Assessment of Safety Performance Measures at Construction Sites

By Alexander Laufer,[1] M. ASCE, and William B. Ledbetter,[2] F. ASCE

Abstract: Various methods for the measurement and classification of safety performance at construction sites, e.g., timing relative to the moment of accident, data collection method, safety effectiveness criterion, performance measure, and frequency and severity of the measured event, are analyzed. The effectiveness of the various methods and the extent of their use at construction sites are examined. Attributes that are investigated include efficiency, reliability, and validity and diagnostic capacity of the measure in order to identify the cause for success or failure, respectively, of the safety program at a site. The data for the study were collected through questionnaires which were addressed to the largest construction companies in the United States. The most effective and the most widely employed measurement methods were lost-day cases, doctor's cases, and cost of accidents. The least effective and most limited in use were the no-injury cases.

Introduction

Safety performance and its improvement at construction sites has received a great deal of attention since the implementation of the Occupational Safety and Health Act (OSHA). A key factor in the control and improvement of any performance aspect on site is the ability to measure the performance. Unmeasured performance precludes a reliable assessment of progress, deterioration or immobility. Measuring safety performance is also important to check the effectiveness of various safety training methods (18) and as an instrument in choosing a contractor (24). Devising effective measurement techniques to reflect performance change for the diverse activities like production, finance and quality is an intricate process that has to take into account the attributes of the measuring method, i.e., cost, reliability and validity (16,17). This is particularly true with regard to the aspect of safety level.

By their nature, accidents are unplanned and uncontrolled events. This is simply another way of describing chance-caused events. Furthermore, man striving to control his environment holds exposure to hazard and risk of accident to the minimum. Taken together, these properties of chance and improbability characterize a class known to statisticians as rare events. Additionally, since accidents occur unpredictably and only rarely, they are normally not given to direct observation. For these reasons most methods are based on post-factum measurement.

When man-hours of exposure are small, i.e., small work force or short duration (a common condition at many construction sites), the difficulties are further accentuated. In a typical site valued $20,000,000 spread

[1]Head, Dept. of Construction Management, Building Research Station, Technion, IIT, Haifa 32000, Israel.

[2]Prof., Civ. Engrg., Texas A&M Univ., College Station, TX 77843-3136.

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J. Constr. Eng. Manage., 1986, 112(4): 530-542

over two years, at which the primary contractor employs about 100 workers, there will be approximately 30 OSHA recorded incidents during the construction period. This averages at four incidents per three-month period, an interval considered suitable for observation (30). Variance of such small numbers allows no significant conclusions with regard to the efficacy of preventative measures (12).

Except for addressing itself to the problematic nature of the experience-modification-rate (11) and to the importance of selecting from the data base the appropriate safety measuring methods (15), the construction industry has paid scant attention to this topic, notwithstanding the great stress placed upon it by industry in general (6,8,12,21,28).

The objectives of this study are to examine: (1) How effective the common safety measures are in meeting criteria such as efficiency, reliability, validity, and diagnostic suitability; and (2) the extent to which safety measures are employed at construction projects.

In view of the superficial treatment accorded to this subject in construction literature, an explanation of the important prevalent terms and a description of the current measuring methods and their characteristics is appropriate. The methods employed in this enquiry and its results will be described in the following paragraphs.

Measurement Purposes

Before considering the question of measurement, one ought to define the term industrial safety and clarify the purpose for which it should be measured. The very term "accident" widely employed in industrial safety is subject to much debate in safety literature (13). Some suggest a definition in terms of operational probability, as a class of events which incurs a low level of expectancy, avoidability and intention (27). Others see an accident as an unplanned, not necessarily injurious or damaging event that interrupts or disrupts the completion of an activity (28).

