction safety is an area that has long been in need of reform. The construction industry, though, continues to shirk this responsibility, prefer-

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ring instead to cling to outdated myths and beliefs about the causes of accidents and the dangerous nature of the occupation. For example, many management people perpetuate the myth that careless workers are the reason for 90% of the accidents. Another popular belief is that the construction site is inherently unsafe and the risks that workers are subjected to are inevitable. The notion that there is little management can do differently to improve safety on construction projects is widely accepted. Could it be that construction managers are refusing to acknowledge that the absence of management control may be the principal reason for the high number of accidents on their projects?

Lack of Accountability

When the site manager and supervisors on a project exhibit little concern for safety, they are often simply reflecting the attitudes of the senior managers within their firm. In this kind of company atmosphere—where there is a lack of commitment to safety at the top—it is a waste of time to even think further about what can be done to improve the safety performance. But what about the more common situation, in which the company's officers have a declared commitment to safety but the company is not very successful in carrying out its safety policies and programs? What is the underlying problem in this case? The answer is that probably mechanisms of safety accountability are lacking. Without line accountability for safety, the company really has no way of systematically managing safety and health on its projects. There is no definitive way of gauging the quality of the safety efforts of the individual site managers and supervisors or knowing whether specific safety problems and hazards are being taken care of or not. Site supervisors set their priorities according to what they have to answer for. Since costs, schedule, productivity, and quality of workmanship are closely monitored and controlled on most projects, this is usually where they put their attention.

Haphazard Management Methods

Project safety, for the most part, is managed intuitively, whereas schedule, cost, production, and quality control are managed with well thought-out controls. For example, how often does a construction company put up a poster at the job site that states "Cost is Everyone's Responsibility" when they are concerned about holding costs down? A construction company would not think of doing this. Yet, is this not one of the ways they try to manage safety?

Even though the management process of controlling is considered to have universal application, construction managers do not seem to think the process applies to safety. Most construction companies do not have methods for measuring the loss potential (safety level) of their projects or for reporting on the quality of the loss control countermeasures that site managers and supervisors are employing or not employing. How can senior managers hope to hold their site managers and supervisors accountable for safety and health and to provide direction as to the methods and means for achieving the desired results if they continue to resort to haphazard management approaches instead of using proven principles of management control?

How Safe Is the Project—Really?

The methods that are presently being used to gauge safety performance on projects are based on the occurrence of lost-time injuries. Because the frequency and severity of lost-time injuries is largely fortuitous, measurements based on their occurrences are not really descriptive of either the safety level on the project or the loss control effort (Grimaldi 1970). Often these measures make a project manager look good, when, in fact, he or she may not be doing a good job at all, and vice versa. They also are of limited value because they are after-the-accident measures. What are needed, instead, are methods of measurement that identify problems before an accident occurs. Further, the measurements should tell us something about the quality of managerial and supervisory efforts to resolve the problems (Tarrants 1980).

Since root causes of accidents can usually be traced to the lack of management control, we need to define what management's loss control work is, set standards, and regularly measure the quality of management effort against these standards. Direct causes of accidents relate to the behavior of the worker and unsafe site conditions. Therefore, we also need to systematically keep track of the hazards (unsafe acts and conditions) that are being created, the risks they pose, and the steps being taken to control them. Finally, we need better methods for recording and utilizing information about accident occurrences. This should include near-misses (accidents that do not result in injury), since near-misses yield information about situations that could potentially cause injury or damage. (It has been estimated that about 300 no-injury cases occur for every lost-day case).

How to Achieve Project Safety Objectives

Loss control approaches that emphasize activities like safety promotion and training are too diffuse to achieve specific project safety and health objectives. Project objectives, safety or otherwise, are accomplished through the activation of the project's hierarchical chain and the distribution and channeling of responsibility, authority, and accountability. The managers and supervisors of the project must first establish clear, attainable, and measurable objectives. Then they plan how they will meet them, assign specific responsibilities to their subordinates, and determine accountability for their performance. This is how the hierarchical system prevails. The achievement of safety objectives should not be an exception. In other words, the project safety and health practices that will work most effectively are ones that assist in the fulfillment of the steps that constitute the work of managing and controlling (Widner 1973). Safety promotion and other motivational and educational techniques have a place in project loss control programs, but these *modi operandi* will not get hazards corrected on a timely basis, nor solve specific safety and health problems, or identify who is responsible for taking action.

