Benchmarking Studies on Construction Safety Management in China

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Abstract: This paper presents information by which to measure safety management performance on construction sites. In China, the conventional construction safety benchmarking approach is to assess safety performance by evaluating the physical safety conditions on site as well as the accident records, while no attention has been paid to the management factors that influence site safety. This paper is to identify the key factors that influence safety management and to develop a method for measuring safety management performance on construction sites. Based on the survey and interview data collected on safety management factors in 82 construction projects in China, the safety management index as a means to evaluate real-time safety management performance by measuring key management factors was developed. The quantified factors were compared with the commonly accepted physical safety performance index, which was derived from inspection records of physical safety conditions, accident rates, and the satisfaction of the project management team. Multifactor linear regression was conducted and the result indicates that safety management performance on site is closely related to organizational factors, economic factors, and factors related to the relationship between management and labor on site. Based on this benchmarking study, a practical safety assessment method was developed and then implemented on six construction projects. The results show that this method can be an effective tool to evaluate safety management on construction projects.

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Introduction

With the rapid increase of Chinese construction activities, construction safety has become a big concern because worker injuries cause tremendous losses (Fang et al. 2000). In 2000, the number of workers in the Chinese construction industry was 35.52 million (National Bureau of Statistics of China 2001). It is conservatively estimated that 3,000 construction workers are killed in work-related accidents each year (Huang et al. 2000).

Peter Drucker wrote, ‘‘What gets measured gets managed’’ (Duff 2000). In China, there exists a safety benchmarking approach for evaluating the physical safety conditions on construction sites, but there are no tools for evaluating the safety management performance, which is regarded as the key for site safety. An effective measure or benchmark of safety management is an important ingredient for improving safety management. It should help to assess site safety and provide guidance in prioritizing the safety management measures on construction sites.

Based on studies of human behavior, Duff (2000) devised a safety performance assessment system in Britain. He suggested that the evaluation of human behavior and of safety management should be combined. He also summarized the properties of the safety assessment system. de la Garza et al. (1998) presented four numerical measures that are commonly used to evaluate the safety performance of contractors in the U.S., e.g., experience modification rate (EMR), the Occupational Safety and Health Administration recordable incident rate (RIR), the lost workday incident rate (LWIR), and the workers' compensation claims frequency indicator (WCCFI). All these indicators are experience related, and may not represent the current situation of a project if the information is dated. Sawacha et al. (1999) utilized the factor analysis technique to study and classify factors affecting safety performance on British construction sites, and concluded that safety performance is significantly influenced by organizational factors and technical factors. Diaz and Cambrera (1997) developed a set of evaluation measures of safety attitudes and the safety climate in Spain. These were based on the assessment of the quality of the differences in the safety climates of different companies and their relationship with the accident rates. However, safety measures on construction projects were not evaluated. Mohamed (1999) investigated the effectiveness of safety management activities as currently adopted by the Australian Contracting Organization, and developed a safety management index reflecting the intensity of the level of safety management activities. He established a safety management index (SMI), based on six safety management commitment variables, and compared it with the safety performance index (SPI), establishing the relationship between them through correlation analysis and clustering analysis. The results demonstrate that close associations exist between SMI variables and SPI vari-

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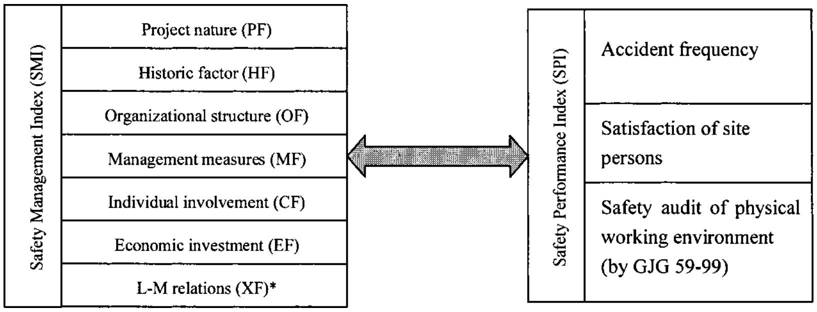

Fig. 1. Framework of safety management benchmark (Note: L-M means labor-management relations)

ables. However, the author did not provide a holistic assessment system to evaluate safety management on construction sites. Jannadi and Assaf (1998) established a standardized checklist to assess safety on construction sites in Saudi Arabia, which essentially assesses both the physical and technical safety aspects of a project. Obviously, existing indicators showing the safety performance of a project or contractor often portray safety management information that may not be an accurate portrayal of the current situation. Assuming that accidents can generally be prevented by managerial intervention, more attention should be focused on present-day safety management performance. This is especially true in China, where everything is changing too rapidly to be effectively evaluated through historical measures.