Grimaldi and Simonds, however, contend that the majority of the so-called accidents are incorrectly classified because they are predictable and therefore not unexpected (e.g., an auto mechanic smoking while washing engine parts in gasoline and getting burned in the inevitable fire). Such cases are not unpredictable, their causes are readily identifiable, only their precise moment of occurrence is unknown (8). This perception leads to the conclusion that industrial safety should focus on control of hazards rather than of accidents, since the hazard is the source of the unwanted, harmful event which must be eliminated. In this school of thought the pursuit of safety ought to be directed at the identification of hazards, determination of their significance, evaluation of the available correctives, and the selection of the optimal remedies. With this orientation the purpose of safety measurement may be defined as:

1. Evaluation of the safety program effectiveness at the site.
2. Determination of the reasons of success or failure.
3. Location and identification of problem areas and determination of the level of remedial effort to be applied (12,28).

This approach has been adopted for the treatment of the subject in this study.

J. Constr. Eng. Manage., 1986, 112(4): 530-542

Measures of Safety Performance

Measuring methods are characterized primarily by the manner in which they relate to the criteria of safety effectiveness, the events measured and the method of data collection. The methods adopted in this study endeavor to conform with these characteristics, though only in a generic sense as each one actually represents a family of measuring methods in practical use. As a result, the current definitions of OSHA or ANSI (Z16.1) do not fully coincide with those employed in this study (1,30).

As with other aspects of site performance, measurements may be of output or of process. Output measurements, i.e., post-accident measurements, can be made from a standpoint of frequency or degree of severity. The frequency element of the undesirable event usually splits up in four subdivisions (8):

1. Lost day cases—cases which bring absence from work in their train.
2. Doctor's cases—non-lost workday cases that are attended by a doctor.
3. First aid cases—non-lost workday cases requiring only first aid treatment.
4. No-injury cases—"accidents" not resulting in personal injury but including property damage or productivity disruption.

Research has shown that the severity of an accident stands in inverse relationship to frequency, i.e., the graver the severity, the lower the frequency (3,6,10). Heinrich, for instance, discovered a ratio of 300 no-injury cases to 30 involving minor injuries (e.g., first aid cases) to one resulting in doctor's attendance or lost-day case. Research conducted outside the construction industry found a considerable proportion of the no-injury accidents associated with substantial damage to property (3,8).

Where degree of accident-severity is the determinant yardstick, lost days due to injury or accident costs are measured. Accident costing practices are not uniform. Some organizations will cost only the more serious accidents (lost-day cases), others will include incidents of lesser human

TABLE 1.—Classification of Safety Performance Measures

Time of measurement (1)	Criterion of safety effectiveness (2)	Data collection method (3)	Performance measure (4)	Frequency of measured unit (5)	Severity of measured unit (6)
Post-accident	Frequency of undesirable events	Secondary data	Lost-day cases Doctor's cases First-aid cases No-injury cases	Very low Low Medium High	High Medium Low Low
	Severity of undesirable events	Secondary data	Days lost Cost of accidents	Low Low-Medium	High High
Pre-accident	Undesirable practices	Observations Questionnaires, Interviews	Unsafe acts Unsafe conditions Safety climate, Critical incidents	Very High Very High High	Very Low Very Low Low

J. Constr. Eng. Manage., 1986, 112(4): 530-542

impact, but not necessarily less costly to the firm (e.g., no-injury cases) (3,8,24). In every case, the direct (insured) and indirect (uninsured) costs are measured (8,21).

Process measures are not obtained via secondary data but through collection from the direct source of observation, or from indirect sources of questionnaires and interviews. In the observational method a distinction may be made between unsafe acts and unsafe conditions. Structured observations that are taken as equivalent to work sampling have been investigated and recommended by a number of researchers (19,20,22, 23,25).

The last method included in this study refers to the utilization of the knowledge found among the workers. Studies have shown that workers command a body of knowledge and experience that are of inestimable value to the assessment of safety. Questioning workers about their firm's safety climate (4) or using the critical-incident interview technique (28), are two recommended methods referred to in the literature dealing with workers' cooperation in the identification of safety risks and safety conditions. Table 1 presents the classification of the safety measurement methods employed in this study.

