Evaluation of Construction Projects in Terms of Cost, Schedule and Safety Performances

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Abstract

Controlling is an important phase in any project. Earned Value Method (EVM) is one of the popular methods used in controlling a construction project. Safety management is an important management function and needs to be controlled efficiently on a project. Safety statistics should be reported in the same manner as cost, schedule, and quality. In EVM, cost schedule index (CSI) is calculated on the basis of cost performance index (CPI) and schedule performance index (SPI) only. We present a conceptual model to determine construction safety index of projects and propose a new total performance index linking it with CPI and SPI. This index represents the performance of cost, schedule, and safety management of a project. This new index can be named cost schedule safety index (CSSI) or total performance index (TPI). The new index should prove to be helpful to different stakeholders in understanding the project performance in a holistic manner.

Keywords

Earned Value Method, Cost Performance Index, Schedule Performance Index, Cost Schedule Safety Index, Safety Performance Deficiency.

INTRODUCTION

Each year there are at least 60,000 fatal accidents on construction sites around the world. This equates to one fatal construction accident every ten minutes (International Labor Organization, 2011). One in every six fatal accidents at work occurs on a construction site. Construction sector in India is the largest employer in the country after agriculture, employing approximately 33 million people (Construction Industry Development Council & Planning Commission, New Delhi, India, 2007). Based on the Indian Government's ambitious projects lined up for the Eleventh Plan Period (2007-2012), the demand for construction industry is expected to grow by at least 8-9 percent and 2.5 million employment opportunities for annum are expected to be generated. The average Fatal Accident Frequency Rate (FAFR= Incidents/1000 employees/year) is estimated to be 15.8 for Indian construction industry, while FAFR for the US construction industry, as per the data published by the US Department of Labour for the year 2005, is 0.23 (CIDC, New Delhi, 2007). This shows that safety management practice in construction sector is not adequate in India.

The success of any project depends to a great extent on the completion of engineering activities within the scheduled time and budgeted cost, and without any injury or accident at site. This performance is measured, compared, and controlled from these angles; progress against schedule and productivity against budgeted level and zero accidents at the site. Earned value is a methodology for determining the cost, schedule, and technical

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performance of a project by comparing it with the planned or budgeted performance (Jha, 2011). The Earned Value Method (EVM) of performance reporting is an effective control technique developed by the U.S.Department of Defence. It is based on the concept that quantitative performance can be evaluated in terms of earned financial value, and it can be used as the single yard stick to measure the project performance efficiency (Joy, 2007). However, the EVM does not reflect safety performance at projects.

In this paper, Earned Value Analysis (EVA) indices like Cost Performance Index (CPI), Scheduled Performance Index (SPI), and Critical Ratio (CR) are briefly described. The importance of safety management and the need of evaluation of projects in terms of safety performance are already established in various literatures. In this paper, we have considered the Construction Safety Index (CSI) proposed by Pathak and Jha (2011) for the measurement of construction safety performance and this index has been linked with CPI and SPI. By combining the three indices, a new index, Cost-Schedule-Safety Index (CSSI) or Total Performance Index (TPI) has been proposed.

LITERATURE REVIEW

Construction is recognised as one of the most hazardous industries across the world due to its unique nature (Jannadi *et al*., 2002). It is a high risk occupational area in modern society (Liao and Perng, 2008; Niza *et al*., 2008). Construction industry also suffers from high accident rates, which results in absenteeism, loss of productivity, permanent disability, and even fatalities (Mohamed, 1999; Niza *et al*., 2008).

A number of researchers have emphasized the importance of safety. According to Stanton *et al.* (1990), safety must be an integral part of the company's procedures. It is noted that many construction companies follow the 'Zero accident' or 'Zero incidence' policy. John Holland's 'Zero Harm' approach to safety in construction sites is described as "sending our people home in the same condition in which they arrived to work" (Patrick *et al.,* 2011). It is known that the most effective way to improve safety performance should be preventing accidents and reducing uncertainty before it happens (Cooke, 1997; Gambatese *et al.,* 2008).