Currently in China, the Standard of Construction Safety Inspection [the national code is JGJ 59-99 (Ministry of Construction 1999)] is used to assess safety on sites. This standard focuses on the quality of the physical working conditions on site, including the safety of scaffolding, machinery, personal protective equipment (PPE), opening protection, and housekeeping. The standard was developed based on the lessons accumulated on past accidents and mainly focusing on correcting unsafe physical conditions. Safety management has a minor involvement in the scoring system. Through site interviews, it was discovered that many people on construction sites thought that this method of safety assessment ignored the factors that were related to safety management, and safety management is still based on the investigation and follow-up measures taken after accidents occurred on the projects. Looking at the worldwide practice, the commonly accepted safety indicators on projects continued to be based on past safety performances and accident records, not on the present (real time) management activities.

This paper, based on site surveys and multifactor statistical analysis, developed a SMI that presents the effectiveness of safety management performance in real time on Chinese construction projects. A practical safety management assessment method to evaluate safety management on projects was established and implemented on six construction projects. Discussions on these benchmarks, as well as future prospects of the research, are presented.

Methodology

This research was conducted to establish a benchmark to measure real-time safety management performance on construction sites. The benchmark, safety management index (SMI), was to consist of a quantified index, so safety management could be measured at any time during the construction of a project. The research can be divided into four phases: preliminary study phase, data collection phase, data analysis phase, and implementation phase.

In the preliminary study phase, an initial step in establishing the SMI was to identify factors that might influence safety management. The process of developing the SMI began with a review of the literature. The criteria to select such factors include (Duff 2000):

- Validity: the factors must be closely related to safety management practice on site;
- Quantifiable: the factors should be objectively defined and can be expressed as a numeric value; and
- Realistic: the factors must accurately reflect actual situations on Chinese construction projects, based on the consideration of both the cultural and economic aspects of the projects.

From this information, a list of questions was developed by which to obtain safety management information on construction sites. In 1999, personnel from 20 on-going construction projects in Beijing and Shanghai, the two major metropolitan areas with a population of over 10 million, were interviewed. These were generally residential (multifamily housing complexes) or commercial building projects with construction areas from 10,000 to 300,000 m^2. These projects were typical Chinese building projects in large cities. For example, in Beijing, the average enclosed space or heated area of a typical residential project in 2001 was 200,000 m^2, with more than 75% of the projects being between 10,000 and 300,000 m^2. Safety supervisors and project managers were asked about their opinions on the impact of different factors on construction safety and their relative importance. The assessment of the importance of these factors was used as the basis to determine the relative weights of these factors. Questions were also asked about the problems and needs regarding construction safety. The literature review and the responses from project interviews resulted in the identification of seven key managerial factors that were used to describe safety management on projects (Fig. 1). The SMI is defined by these key variables that describe safety management on a project

$$SMI = F(PF, HF, OF, MF, CF, EF, XF) \quad (1)$$

Definitions of these variables are shown in Table 1. The components of each variable and their weights were determined through the literature review and project interviews.

In the data collection phase, survey forms were developed to obtain objective measures of the managerial factors in the function defining the SMI. Four different questionnaires were designed to obtain information from four groups of individuals on construction projects, namely project managers, safety supervisors, foremen, and workers. In addition, a safety assessment tool sheet was designed to evaluate project safety performance