Computerized Loss Control System Proposed

One way in which effective loss control of the type described can be achieved is through the development of a computerized loss control system. In order to accomplish this, however, it is necessary to first establish a conceptual

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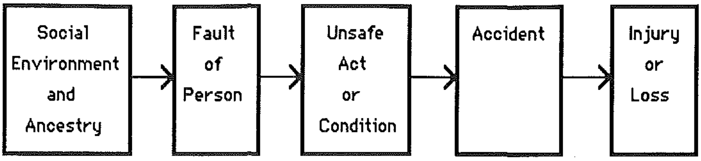

FIG. 1. Heinrich's Domino Theory (Heinrich 1959)

framework as the basis for the computerized control system. The remainder of this paper will explore seven key concepts affecting construction safety control. The thoughts expressed, for the most part, come from the writings of safety professionals and others representing a broad spectrum of interests in the construction, industrial safety and health, insurance, management science, and data processing fields. A conceptual framework consisting of seven concepts is the result.

Concept 1

Concept 1 is: Unsafe acts and conditions are only proximate causes of accidents; behind them lies a lack of management control.

Sixty years ago, Heinrich performed pioneering research in the conditions and circumstances that cause industrial accidents. Resulting from this study was his accident cause-analysis theory, better known as the "domino theory." The accident sequence in this approach is represented as a series of dominos (Fig. 1). The approach centers on the unsafe act or condition. Interrupt the sequence by removing the domino representing the unsafe act or condition, and the accident with its possible attendant injury will not happen. Probably no other accident theory has had such an impact upon loss control thinking. It has become a classic in industry. The theory, however, has come under criticism because it diverts undue attention to the immediate causes of accidents. Modern-day safety professionals think that the theory does not cause one to think enough about the importance of supervisory and management practices in accident causation and prevention. As Petersen points out in his book, *Techniques of Safety Management*:

> When we are looking at the act and condition, we are looking only at symptoms, not at causes. Too often our narrow interpretation of the domino theory has led us only to accident symptoms. If we deal only at the symptotmatic level, we end up removing symptoms and allowing root causes to remain to cause another accident or some other type of operational error. To effect permanent improvement we must deal with root causes of accidents. Root causes often relate to the management system (Petersen 1971).

Fig. 2 shows another way of representing the five key domino positions. This modification allows us to seek causes and corrective actions in supervisory and management practices. In this representation, the "Basic Causes" domino refers to personal factors such as a lack of motivation to work safely and environmental factors such as uncorrected hazards—factors over which management has a great deal of control. The "Lack of Control" domino

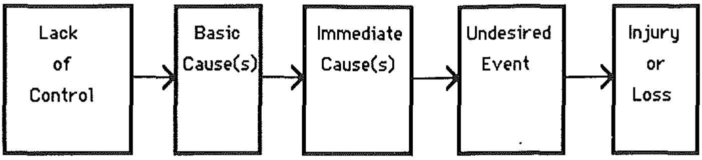

FIG. 2. Updated Domino Theory (Widner 1973)

refers to inadequate operational controls in the safety area. While each of the dominos in this sequence serves as an opportunity for intervening action, the greatest potential for accident prevention is with the first domino. If this domino is permitted to fall, the possibility of a chain reaction becomes a matter of luck. When the domino theory is presented this way, management control is seen as the most important factor in the accident sequence.

Concept 2

Concept 2 is: Loss control policies will not be reliably carried out unless established tenets of professional management are used.

The four fundamental functions of management—planning, organizing, actuating, and controlling—are the widely recognized means by which a manager gets things done (Terry and Franklin 1982). These management functions are considered so basic that they apply no matter what is being managed. The process is universal. Construction companies use the process to manage cost, schedule, production, and quality control. They usually do not manage safety this way. This is probably the most important reason why the accident rate in the construction industry is so high.