Attributes of an Effective Performance Measure

In its broadest sense, measurement is the assignment of numerals to objects or events according to rules (26). In point of fact, it is not the objects or events that are being directly measured, but rather their properties and characteristics (14). The value of a given measuring method depends on the quality of the rule. In order to evaluate the effectiveness of a given measuring method the attributes of the measure must be examined. Literature dealing with measurement in general (14,17) and with safety in particularly (12,22,28), enumerates many such attributes. Only four have been selected from an extensive list, based on considerations of relevance to safety measurement in construction, suitability of evaluation through the medium of a questionnaire, and the practical limits of a questionnaire's size. The attributes selected are: efficiency, reliability, validity, and diagnostic capacity.

The predicate of efficiency implies that the cost of acquiring and employing a method be consistent with the benefit to be gained. It should also be easily and rapidly applied, with minimal disruption to normal on-site operations (28). Reliability is established when repeated applications of the same method to the same object yields the same result every time (2). Reliability has a number of synonyms: dependability, stability, consistency, predictability, and accuracy (14). The types of reliability that are particularly germane to performance assessment, are consistency and stability. The changes we observe when applying the measurement technique at two points in time should reflect actual changes in the criterion variable and not internal fluctuations in the measurement technique itself.

The third attribute examined in the study is validity which is the extent to which an empirical measure adequately reflects the real meaning of the concept under consideration (2). Validity is a complex but indispensably crucial attribute in the measurement of safety performance. As

J. Constr. Eng. Manage., 1986, 112(4): 530-542

there are no fixed criteria of safety effectiveness, the selection of a particular safety measure to serve as a valid indicator of safety performance on site becomes of prime importance.

The aforementioned measuring method characteristics (i.e., efficiency, reliability, and validity) are used as proof for the acceptance of administrative procedures and the operative measuring rules. The higher the check-out rating the closer the attainment of the first purpose, namely, the assessment of the effectiveness of a safety program at a construction site. In order to attain the other two goals—identification of the causes of success or failure of a program and of the problem areas in need of remedial action—measurements must possess the fourth of the attributes selected for the method evaluation process, the diagnostic capacity.

Research Method

Data were collected through the medium of a questionnaire mailed to safety directors of the 400 largest U.S. contractors listed in the Engineering News Record (5). The group was picked with the purpose of: (1) Reaching experts with specific background and experience in construction safety and its measurement; and (2) to obtain a representative sampling from construction firms engaged in construction projects of varying sizes, including small ones. Sixty-seven companies, whose profile is presented in Table 2, responded to the questionnaire.

Results

Effectiveness of Safety Performance Measures.—Participants were presented with a description of the safety performance measurement techniques and the attributes under consideration. They were asked to

TABLE 2.—Profile of Participating Companies

Characteristics (1)	Company Size: Small (2)	Medium (3)	Large (4)	Total (5)
Number of respondents	33	24	10	67
Size of companies (Median values)				
a. Annual volume (in millions of dollars)	115	325	1,550	200
b. Number of employees at construction site	450	1,400	4,500	850
c. Number of full-time field safety representatives	2	3	16	2
Type of construction (Mean values)				
a. Building construction	43%	47%	10%	40%
b. Heavy construction	53%	27%	20%	39%
c. Industrial construction	4%	26%	70%	21%

J. Constr. Eng. Manage., 1986, 112(4): 530-542

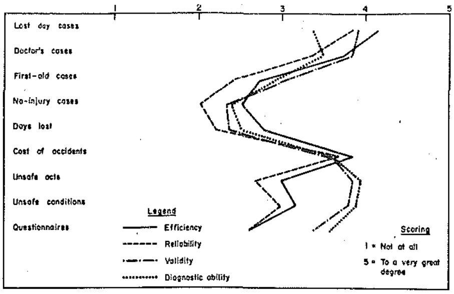

FIG. 1.—Effectiveness of Safety Measures

grade each measure with regard to being: (1) Efficient; (2) reliable; (3) indicative of the level of safety performance on site (validity); and (4) able to serve as a diagnostic tool. Answers were given on a 5 point scale from [1] "not at all" to [5] "to a very great degree." Answers did not vary significantly with company size or type of construction, hence the results and their analysis are presented as a single group. In Fig. 1, the mean values of the safety measures evaluation are shown.