J. Constr. Eng. Manage., 2004, 130(3): 424-432

Table 1. Key Management Factors and Their Items

Indicator	Factors	Items	Questions
SMI	Project nature (PF)	Size of the project (PFI)	The height of the work; The total area; Total projected cost of the project
		Complexity of project construction (PF2)	Ratio of site area to building area; Application of new technology; Complexity of the design
		Complexity of project management (PF3)	Quantity of workers on site; Number of layers of management; Number of subcontractors
	Historic factors (HF)	Age and experience (HF1)	Age; Education years; Years working in construction industry; Years working on the project; Safety training received; Marital status
		Percentage of new workers on site (HF2)	Percentage of workers that have been working in the construction industry for less than 1 year; Percentage of workers that are new to the project
		Accident experience (HF3)	Whether any accident happened in the past 3 months; Whether the worker has been injured in an accident; Whether the worker has witnessed any accident
		Experience of safety punishment and rewarding (HF4)	Whether the worker has been punished because of unsafe performance; Whether the worker has been punished for unsafe actions
	Organizational structure (OF)	Quantity of safety supervisors (OFI)	The ratio of the number of workers to safety supervisors; The ratio of the building area to safety supervisors
		Involvement of contractor top management (OF2)	Whether top management inspects site safety regularly; Whether top management checks safety records of the project; The most important contractor concerns
		Authority of safety supervisor (OF3)	Whether the safety supervisor has authority to stop site work for identified hazards
		Authority of foreman (OF4)	Whether the foremen has extensive authority in the crew
		Size of the crew (OF5)	Number of workers in the crew
	Management measures (MF)	Safety inspection (MF1)	Frequency of safety inspections conducted by the safety supervisor; By the project manager; By the contractor; By the owner (representative); By the local authority
		Safety meetings (MF2)	Frequency of safety meetings convened by the safety supervisor; Attendance of project manager at the safety meetings; Whether any safety meetings are attended by workers before each activity begins
		Safety plan and record (MF3)	Whether there is a detailed safety plan before each activity begins; Whether daily safety records are kept
		Safety rewards (MF4)	Whether there is any reward for safe workers; Whether there is any reward to workers with high productivity; The maximum fine to workers without hard hats
		Safety training (MF5)	Whether there is any safety training of new workers; The effect of the safety training
		Other safety measures (MF6)	Whether workers are encouraged to work with their friends; Whether the schedule pressures are passed on to the workers; Whether workers with obvious mental distractions are required to stop work

J. Constr. Eng. Manage., 2004, 130(3): 424-432

Table 1. (*Continued*)

Indicator	Factors	Items	Questions
SMI	Individual involvement (CF)	Safety knowledge (CF1) Safety awareness (CF2) Safety involvement (CF3)	Safety quiz results Safety awareness results Worker involvement in safety activities and compliance with safety requirements
	Economic investment (EF)	Safety investment (EF1) Workers' compensation insurance (EF2) Safety investment on PPE (EF3)	Ratio of safety investment to total project volume Whether the contractor buys workers' compensation insurance for workers Average investment on worker's PPE on the project; Whether the project provides adequate PPE to each worker; Whether the contractor pays for the medical expenses of injured workers
	XF	Relations between the management and labor on site	Duration that the contractor has cooperated with the labor subcontractor; Percentage of the workers on site that are familiar to the project management staff

through physical jobsite inspections. The questionnaires were modified through evaluations made by 10 construction safety experts in Beijing. Afterwards, interviews were conducted on 10 projects in a pilot study. Comments and suggestions made in the pilot study were used to further modify the questionnaires. In summary, five types of data collection instruments were used on each construction project, namely one assessment tool sheet to be filled out by the researcher to evaluate the physical safety performance of a project, and four types of interview questionnaires to be completed by project personnel. The number of questionnaires on each project were approximately as follows:

- 1 safety audit tool sheet;
- 2 questionnaires to be completed by two individuals at the project manager level;
- 2 questionnaires to be completed by two different safety supervisors;
- 2 questionnaires to be completed by two selected foremen; and
- 20 questionnaires to be completed by randomly selected workers.

In July 2000, 100 undergraduate students studying at the Department of Civil Engineering, Tsinghua University were trained to objectively assess physical safety performance on projects with the assessment tool sheet and to interview selected individuals on the projects. The students are required to work on construction projects for 6 weeks for construction practice credit. They evaluated the safety performance with the assessment tool sheet and interviewed different individuals on site with the questionnaires. Following the criteria that the project volume should be at least 10,000 m^2 in construction area, a total of 82 projects were included in the study. These projects were mainly residential and commercial building projects, located in major cities in China, including Beijing, Shanghai, Tianjing, and Shenzhen. From these 82 projects, a total of 1,714 valid questionnaire interviews were conducted including:

- 82 project safety assessment tool sheets;
- 136 questionnaires by interviewing project managers or directors;
- 127 questionnaires by interviewing safety supervisors or managers;
- 130 questionnaires by interviewing foremen; and
- 1,239 questionnaires by interviewing workers.

In the data analysis phase, the data obtained from the questionnaires were quantified. The assessment of the project physical safety environment by using the Standard (JGJ 59-99), the accident and incident rate, and the satisfaction of people on site were used to establish the safety performance index (SPI). Information concerning safety management on the project was obtained for each of the seven key managerial factors and the other items (subfactors), in order to establish the safety management index (SMI). The various responses to the questionnaires were categorized as belonging to one of the seven key managerial factors. Based on the weighting established in the preliminary study, different weights were given to the different elements in each category. The items that define each factor were obtained through the questionnaires and were given values of -1, 0, or $+1$, indicating their perceived negative, normal, or positive influences on safety management. The requirements of regulations and codes (Qin 1994) on construction safety management were used as the criteria to determine if the value of an item should be -1 (lower than the requirement), 0 (just fits the requirement), or $+1$ (above the requirement). Each item is weighted, as determined through the interviews and the literature review in the preliminary study. To standardize the values of each factor, they are all quantified to be ten-point scores.