Peterson points out the difference between having a safety program and managing the safety effort:

> For many years, the slogan of the National Safety Council was "Safety First." . . . Safety professionals were oriented to safety programs for their companies. The aim was to superimpose a safety program on the organization. Today, safety men realize that what is really needed is "built-in" safety, "integrated" safety, and not some artificially introduced program. Safety must be an integral part of the company's procedures (Petersen 1971).

Levens (1974), corporate director for safety, at the McDonnell Douglas Corporation, depicts management as an integrated effort that depends on the interaction of technical, managerial, and cultural subsystems. He thinks that this management model applies to safety as well. Writing in the *American Society of Safety Engineers* [*ASSE*] *Journal,* he explains it this way:

> My basic premise is that the methods for effectively managing safety do not differ significantly from those for managing any other function in the organization. If the results of the safety effort do not meet reasonable expectations, then the effort has probably not been given at least as much attention as the traditional areas of management concern: production, quality, schedules, and cost.

> Every function in an organization must be managed. That is, action must be planned, organized, co-ordinated, and directed before it is taken: then controlled to ensure that what is done is both appropriate and timely (Levens 1974).

Concept 3

Concept 3 is: A system of line accountability is the most important key to effective loss control management.

Walters (1983), just prior to his retirement in 1981 as Dupont's Manager of the Safety and Fire Protection Division, made the following comment in a presentation at the ASSE Annual Professional Development Conference: Where I come from, accountability is the bottom line when it comes to safety. It's really very simple. If you don't have accountability, you don't have effective safety management" (Walters 1983).

Petersen also considers accountability to be the single most important principle behind a successful safety and health program. He writes:

> The key to effective line safety performance [is] management procedures that fix accountability. . . . The lack of procedures for fixing accountability is safety's greatest failing. When a man is held accountable, he will accept the given responsibility. If he is not held accountable, he will not in most cases—he will place his efforts on those things that management is measuring; on production, on quality, on cost, or on wherever the current management pressure is (Petersen 1971).

In any industrial endeavor, or on construction projects, it is naive to assume that managers and supervisors are naturally motivated to generate the degree of risk control activity that will keep losses or harm within acceptable limits. For one thing, considerations for safety and health often conflict with the other demands and pressures of their work. For another, individual values and judgment vary too much to ensure that the right trade-offs will always be made. For these reasons, there needs to be a managed approach to accountability for health and safety. If a company does not develop mechanisms of accountability, it is highly unlikely that its safety and health objectives will be achieved.

Concept 4

Concept 4 is: The degree to which accountability is possible is a function of the soundness of the performance measures used.

In order to hold supervisors and managers accountable, legitimate measurements of their performance efforts must first be devised. In the words of Petersen: "The principle of accountability cannot be separated from techniques of measurement. Measurements are made for the purpose of accountability—accountability without measurement is meaningless" (Petersen 1971).

Tarrants has made the area of safety performance measurement one of his main research pursuits. Like Petersen, Tarrants believes that safety performance measurement is essential for control. In his book *The Measurement of Safety Performance,* he writes:

> Measurement is the backbone of any scientific approach to problem definition and solution. Without measurement, the state of our oper-

ation is unknown. Sound measurement is an absolute prerequisite for control, and both are necessary for prediction (Tarrants 1980).

Tarrants stressed the importance of measurement again in an article written for the *Journal of Safety Research:*

> Control must begin with sound management. The degree to which accident control is possible is a function of the adequacy of the measures used to identify the type and magnitude of potential injury-producing problem areas existing within our field of concern (Tarrants 1970).

Current Safety Measures

Two methods for measuring safety performance are widely used. The American National Standard method of recording and measuring work injury experience (*ANSI Standard Z 16.1*) is the oldest method and dates back to 1920 ("Method" 1973). The ANSI standard quantifies safety performance by taking the ratio of lost-time injuries and illnesses to manhours worked. The Occupational Safety and Health Administration (OSHA) incident rate is the other measure used. It is similar to the ANSI ratio, except that the classification of injuries and illnesses has been broadened to cover cases without lost workdays (Tarrants 1980).

These methods provide a practical and uniform method of measuring injury experience. They serve as a barometer for measuring how accident experience has risen or fallen over time. Further, they allow comparisons to be made among various industries and their divisions. Unfortunately, these measures are not good indicators of the level of safety effectiveness on a project. An individual must have been killed or injured for the techniques to be applied. Because these events occur randomly on a construction site, they are not useful as a basis for decisions about a project's safety program. Senior managers, in fact, often overreact to reports of serious accidents by jumping in and making drastic changes in an otherwise technically sound program.