''What gets measured gets managed'' is a well-established fact. Unfortunately, most conventional metrics of safety performance have inherent limitations; it is reactive in nature, causal relationships cannot be established, and it does not include positive aspects of safety performance (Marosszeky *et al.,* 2004 cited in Ghosh *et al.,* 2009). The Frequency Rate (FR), Severity Rate (SR), and Incidence Rate(IR) that measure occupational injuries or death used extensively by government agencies only reflects the status of the occupational safety, but either of them fails to provide the management any information for improvement. A proper measure of the safety performance is also found to be crucial for effective safety management (Chin and Choi, 2003).

There was one of the review recommendations that the Hong Kong Government should provide a framework within which self regulation was to be achieved through a company system of safety management (Labor Department of Hong Kong, 2002). Many researchers emphasize incorporating safety management system at construction projects and establishment of a framework for their continuous assessment.

To improve safety performance of the construction industry, safety professionals are the key to carry out assessment on site (Aksorn and Hadikusumo, 2008). For the same, construction firms need a rational framework for Safety Performance Evaluation (SPE) in order to objectively gauge their effectiveness in accident prevention over time (Ng *et al*., 2005).There is a need for research that provides realistic and comprehensive evaluation of construction safety (Jaselskis *et al*., 1996).

The literature has focused on measuring and analyzing the safety climate of organizations and only a few comprehensive models of a safety management system and its evaluation have been developed in recent past (Fernandez *et al*., 2007). Mohamed (1999) investigated the effectiveness of safety management activities as currently adopted by the Australian Contracting Organization, and developed a Safety Management Index (SMI) reflecting the intensity of the level of safety management activities. Ng *et al.* (2005) used the results of the questionnaire survey to develop a safety performance evaluation (SPE) framework suitable for use in the construction industry for evaluating the safety performance at the organizational and project level. Teo and Ling (2006) developed a model to measure the effectiveness of safety management systems (SMS) of construction sites. Fernandez *et al*. (2007) developed a Safety Management System (SMS) scale based on the results of a questionnaire survey of 455 Spanish companies. Rajendran (2006) found a lack of a significant difference in safety performance between non LEED and LEED projects. Rajendran and Gambatese (2009) developed and validated a Sustainable Construction Safety and Health (SCSH) rating system, which may be useful to evaluate the safety performance of construction projects.

In India, Mahalingam and Levitt (2007) studied and identified challenges for international contractors to implement safety management system in developing countries like India and Taiwan for joint venture in construction projects. Bansal (2010) applied GIS in construction safety planning along with 4D modelling, geospatial analysis and topographic modelling in the development of safe execution sequence in construction project. Rajaprasad and Reghunath (2010) have made empirical analysis of construction safety climate by interviewing 52 experts from construction projects. Chockalingam and Sornakumar (2011) visited six construction sites for 40 weeks and studied the role and effect of management support and workers' behaviour to improve safety performance at construction sites. Beriha *et al.* (2011) evaluated the safety performance of construction, refractory and steel industries by using Data Envelopment Analysis (DEA). They made comparison and found that construction sector is poor in safety management. Their study is limited up to 30 organizations and mainly in eastern part of India.

Weights and attributes of construction safety management are strongly influenced by local environment and culture (Teo *et al.,* 2006). Hence, it is needed to conduct the study in the Indian context involving large number of experts' opinions and samples for developing an evaluation tool for the safety management system of any construction project.

EVM has become a popular tool among many project managers (Kim *et al.,* 2003).Construction companies use them to manage cost, schedule, and production. Earned Value Analysis (EVA) is used to measure the amount of work actually performed on a project and to forecast a project's cost and date of completion. The method relies on a key measure known as the earned value. This measure enables one to compute performance indices for cost and schedule, which shows how the project is doing relative to its original plans. These indices also enable one to forecast how the project will do in the future. But, it does not show the safety performance at sites. Thus, there is a need to have an index, which reflects the overall idea about cost, time and safety management at a project site.

NEED AND OBJECTIVE OF STUDY

Construction companies do not measure and control the safety performance in the manner they do for cost, schedule, and quality. This is probably the most important reason why the accident rate in the construction industry is so high (Stanton *et al.,* 1990). Earned Value Analysis (EVA) does not provide any information regarding safety performance at sites. This had led the authors to propose and work on developing a new index, which will provide information on cost, schedule and safety management at sites. The index will be useful to top management of the companies and other stake holders to review the various on-going projects in the combined perspective of cost, schedule, and safety performance at project sites. The development of index has relied heavily on the available indices for measurement of schedule, cost, and safety performances. The performance indicators and performance indices are described in brief in the following sections.