The SPI is based on the assessment of past safety performance of the project, and is commonly accepted in China. The data analysis sought to establish the importance of each variable in the SMI in influencing the SPI. Multifactor statistical analysis and linear regression were applied to the data using the *Statistical Package for the Social Sciences (SPSS v 8.0)*. Coefficients of the variables in the SMI were determined, which represent real-time safety management performance. These variables impact or influence the SPI. Based on the results, a real-time safety management assessment method was established.

In the implementation phase, the developed safety management assessment method was further modified and used to assess safety management on six construction projects in Beijing. The results were then compared with the inspection results conducted by the site safety supervisors, in order to evaluate the feasibility and acceptability of utilizing this approach on site. The results were discussed with the site safety persons, and comments and suggestions from them were then summarized for future application of the method.

J. Constr. Eng. Manage., 2004, 130(3): 424-432

Quantification of Data

Both SPI and values for the seven factors that comprise the SMI on the 82 projects were quantified. Meanings of each factor, as well as the items that make up the factors, are presented in Table 1.

Physical Safety Performance Index

In the safety assessment tool sheet filled out by the students on each individual construction project, three categories of data were obtained. They are safety audit (inspection) records of the student based on his/her walkthrough audit during their stay on the projects, the incident rate (incidents per month), and the satisfaction of the site persons with safety. A safety audit was conducted by the students with reference to the Standard of Construction Safety Inspection (JGJ 59-99), mainly focusing on factors including housekeeping, PPE, observation of unsafe behaviors, and the frequency of near misses. A perfect score on the audit result was 10 points, and it was modified with the frequency of incidents (on a monthly basis, if greater than once monthly the rating was -1), and the satisfaction of site persons with safety. The satisfaction with safety of the 26 individuals interviewed on the project was rated as -1 (unsatisfied), 0 (fair), and $+1$ (satisfied), and then averaged and added to the sum of the safety audit results and frequency of incidents.

In the pilot study, this method to measure the project physical safety performance was conducted and discussed with the site safety persons. It turned out to be an effective and acceptable method to them and was compatible with the safety inspection records maintained on site.

Project Factor

The project factor (PF), representing the nature of the project, is supposed to have a strong influence on describing the complexity of safety management on site. After the site inspections were completed and the interviews were conducted with safety supervisors on site, three descriptors were identified for PF. These include the size of the project (PF1, measured by the volume and total areas of the project, etc.), complexity of project construction (PF2, measured by the type, size of the project, and the implementation of new technologies, etc.), and complexity of project management (PF3, measured by the number of workers on the project and the number of subcontracts awarded).

Historic Factor

The historic factor (HF) mainly indicates the safety-related experiences of people on site, as human experiences influence their safe or unsafe actions, and their involvement in safety management on site. The factor is determined by four variables, including worker age and experience (HF1), percentage of new workers on site (HF2), accident experience (HF3), and experience of safety punishment and rewards (HF4).

Organizational Factor

The organizational factor (OF) indicates the organizational structure or the involvement of the organization in safety management on site. It is influenced by the number of safety supervisors (OF1), the involvement of contractor top management (OF2), authority of safety supervisors (OF4), authority of foremen (OF4), and size of the workforce on site (OF5).

The ratio of the number of safety supervisors on site (OF1) to the total area (square meters) of the project, and the ratio of the number of safety supervisors to the number of workers on site are both taken into consideration to quantify this item. The more time that safety supervisors spend on site, the better the safety management is expected to be on the project. If the ratio between the number of safety supervisors and the total enclosed construction area (m^2) of the project was between 1:5,000 and 1:10,000 (a requirement in most Chinese metropolitan areas and commonly accepted as the criteria to determine the number of safety supervisors), OF1 will be 0. If the ratio is below or above the range, OF1 will be -1 or 1, respectively. The ratio of the number of safety supervisors to the number of workers on site is determined similarly, with a rating of ''0'' indicating a ratio of 1:200–1:400.

If the top manager of the general contractor personally participates in safety inspections on site, and if he or she reviews safety records of a project regularly (measure of OF2), the importance of safety would certainly be emphasized for people on the project. If the frequency of safety inspections conducted by top management were monthly (which is the regular frequency in most construction firms), OF2 would be 0. If the frequency was less, OF2 would be -1 and if more than once a month OF2 would be $+1$.