Grimaldi, former director of the Center for Safety at New York University, made the following observation with regard to the limitations of accident loss measures:

> It may appear logical to conclude that the rate of work injury occurrence is a direct function of the safety effort, but anyone who has noticed that disabling injuries do not necessarily follow risk taking ventures will realize that zero and low frequency rates may occur in spite of a poor safety approach. The converse can also be observed (Grimaldi 1970).

How Should Safety be Measured?

If current measures for measuring safety performance are inadequate, then what kinds of measures are needed? Answers may be found in the writings of Tarrants and Grimaldi.

Tarrants expressed the idea that safety performance measurements should indicate the safety level existing within a system or system component in terms of the worker behavior and the environmental problems that contribute to the loss-potential conditions. He believed the measure should tell us when and where to expect trouble and should provide us with guidelines on what should be done about the problems. He also believed that the evaluation should report continuously on the change in the safety level within the operation and the effectiveness of countermeasures (Tarrants 1980).

Grimaldi believed that it was especially important that the safety performance measurements be responsive to the way managers get things accomplished. Grimaldi expressed this idea as follows:

> Safety achievement relies heavily on management effectiveness. . . . A manager cannot prevail, however, unless his objectives are clear, attainable, and measurable. Then he is able to plan to meet them, assign appropriate responsibilities to his subordinates and determine accountability for their performance.
>
> . . . The industrial hierarchy is an outcome of the need for distributing and channeling the responsibility, authority, and accountability for fulfilling corporate objectives. And safety is no more likely to be accomplished than any of industry's responsibilities, if the hierarchical chain does not activate it as well. For this reason, it appears especially important for the safety performance measure to be responsive to managerial measurement requirements (Grimaldi 1970).

Concept 5

Concept 5 is: Hazards are controlled by the application of specific technical controls initiated and subsequently supported by sufficient motivational controls.

In the period 1979–1982, three researchers—Dawson, Poynter, and Stevens—worked together on the case studies of the safety programs of eight British chemical and petrochemical establishments (Dawson et al. 1987). The research project was funded through the Joint Committee of the Science and Engineering Research Council and the Social Science Research Council of Great Britain. The aim of the study was to develop strategies that could be used to achieve effective management of safety and health on any industrial worksite.

The research work led the team to classify hazard control strategies into two categories. They called one type "technical control." The objective of this type of control was to identify and control specific hazards. They called the other type of control "motivational control." This type of control had more diffuse coverage in terms of purpose and was concerned with the development and maintenance of general safety awareness and management's commitment to maintain and support technical controls. Technical control has been the traditional focus of those concerned with health and safety in the workplace. The research team, however, broadened the concept of control because their case studies showed that a specific focus on technical control activities was not addressing the whole hazard control problem. A purely technical focus failed to recognize the importance of sources of organizational power and influence in support of hazard control efforts.

The Use of Technical Controls

Technical controls, as defined by Dawson et al. (1987) are procedures that are brought to bear upon the physical characteristics of the working environment and/or the behavior or attitudes of individuals. Their common