Lost-days measurement was deemed the most efficient method with an average of 4.2, cost of accident and doctors' cases scoring 3.9 and 3.7, respectively. No-injury cases and worker interviewing were considered least efficient, scoring averages of 2.5 and 2.6, respectively. The leading scores for reliability were similar, lost-day with 3.8, and cost of accident with 3.7. Lowest scores were given to no-injury cases and days-lost 2.0 and 2.2, respectively. Generally, the grading of most methods in reference to reliability were lower than for the rest of the attributes. The validity of lost-day cases, doctor's cases, unsafe acts, and unsafe conditions received high scores from the respondents, 3.9 for the first and 3.8 for the others. The pattern repeats itself with the lowest scores given to no-injury cases and days-lost, 2.3 and 2.4, respectively. Unsafe acts and unsafe conditions were accorded the highest score as diagnostic tools for the identification of causes of success or failure of safety programs—the only instance in which process methods received the highest score. Causes for success or failure of safety programs—unsafe acts and unsafe conditions—obtained a mean value of 3.9. Here again, no-injury and days-lost cases were given the lowest mean values, 2.4 and 2.5, respectively.

The overall mean of the four attributes for each method ranged from 3.8 for the lost-day cases as the most effective, to 2.3 for the no-injury cases as the least effective measure. Between the two ends of the scale, the following measures took their place in descending order: cost of accidents (3.7), Doctor's cases (3.6), unsafe conditions (3.4), unsafe acts (3.3), questionnaires (3.0), first-aid cases (2.8), and days-lost (2.5).

Fig. 1 shows the first three measuring methods in the overall grading (i.e., lost-day cases, cost of accident, and doctor's cases) to stand out for high score in all four attributes, whereas the last three in the overall rating share a low score across the board. The three intermediate process

J. Constr. Eng. Manage., 1986, 112(4): 530-542

methods scored particularly well with regard to validity and diagnostic capacity, but rather poorly in efficiency and reliability. These findings are in accord with the relevant literature which draws attention to the conflicting demands between reliability and validity and the frequent trade-off between them (2,14). They are likewise consonant with the low rating given by the Department of Labor to lost-days, i.e., "Frequency is a much more valuable indicator for safety performance than severity, since blind chance usually plays a greater part in determining the seriousness of an injury than it does in determining how frequently accidental injuries occur" (30). The relative spread that characterizes the evaluation of days-lost and cost of accident is noteworthy. Their standard deviations are 1.0–1.2, against the standard deviations for the other measurements that occupy a range of 0.7–0.9.

The Extent Safety Measures are Employed.—In the section of the questionnaire, "The Extent Safety Measures are Employed," the safety directors were asked about the frequency of usage of the various measures and were requested to grade their answers on a scale of 5 points, from [1] "Never" to [5] "Always." As mentioned earlier, when man-hours of exposure is small, the output measures are unstable due to the rarity of the events. An assumption was made that process measures are more extensively used in smaller construction sites. Consequently, the questionnaires were set up to deal separately for sites with a volume of $20,000,000 or less and for sites larger than $20,000,000. An analysis of the results showed a negligible difference between the two site size groups (0.25 on a scale of 1–5). Furthermore, employment of measurements is more extensive, albeit only to a marginal extent, including process measurement, at the larger sites. One explanation why the assumption was not substantiated, could be the inefficiency of process measures (as elaborated earlier), which require manpower resources not readily available at the smaller sites. It was therefore decided to present only the results from the large projects.