If the safety supervisor can suspend construction operations at any time he or she finds that a serious hazard exists (measure of OF3), the safety supervisor is considered to have adequate authority. This reflects the emphasis placed on project safety by the contractor. If the safety supervisor was granted the power to stop site work whenever he or she thinks that a serious hazard exists on site, the value of OF3 would be $+1$. Otherwise, OF3 would be -1.

The level of authority of foremen on site (OF4) is key to safety management on site because first-line supervisors directly influence workers on the project (Hinze 1997). A foreman with good leadership skills will be able to direct the work team to work safely, thus safety management on site is stronger because of the foreman. This item is determined by the self-assessment of the foreman and the workers in the crew. If the foreman and the workers all think that he or she has good leadership skills, OF4 would be $+1$. Otherwise, OF4 would be 0 or -1.

Currently in China, the average number of workers in a typical crew (OF5) is 20–30. With this many workers in the crew, the foremen often find it difficult to adequately oversee all the workers. In many cases, workers may perform work in an unsafe manner without the foreman being able to discover and correct it before an accident occurs. If the number of workers in a crew were within the range of 20–30, OF5 would be 0. If below the range, OF5 would be $+1$ and if above OF5 would be -1. While the researchers felt that the size of a crew consisting of 20–30 workers was too large to ensure the safety of the workers, this range was used as a median value because of the current practice in China of maintaining such large crews.

Management Factor

The management factor (MF) reflects the implementation of safety management approaches on site. In comparison with those involved in the organizational factor information, these measures are ''dynamic'' and are quantified by taking several ''readings.'' The MF is determined by six items: safety inspections (MF1), safety meetings (MF2), safety plan and records (MF3), safety rewards (MF4), safety training (MF5), and other safety management measures (MF6), including whether the workers are encour-

J. Constr. Eng. Manage., 2004, 130(3): 424-432

Table 2. Numbers of Projects in Each Class According to the Safety Performance Index (SPI)

	SPI categories					
	Poor		Weak	Fair	Good	Outstanding
Range of SPI	0–2	2–4	4–6	6–8	8–10	>10
Number	4	4	26	20	20	8

aged to work with friends, whether the foremen can fire workers directly, and whether or not schedule pressure is passed onto the workers, etc.

Individual (Involvement) Factor

Individuals on each project were divided into project managers, safety supervisors, foremen, and workers, based on their influence on site safety management. The factor of individual involvement was determined by the safety knowledge (CF1), safety awareness (CF2), and safety involvement (CF3) of the individuals.

Economic (Investment) Factor

Economic investment in safety has considerable influence on safety management. However, currently in China many projects generate little profit for the contractors and in some cases huge losses are incurred. Thus there is often an inadequate economic investment in safety on most projects. The economic (investment) factor (EF) is determined by the safety investment (EF1, the criteria range is 0.5–1% of the project volume), whether there is workers' compensation insurance coverage (EF2), and the level of investment in PPE (EF3).

Management-Labor Relations Factor

It was found that relations between management and labor on site impact safety management on the project. It is now very common in China for workers on site to be employed by others and not by the general contractor. The practice of using "labor subcontractors" has grown in recent years. The labor subcontractor recruits and trains the workers selected to finish most of the operations and activities on site. Therefore workers on site are often only indirectly managed by the project management team. The management-labor relations factor (XF) was mainly determined by the duration for which the contractor had previously worked with the labor subcontractor, and the familiarity of the workers with site management.

Establishment of the Safety Management Index

In order to establish the safety management index (SMI) to reflect the real-time safety management on site, it was necessary to use an index that was already commonly accepted on construction sites. SPI is such an index that is mainly determined by the existing Standard, JGJ 59-99, modified by the accident/incident rate on the project and the satisfaction of the people to the safety performance on site. It was considered to be an indicator to demonstrate the results of safety management efforts. In the research, each inspector evaluated site safety according to JGJ 59-99, and examined the accident records, while the level of satisfaction of the people with site safety was collected through the questionnaires.

The projects were categorized into five classes by their SPI, including poor, weak, fair, good, and outstanding. Most SPI values of the 82 projects were between 4 and 10, with an average of 6.72 points and a standard deviation of 0.30. The information about the SPI is summarized in Table 2.

After the seven key management factors were evaluated and quantified, the relationship of the SMI with the SPI was analyzed by means of *SPSS* (v 8.0), to identify those factors that were most closely related to the safety performance. Pearson's correlation coefficients between the seven factors and SPI are shown in Table 3.