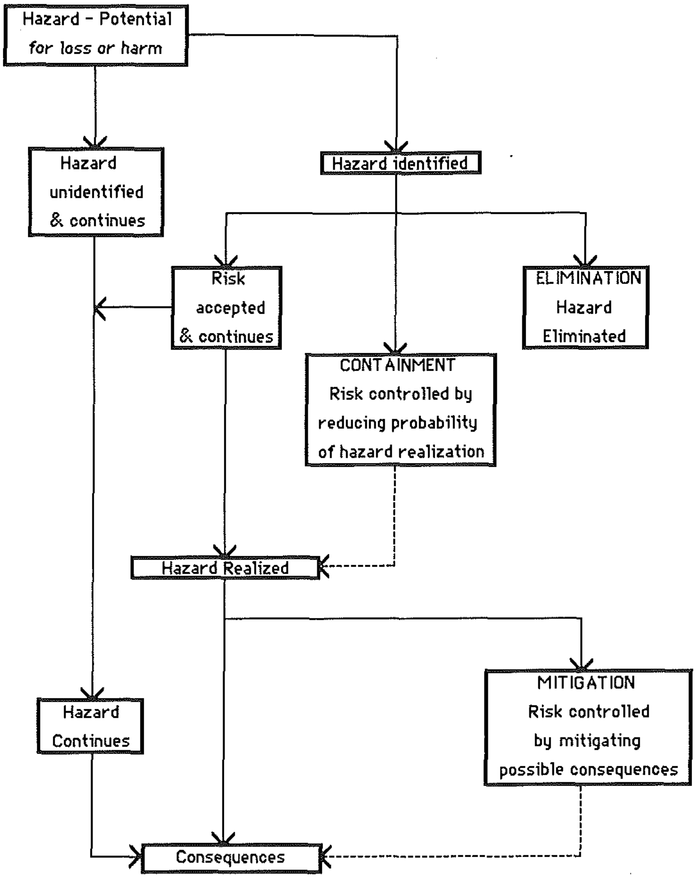

FIG. 3. Methods for Controlling Hazards (Dawson et al. 1987)

characteristic is that they control specific hazards. The researchers identified four stages in the technical control process:

1. The identification of the need for control measures: A decision is made about whether the presumed situation presents a potential for harm significant enough to warrant controls. This decision depends upon assessments of the probability and consequences of hazard realization.
2. The determination and prescription of control processes that are going to be applied: This involves considering which combinations of the options of elimination, containment, and mitigation are the most feasible and appropriate. Such interventions may be taken as shown in Fig. 3.
3. The implementation of control processes: This involves putting into effect the procedures decided on in stage 2.
4. The maintenance and adaptation of control processes: The implementation of controls is not a once-and-for-all activity. They may cease to be effective or they may be overtaken by changes in people or the working environment.

Need for Motivational Controls

The ultimate concern of most industrial companies is the maintenance of liquidity and the generation of profits. In an environment such as this, it is naive to assume that "natural" motivations will be sufficient to generate the quality and quantity of risk control activity that will keep losses or harm within acceptable limits. Control over these conflicting situations and processes can only be achieved by purposely managing the motivation to implement safety and health plans. Thus, we have a need for motivational controls. The common themes with regard to motivational control that Dawson et al. (1987) encountered across their case studies were:

1. The overall climate of safety awareness was crucial to success in hazard control, and this climate was substantially dependent upon the words and deeds of senior site and company management.
2. The allocation of responsibilities for risk control was relatively haphazard. The study showed fairly wide acceptance of the principle of line responsibility for safety, but emphasis was usually placed on the general objectives to be achieved rather than on specific means or methods to achieve these objectives.
3. The companies were generally not successful in developing mechanisms of accountability. Two problems emerged. First, the companies were not able to generate data about the control of hazards that were seen by line supervisors as legitimate measures of their technical control efforts. Second, the companies were not able to develop methods for measuring the motivational performance of managers.

Concept 6

Concept 6 is: Loss controls will fail unless they are based on fundamental controlling principles.

Controlling is a process that is difficult to do well, whether it involves controlling safety, production, schedule, or any other aspect of the project. Fundamental controlling principles underlie good controls. Like the processes of planning, organizing, and actuating, the controlling process has universal application. The construction industry has progressively improved controls in the production, cost, schedule, and quality areas to the point where they are now very sophisticated. Unfortunately, the safety and health area has not received the same management attention. In safety and health matters, we find that managers are trying to achieve objectives through innocuous activities like placing posters around the workplace, safety preaching, incentive gimmicks, and monthly inspection tours by the insurance carrier.

Construction managers are getting the safety and health results they deserve—no more or no less. Controlling production, schedule, cost, and quality on a sizable construction project is demanding of managerial time, effort, and skill. Managers have readily accepted this challenge. Most managers have not accepted the similar challenge that safety and health control imposes. Statistics cited earlier in this report indicate that it is inhumane and extremely costly for the construction industry to continue to operate in this way. Professional management controlling procedures need to be used in the safety and health area, as well.