Fig. 2 presents the extent to which safety measures are employed. Mean values are seen to range from 4.7 for the method in most frequent use—lost-day cases—to 2.3 for no-injury cases. Between the two, the following methods extend in descending order: doctor's cases (4.5), cost of accidents (4.2), unsafe conditions (3.3), unsafe acts (3.1), first-aid cases

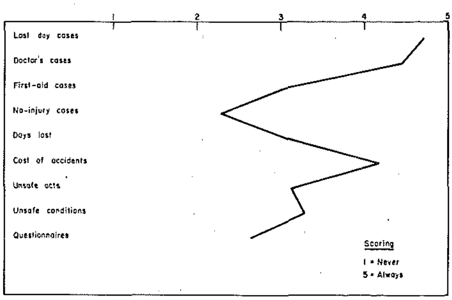

FIG. 2.—Frequency of Use of Safety Measures

(3.0), days lost (3.0), and questionnaires (2.6). Some output measures are very much in use, with process measures to a lesser extent, though occasionally quite frequently. In any case, measures and methods are intensively employed, which corresponds with what the relevant literature recommends about performance measurement in general (17), specifically with regard to safety (7,19,28), namely, to use multiple measures (criteria) and multiple data collection methods. It appears that the large number of different methods reflect the desire to attain multifaceted safety goals, to meet the human, legal, economic, personnel relations, and public relations expectations.

The findings of no-injury cases being less frequently used deserves attention. The manufacturing industry research literature brings to light that no-injury cases with property damage are numerous and involve significant damage. Grimaldi and Simonds found the ratio of lost-day to no-injury cases to be 1:1 and the cost of damage to property without incidence of injury to be double that of the lost-day cost (8). These facts have been known for some 30 years, and it is likely that they are known in construction circles. One might possibly assume that the relatively low ratio of property accidents without injury derives from the fact that construction is labor intensive, a fact that remains valid even for construction employing equipment on a large-scale (as in heavy construction), when comparing it with the enormous damage potential in the power and chemical industries. Support for this explanation may be found in the Business Roundtable research (24) that examines accident costs. The findings of the report establish that the frequency and cost of property accidents in construction is considerably lower than that recorded in the literature for industry (8).

One must remember, however, that some measures were undoubtedly used because of other attributes that were not examined in this study, or for the pursuit of additional purposes. The recurrent use of the lost-day measure, for instance, may have been dictated by OSHA report requirements.

The extent to which methods have been employed appears reasonably compatible with their overall effectiveness, as evident from the average rating related to the four attributes. How far the use of the various measures were affected by each of the attributes is worth contemplating, but the data collected by the method pursued in this study do not meet the necessary requirement of inductive statistics which would permit, for instance, forecasting. But the data can serve for the calculation of indices of relationship, such as product moment correlation as descriptive statistics (9). Such calculation shows the Pearson correlation between the extent that the method was used and the valuation of the following attributes as: 0.95 with efficiency, 0.93 with reliability, 0.67 with validity, and 0.38 with diagnostic capacity. These results suggest that extent of use is greatly affected by efficiency and reliability of the measurement effort, moderately by validity, and to a lesser extent by diagnostic capacity.

An attribute that was not examined in this study is the reactivity of the various methods, i.e., the degree to which the use of the method changes the situation simply because it is used. Studies have established that secondary data are virtually non-reactive, interviewing is generally accompanied by low reactivity, with observation often entailing a higher reactivity (17). High reactivity impairs the effectiveness of the measuring purpose that the measuring process, defined in the early part of this paper, set out to accomplish. Research in attributes of data collection methods has found that employing the low reactivity method may be important in some cases but not in others. Some methods, in fact, are used precisely because they are reactive. The distinction depends on the purpose for which the data is collected. If the purpose is to report the condition of the organization, reactivity is undesirable. If, however, the assigned purpose is to bring about a change in the situation, reactivity would be desirable indeed (17). Thus, if improvement in safety is the primary and immediate concern, reactivity coupled with suitable feedback to the workers can, in some situations, become an asset that overrides the need for greater measurement effectiveness, a phenomenon that was reported following measurement observations of unsafe acts and unsafe conditions (20). Consequently, if the list of aims (general information about the effectiveness of the program, diagnostic information regarding the success and the required steps for the improvement of safety) is augmented by including the measurement process (with its feedback) as part of the improvement process, reactivity can become, in an entire range of situations, an asset rather than a liability.

The findings and preceding analysis suggest that the more ambitious the measurement aims—if these are upgraded from a passive role as a source of general and comparative information about the past, to an active role as an instrument designed to supply specific information useful in the decision process for the improvement of safety in the future, to the ultimate level of becoming an integral part of the improvement process itself—the higher will be the relative merit of the process methods.