The factors OF (organizational structure), EF (economic investment), and XF (labor-management relations) are positively correlated to SPI. HF (historic factor) is not positively related with SPI, indicating worker experience on site currently has no measurable impact on safety performance in China. Further analysis of the data showed that construction worker safety awareness did not improve with construction experience. This indicated that workers were poorly educated and trained at work and gained no evident safety knowledge or safety awareness with the accumulation of experience on site. PF (project nature) was not found to be significantly related to the SPI, indicating that safety performance of each project is primarily determined by safety management, not by the nature of a project itself. As most of the projects interviewed in the research were building and commercial projects, the complexities of the projects were quite similar, and did not show strong differences. The correlation analysis also shows that MF (management factor), OF (organizational factor), and CF (individual factor) are significantly related with each other. It is reasonable to believe that a better organizational structure for safety management on the project will lead to better safety management and more involvement of people in safety management.

Table 3. Pearson Correlation Coefficients between the Safety Performance Index (SPI) and Factors Influencing the Safety Management Index (SMI)

	SPI	PF	HF	OF	MF	CF	EF	XF
SPI	1	−0.038	−0.104	0.308[a]	0.111	0.229[b]	0.360[a]	0.334[a]
PF	−0.038	1	−0.029	−0.093	−0.014	0.022	0.292[a]	0.017
HF	−0.104	−0.029	1	0.084	0.112	0.132	0.141	−0.005
OF	0.308[a]	−0.093	0.084	1	0.361[a]	0.321[a]	0.214	0.11
MF	0.111	−0.014	0.112	0.361[a]	1	0.655[a]	0.293[a]	0.163
CF	0.229[b]	0.022	0.132	0.321[a]	0.655[a]	1	0.372[a]	0.476[a]
EF	0.360[a]	0.292[a]	0.141	0.214	0.293[a]	0.372[a]	1	0.181
XF	0.334[a]	0.017	−0.005	0.11	0.163	0.476[a]	0.181	1

[a]Correlation is significant at the 0.01 level (2-tailed).

[b]Correlation is significant at the 0.05 level (2-tailed).

J. Constr. Eng. Manage., 2004, 130(3): 424-432

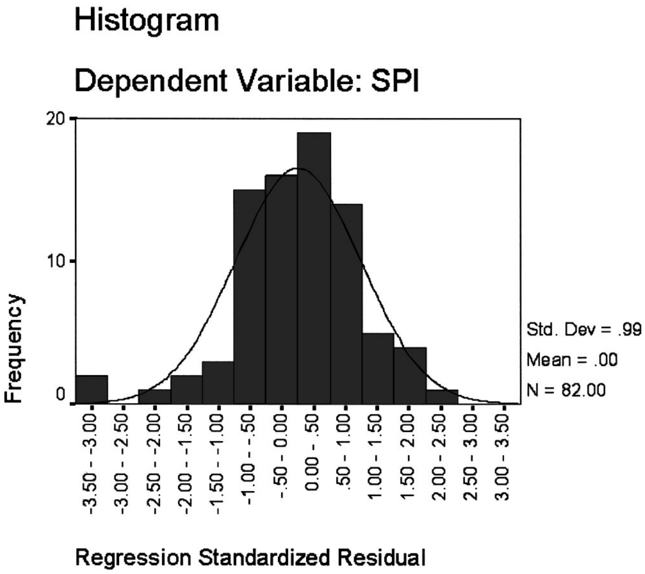

Fig. 2. Histogram of the regression

In order to determine the function of the SMI, multifactor linear regression was conducted by making the SMI (which reflects the current safety management on the project) equal to the SPI (which represents the safety performance of the project in the past). The SMI was established as the dependent variable and factors influencing SMI as independent variables. Forward linear regression was carried out. The SMI and the coefficients of the factors are shown in Eq. (2).

$$\mathrm{SMI} = (\mathrm{OF} \times 0.485) + (\mathrm{EF} \times 0.4) + (\mathrm{XF} \times 0.254) \qquad (2)$$

The histogram and the normal *P-P* plot of the regression-standardized residual are shown in Figs. 2 and 3. It is evident that the normality assumption of the linear regression is reasonably satisfied. The R square of the regression is 0.899, which means that the results can explain 89.9% of the variability of the dependable variable, SMI. Therefore it is concluded that SMI has a linear dependency with factors that influence it.