The Control Process

Fig. 4 graphically shows the control process. Controlling is an iterative

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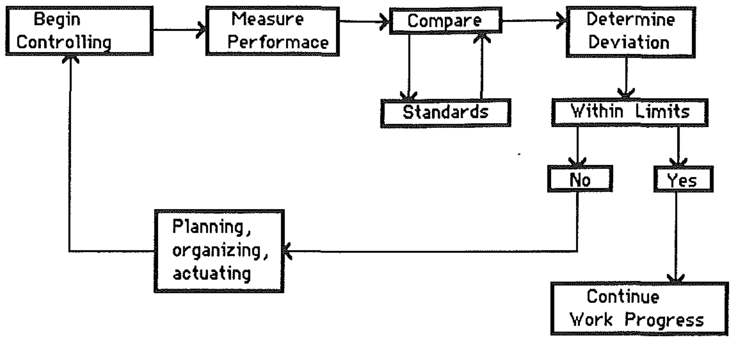

FIG. 4. Control Process

process that is made up of three definite steps that have universal application:

1. Establish standards.
2. Measure performance against these standards.
3. Correct unfavorable deviations by means of remedial action.

Stated in a slightly different manner, controlling consists of: (1) Establishing goals; (2) finding out what is being done as compared with expectations; and (3) analyzing differences and approving or disapproving the results. (If the latter is the case, then step 3 also includes applying remedial measures and repeating the process over again.)

Three Methods of Control

When people think of the control process, they usually conceive of it in terms of feedback control. You wait for an event to be completed, then compare the results against expectations. With this information, you attempt to correct future deviations from standards. This is, however, only one form of control. Preliminary control and concurrent control are also effective ways of controlling. Preliminary control takes place before operations begin and includes the development of policies, procedures, rules, and other preparatory steps that are designed to ensure that planned activities will be carried out properly. Concurrent control takes place during the action phase of operations and includes the direction, monitoring, and fine tuning of events as they occur. Since construction is so dynamic, safety and health performance can only be effectively managed by using all three methods of control.

Concept 7

Concept 7 is: The control process depends upon a management information system that generates timely information about safety problems and the efforts to control them.

A role of information in the control process is critical. A control system will fall apart without accurate, timely information that can be easily used for decision-making. The control process involves the two-way transmission of information. After information is received, it is evaluated, and, if some type of change in operations must be made, decisions are conveyed back

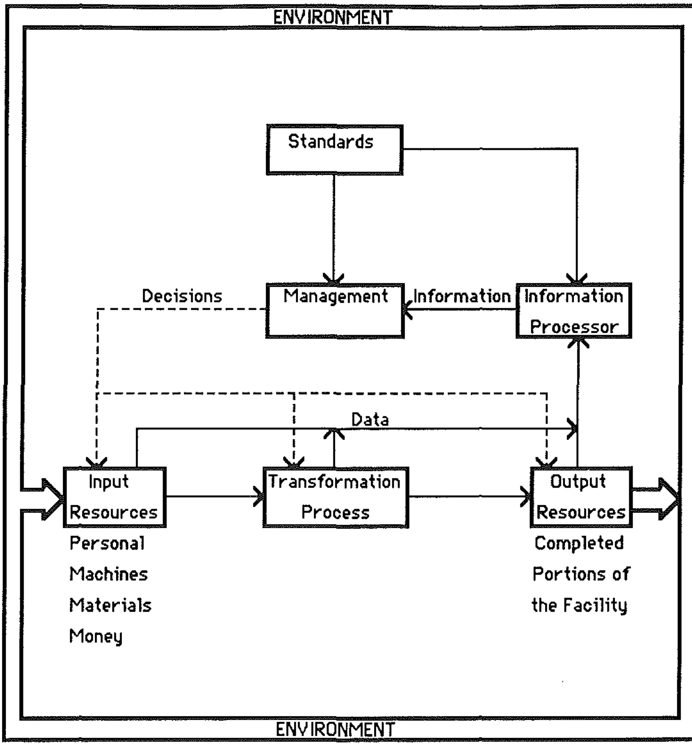

FIG. 5. General Construction Systems Model

through the system to whomever is in the position to effect the changes.