Conclusions

This study examined the effectiveness and the extent to which the various safety measuring methods at construction sites are used. The conclusion is drawn that for the successful safety performance at construction sites, the simultaneous employment of a number of measuring methods is required. The most effective and at the same time the most widely used have been found to be: lost-day cases, doctor's cases, and cost of accident. No-injury cases were least effective and least in use. Process methods were found to be effective as far as their validity and diagnostic capacity extends, though their efficiency and reliability are low. Nothing conclusive can be said about the interaction between the method attributes and the extent they are applied, since the disposition of the respondents may have been affected in the course of application. Nevertheless, the fact that the methods rated highest for validity and diagnostic value, and received low marks for efficiency and reliability, are used very little in practice (as expressed in the Pearson correlation), give ground for the assumption that the efficiency and reliability of the methods exercise a significant influence over the extent to which the methods are being employed.

The study is based primarily on a sampling of medium and large construction sites. Rarity of events termed "accidents" is not a problem at

J. Constr. Eng. Manage., 1986, 112(4): 530-542

these sites which is why normal output measures largely meet management needs. It may be assumed that process measures are of greater advantage to the smaller sites. In order to render process measures more useful and widespread, more research and development, with emphasis on increasing their efficiency and reliability, is recommended.

Appendix I.—Questionnaire

Part I

Profile of Your Company

1. Please indicate the average distribution of your company's annual dollar volume in following construction categories (in percent).
   a. Building construction ________%
   b. Heavy construction ________%
   c. Industrial construction ________%
   d. Other (please specify) ________ ________%
   Total 100%
2. What was your company's approximate annual dollar volume of construction in 1983? $________
3. What was the total number of workers employed at construction sites (excluding subcontractors' workers) during 1983? (company's annual average).

   ____
4. How many full-time field safety representatives does your company employ?

   ____

Part II

Suitability of Safety Measures

IN THE NEXT QUESTIONS YOU ARE ASKED TO RATE THE SAFETY PERFORMANCE MEASURES ACCORDING TO VARIOUS CRITERIA

	Not at all	To a slight degree	To some degree	To a large degree	To a very great degree
1. To what degree is *each* of the following SAFETY MEASURES "efficient" in terms of cost and time requirements					
a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
b. Doctors' Cases	(1)	(2)	(3)	(4)	(5)
c. First Aid Cases	(1)	(2)	(3)	(4)	(5)
d. Non Injury Cases	(1)	(2)	(3)	(4)	(5)

J. Constr. Eng. Manage., 1986, 112(4): 530-542

e. Injury Related Absenteeism	(1)	(2)	(3)	(4)	(5)
f. Total Accident Cost	(1)	(2)	(3)	(4)	(5)
g. Unsafe Acts	(1)	(2)	(3)	(4)	(5)
h. Unsafe Conditions	(1)	(2)	(3)	(4)	(5)
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)
2. To what degree is *each* of the following SAFETY MEASURES "reliable" (i.e. stable and consistent over time)?					
a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
⋮					
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)
3. To what degree are *each* of the following SAFETY MEASURES "indicative" of the level of safety performance on site.					
a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
⋮					
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)
4. To what degree can *each* of the the following SAFETY MEASURES serve as a "diagnostic tool" determining the causes for the success or failure of safety programs?					
a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
⋮					
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)

Part III

Company Practices

IN THE FOLLOWING QUESTIONS YOU ARE ASKED TO DESCRIBE *YOUR* COMPANY'S PRACTICES

	Never	Seldom	Often	Very often	Always
1. How often are the following safety performance measures used at *small and medium* size construction projects (up to $20 million)?					

a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
⋮					
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)
2. How often are the following safety performance measures used at *large construction* projects (more than $20 million)?					
a. Lost Day Cases	(1)	(2)	(3)	(4)	(5)
⋮					
i. Workers' Perceptions	(1)	(2)	(3)	(4)	(5)

COMMENTS:

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