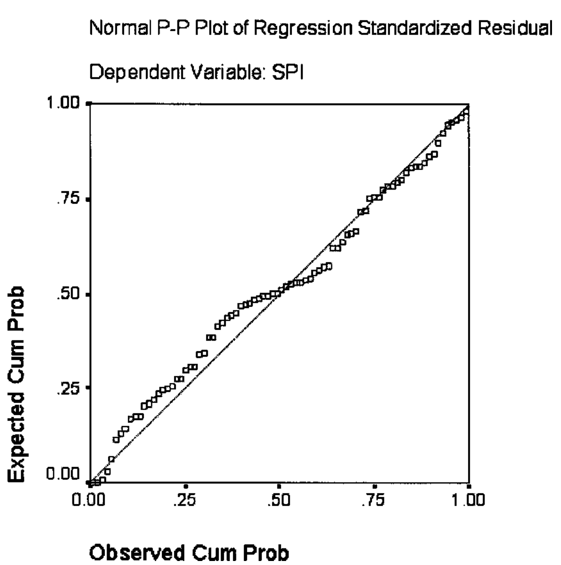

Fig. 3. Normal *P-P* plot of regression standardized residual

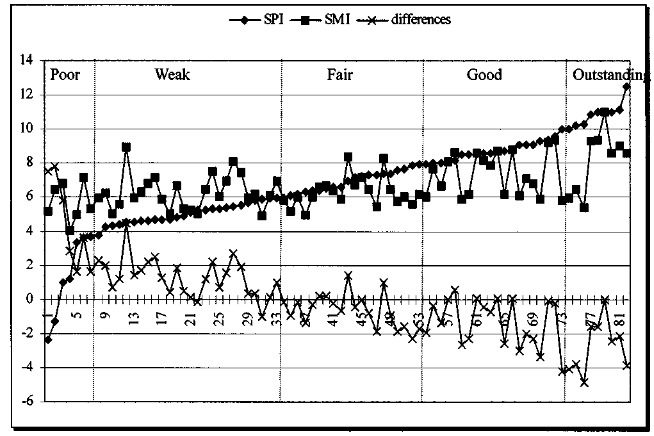

Fig. 4. Safety management index (SMI), safety performance index (SPI), and their differences

HF and PF are not significantly related to the SPI, and it is reasonable that they are not included in Eq. (2). MF and CF are significantly related with OF, and they are also excluded to avoid multicollinearity. The coefficients of the factors demonstrate their priority in the determination of safety management. OF has the greatest weight because organizational structure generally reflects the contractor's top management commitment to safety and has a very strong influence on safety management. The organizational structure can also impact safety management and individual involvement. Economic investment is significantly related to SPI, and can influence the management measures (MF), as well as individual involvement (CF) on the project (especially with an effective safety recognition and training program). As a special but important management factor to influence safety management performance, the labor-management relations factor (XF) is also included in the equation; however, its weight is not as large as MF or CF.

Fig. 4 shows the comparison of the SMI with the SPI for the projects included in this research. The horizontal axis is the rank of the projects in ascending order by their SPI values. It can be observed that the SMI is not as good at predicting the SPI when the SPI values are in the classes of "poor" (when the SPI is less than 4) or "outstanding" (when the SPI is more than 10). The prediction of the SPI is stronger when the SPI is in the "weak," "passed," or "good" (when SPI is between 4 and 10) range. This shows that the SMI values are similar to the SPI values when the safety performance index on the project is moderate.

Safety Management Assessment Method and Its Application

Referring to the aforementioned results, a practical safety management assessment method was developed. Three factors are evaluated in the method, namely the organizational and managerial factors, safety economic investment factors, and management-labor relations factors (see Table 4). These factors consist of different types of information that can be ascertained through questions. Organizational structure is closely related to management measures and individual involvement in safety management. Other items, such as the involvement of the project managers and safety managers are also taken into consideration. In order to make the assessment method more applicable, changes

J. Constr. Eng. Manage., 2004, 130(3): 424-432

Table 4. Safety Management Assessment System to be Used on the Projects

Indicator	Factors	Items	Questions
SMAI	A: organizational factor$=(A1)+(A2)+(A3)+(A4)+(A5)$	Quantity of safety supervisors ($A1$)	The ratio between the number of workers and the number of safety supervisors; The ratio between the building area and the number of safety supervisors
		Involvement of contractor firm ($A2$)	Intensity of safety inspection conducted by top management; Whether the top management checks safety records of the project; Whether the hierarchical responsibility system exists in the contractor firm
		Authority of safety supervisor ($A3$)	Whether the safety supervisor has authority to stop site work when he or she discovers a serious hazard
		Authority of foreman ($A4$)	Whether the foremen has great authority in the working group
		Size of the crew ($A5$)	How many workers are in one crew
	B: economic investment$=(B1)+(B2)+(B3)$	Safety investment rate ($B1$)	Ratio between safety investment and total project volume; Whether the project can invest in safety on time
		Workers' compensation insurance ($B2$)	Whether the contractor buys workers' compensation insurance for each worker on site
		Safety investment on PPE ($B3$)	Average investment on worker's PPE on the project; Whether the project provides enough PPE to each worker; Whether the contractor pays for the medical expenses if a worker is injured
	C: Labor-management relations	Relations between the management and labor on site	Duration that the contractor has cooperated with the labor subcontractor; Percentage of the workers on site that are familiar with the project management staff

Note: SMAI=safety management assessment index.

have been made to Eq. (2). The safety management assessment index (SMAI) to indicate safety management on a project is expressed as

$$\mathrm{SMAI}=(A\times 0.45)+(B\times 0.35)+(C\times 0.20) \qquad (3)$$

where A=demonstrated organizational structure; B=demonstrated economic investment; and C=demonstrated management-labor relations.