Fig. 5 shows, conceptually, how a construction project is managed through a project management information system (PMIS). Feedback and feedforward loops provide the communication channels for the transfer of information to and from decision-makers. Through the exchange of information, management monitors the project and makes necessary changes.

The purpose of the construction project is to produce output (completed portions of the project); therefore, monitoring output is the chief purpose of project controls. However, management also needs to know the status of the project in terms of inputs and transformation processes. Therefore, information-gathering activities are shown at all three stages of operations. An information processor is shown in the feedback loop since information, unless it is of a simple nature, does not usually travel directly to management. It is processed first. Standards are also an important part of the project information system. Management controls the project by comparing the "current state" of the system with the "desired state." If the two states are different, some problem is the cause and must be solved. Finally, the dashed lines on the construction systems model reflect the manner in which decisions can change project operations. The reader will note that the lines show management responding directly to problems throughout the entire construction process.

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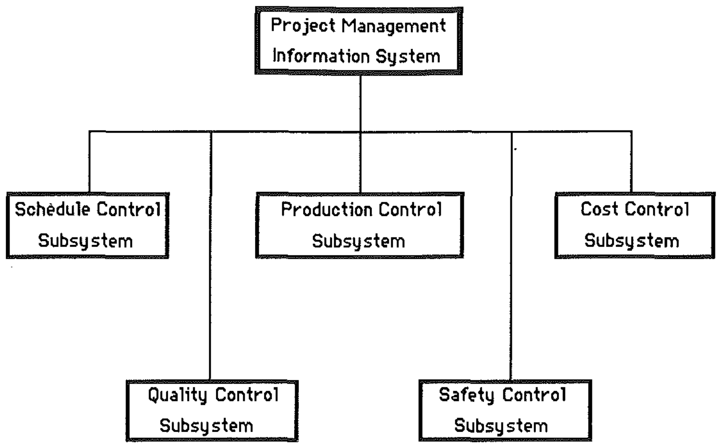

FIG. 6. Project Management Information System

General Application of the Construction Systems Model

A construction PMIS is usually organized into five smaller management information systems: the schedule control subsystem, the quality control subsystem, the production control subsystem, the safety control subsystem, and the cost control subsystem (see Fig. 6). Each of these subsystems has its own objectives, but these subsidiary objectives support and contribute to the overall objective of the PMIS—controlling the entire project.

The construction system model shown in Fig. 5 can be applied generally to any of the five subsystems. By applying the model to safety, we are able to determine what kind of performance measurement data is needed and how to use information in controlling specific safety and health hazards and problems. By showing information-gathering taking place at the input, transformation, and output stages, the model indicates that safety performance should be monitored by taking continuous measurements at these points. For example, before a work operation is begun, safety preplanning, crew orientation, and other preparatory steps should be evaluated. Once work is underway, we need to monitor for unsafe acts and conditions that may materialize. Finally, as work progresses, injuries, property losses, and near-misses that occur should be recorded. The model also indicates (note dashed lines) the need to constantly monitor management's action (or inaction) in responding to safety problems and hazards.

Summary

The seven concepts provide a conceptual framework for analyzing construction safety management and control. The important things to consider in the development of a computerized loss control system may be summarized as follows:

1. In most construction companies, the safety emphasis is on motivating and training its workers to work safely. The safety programs are probably designed

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this way because construction managers and supervisors believe that accidents are largely the result of carelessness on the part of the workers. A more enlightened format for thinking about the cause of accidents is in terms of a modified version of Heinrich's domino theory. When thought of this way, every accident is viewed as the result of a cause-effect sequence that starts with a lack of management control. The primary purpose of a computerized loss control system, therefore, should be to monitor management's loss control work.

2. Management principles have universal application. This paper has attempted to show that there is no reason why the principles cannot be applied as successfully to safety as they are to the other critical project management functions. The general construction systems model is a graphic illustration of how management controlling and MIS principles can be applied. One of the hurdles in proposing a computerized safety control system as a solution is convincing project managers that safety can be managed like the other traditional project management concerns.

3. The effectiveness of a computerized safety control system will crucially depend upon the mechanisms of accountability that are created. Accountability, in turn, depends upon legitimate measurement schemes; therefore, the development of methods for measuring loss control performance is one of the primary tasks to be accomplished in the development of a computerized safety control system. The methods of measurement that are developed should be valid indicators of the level of safety on the project and definitive enough to hold individual site managers and supervisors answerable for their actions in responding to and solving specific safety and health problems.

4. Effective loss control requires the application of technical controls supported by motivational controls. Therefore, an important consideration in designing an effective project loss control system will be how to evaluate project loss control efforts on these two levels.

5. When designing the computerized control system, it should be thought of as a management information system that is based on the iterative control process. The safety MIS should provide for safety control at the input, transformation, and output stages of each construction operation or defined work activity. In this way, the safety control system brings all three methods of control, preliminary, concurrent, and feedback, into play.

Conclusion

The writers are proposing that a safety control system be developed that would be similar in principle to the control systems now being used for cost, schedule, and quality control. As with the design of most types of control systems, it entails deciding what constitutes safety control work, breaking down the work into measurable categories, setting standards of performance for these categories, and providing the means to continuously monitor actual performance against the standards. There are, of course, essential elements that are peculiar to the development of a safety control system. Most of these elements have been discussed in this paper.

Finally, just as cost and schedule control systems have been computerized, a safety control system can likewise be computerized for use on the job site and in the home office. The writers are in the process of preparing a follow-up article to this paper that will show how the computerized system can be implemented.

APPENDIX I. GLOSSARY

Accident: An unplanned, not necessarily injurious or damaging event, that interrupts the completion of an activity and is invariably preceded by an unsafe act and/or condition or some combination of unsafe acts and/or conditions.

ANSI Standard Z 16.1: A national standard by which a company appraises its work safety effort based on injury frequency and severity ratios.

BLS-OSHA Incidence Rate: The total of lost-time and non-lost-time injuries and illnesses per 200,000 manhours worked.

Concurrent control: Control that takes place during the "action" or process phase of carrying out plans.

Controlling: The measuring and correcting of activities of subordinates to ensure that events conform to plans. That phase of the managerial process that maintains organization activity within allowable limits as measured from expectations.

Feedback control: The use of information about previous results to correct possible future deviations from the acceptable standard.

Feedback loop: A communications channel for receiving information about a system and transmitting it back when some type of change must be made.

Hazard: Any existing or potential condition in the workplace which, by itself or by interacting with other variables, can result in the unwanted effects of death, injuries, property damage, or other losses.

Hazard control: The function that is directed towards recognizing, evaluating, and eliminating (or at least reducing) the destructive effects of hazards resulting from human errors and from the situational and environmental aspects of the workplace.

Heinrich's domino theory: A notion that an accident is one of five factors in a sequence that results in an injury. The accident is invariably preceded by the existence of an unsafe act or condition caused by the fault of a person, which in turn is the result of social, environmental, or ancestral factors.

Management: A distinct process consisting of planning, organizing, actuating, and controlling performed to determine and accomplish stated objectives by the use of human beings and other resources.

Management information system (MIS): An organized method of providing past, present, and projection information relating to internal operations and external intelligence. It supports the planning, control, and operational functions of an organization by furnishing uniform information in the proper time frame to assist the decision-making process.

Mechanisms of Accountability: The generation and use of data about loss control efforts which are seen by line managers and supervisors as a legitimate measure of their performance. Something counted or measured with sufficient reliability and validity that line managers and supervisors accept it for appraisal, praise, blame, correction, and reward.

Motivational controls: Controls that are concerned with the development and maintenance of general safety awareness and commitment to technical controls.

Preliminary control: Control that takes place before operations begin.

Proximate causes: Accident causes directly ascribed to an accident, e.g., unsafe acts and conditions.

Root causes: Accident causes that relate to the management system—its policies, procedures, supervision, definitions of responsibilities, training, etc.

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Safety (first definition): Freedom from conditions that can cause injury, illness, or death to personnel or damage to or loss of equipment or property, or environmental harm.

Safety (second definition): A judgement of the acceptability of risk. A thing is safe if its risks are judged to be acceptable.

Technical controls: Controls that are directed towards the identification and control of specific hazards and involve four stages: (1) The identification of the need for control measures; (2) the determination and prescription of control standards and processes that are going to be applied; (3) their implementation; and (4) their maintenance and adaptation.

Appendix II. References

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