Compared with Eq. (2), the maximum values of A, B, and C have all been changed to 10, in Eq. (3), for easy application. Their weights have been changed to assure that the same result as the SMI could be obtained by the SMAI.

The SMAI was then applied on six residential and commercial building projects in Beijing. The projects were of different sizes and in various stages of construction. The factors determining SMAI were quantified. The SPI and the results of the safety assessment by the safety supervisors were also obtained, as shown in Table 5. The SMAI of the six projects were basically in accordance with the SPI of the projects, with the exception of project P5 where a discrepancy is apparent. Safety management on projects P1 and P2 was rated as outstanding, and their safety performance was also excellent. Safety management on projects P3 and P4 were fair, as were their SPIs. Projects P5 and P6 were poor in safety management; their SMAI and SPI were both very low. By review of the evaluation of SMI, the reasons that cause poor safety performances in P5 and P6 are: poor organizational and managerial safety management measures (A in Table 5) and bad relations between management and labor (C in Table 5). By completing SMAI, management on a project can have a clear understanding of its safety management on site, and can easily

Table 5. Comparison of Safety Management Index and Safety Management Assissment Index Applied to the Projects

Project number	P1	P2	P3	P4	P5	P6
Safety assessment by safety supervisor	9.5	9.0	8.7	8.3	7.5	7.0
Safety performance index (SPI)	9.45	8.2	6.95	6.85	5.2	1.6
Organizational structure (A)	9.9	9.5	4.5	8.5	2	0
Safety economic investment (B)	6	8	7	6	7	5
Management-labor relations (C)	9.9	6.6	9.9	0	0	0
$\mathrm{SMAI}=0.45\times A+0.35\times B+0.2\times C$	8.54	8.40	6.46	5.93	3.35	1.75

J. Constr. Eng. Manage., 2004, 130(3): 424-432

find what they need to do to improve safety performance. Safety management on project P5 was very poor because the site work has just commenced, and the safety management was not well established, therefore the relationship between labor and management was not good. Another contributing factor is that project P5 had quite limited space, making it difficult for workers to work safely. Although the safety organizational structure on the project was mediocre, and the safety management was not strong, it also indicated that SMAI and SPI were not always correspondent with each other. If safety management on site changes, the SMAI can reflect the change immediately, but the SPI might change a considerable time after the changes have taken effect.

On the projects that use the safety management assessment method, safety supervisors and the project managers all agreed that the method effectively assessed safety management on the project in real time, and they could have a clearer understanding of what they should do to improve safety. However, as resources invested for safety management on the project were generally limited, further research on the reasonable allocation of safety investment by cost-benefit analysis of safety management is necessary. Then, project management could determine the most economical and effective actions they should take in order to improve safety management.

Conclusions

In this paper, relying on site interviews and a review of the literature, seven categories or factors were identified to assess safety management on construction projects. Questionnaires and site inspection forms were then designed to collect data from 82 construction projects in China. The items and factors were quantified and relations between the factors were identified by correlation and regression analysis. It was found that organizational structure (OF), economic investment (EF), and labor-management relations (XF) are significantly related to the safety performance on construction sites. A linear equation to calculate the SMI with the three factors was obtained and a method to assess safety management on the project was developed and applied on six projects in Beijing.

After careful discussion with safety supervisors and project managers on various sites, it became apparent the safety management assessment method suggested in this paper could be easily applied on construction projects. It can efficiently reflect safety management performance on site. Since most of the items in the method were evaluated objectively, the results are reliable. Sensitivity and stability of the method are good when considering that the items are measured by different aspects of project safety management. Safety supervisors on site can readily understand the method, and they can assess safety management on the project by answering approximately 20 questions within 30 min. By using this method, reasons that lead to poor safety management on site can be easily detected, and countermeasures can be implemented. Some safety supervisors, as well as project managers, have indicated that they are in need of such a safety management assessment tool to guide their efforts on safety. If the method can be further tested and modified, it will effectively help improve site safety management.

In general, the safety management assessment method can be used to assess safety management performance on construction projects in China, and has the potential to be used as a safety management tool on construction sites.

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J. Constr. Eng. Manage., 2004, 130(3): 424-432