SCHEDULE PERFORMANCE INDICATORS

Earned value management provides two well-known schedule performance indices, the schedule variance (SV) and the schedule performance index (SPI), to measure project progress (Chitkara, 2011). Budgeted Cost of Work Performed (BCWP), Budgeted Cost of Work Scheduled (BCWS), and Actual Cost of Work Performed (ACWP) are the key terms used in EVM. These are also known as Earned Value (EV), Planned Value (PV) and Actual Value (AV) respectively. The SV is the difference between the earned value (EV) and the planned value (PV), i.e. SV = EV- PV. If SV < 0, project is behind the schedule and If SV > 0, project is ahead of schedule. If SV = 0, the work is exactly as per schedule. The SPI is the ratio of the earned value and the planned value, i.e. SPI = EV/PV. This is a dimensionless indicator to measure the efficiency of the work. If SPI < 1, the schedule efficiency is lower than planned and vice versa. If SPI=1, then schedule efficiency is as per the plan. It is obvious that at the end of a project, the SPI is always equal to 1.

COST PERFORMANCE INDICATORS

Cost variance (CV) and cost performance index (CPI) are used to measure the project progress in terms of cost of the project. Cost variance is the difference between budgeted cost of work performed (EV) and actual cost (AC), i.e. CV=EV-AC. If CV < 0, project is over budget and If CV > 0, project is under budget. If CV = 0, the work is proceeding as per the budgeted cost. The CPI is the ratio between the earned value and the actual value, i.e. SPI = EV/AC, and is a dimensionless indicator to measure the efficiency of the work in term of cost. If CPI < 1, the cost efficiency is lower than the planned and vice versa. If CPI=1, the cost efficiency is as per the plan. At the end of a project, the CPI is always equal to 1.

COST SCHEDULE INDEX (CRITICAL RATIO)

The Cost Schedule Index (CSI) is the product of CPI & SPI (Meredith and Mantel, 2000). It can also be called the critical ratio (CR) (Anbari, 2003). A CSI of 1.00 indicates that the overall project performance is on target. This may result from both CPI and SPI being close to target, or if one of these indices suggests poor performance, the other must be indicating good performance.

A CSI of more than 1.00 indicates that the overall project performance is excellent. This may result from both the CPI and SPI being better than target, or if one of these indices is indicating poor performance, the other must be indicating outstanding performance. A CSI of less than 1.00 indicates that the overall project performance is poor. This may result from both the CPI and SPI being worse than target, or if one of these indices is indicating good performance, the other must be indicating extremely poor performance.

CONSTRUCTION SAFETY INDEX

Pathak and Jha (2011) have proposed a Construction Safety Index (CSI) in context to Indian construction industry. This index is helpful to quantify and evaluate the safety management system of any construction project. They have identified potential factors affecting the success of safety programs from various literatures. CSI is developed on the responses to a questionnaire survey conducted in Indian construction industry. They developed a hierarchy consisting of 4 first level factors, 14 second level attributes, and 45 third level attributes. The relative weights of the first level factors and second level attributes of the framework have been computed using Analytical Hierarchy Process (AHP), while the relative weights of third level attributes have been computed using Mean Ranking (MR) and Mean Score (MS) method.

$$\text{Overall Weight} = W_j \times RI_{ij}$$

$$CSI_{ij} = W_j \times RI_{ij} \times r_i$$

Where, CSI_{ij} is the construction safety index of i^{th} third level attribute under j^{th} second level attribute, W_j is the global weight of j^{th} second level attribute, RI_{ij} is the relative importance of i^{th} third level attribute under jth second level attribute and r_i is the auditor's assessment on i^{th} third level attribute of a specific construction site. The CSI represents the score that can be assigned to each third level attribute according to the actual safety performance at a particular site. The construction safety index (CSI) for a given site can be calculated by rating the third level attributes on a 0/1 scale easily. The CSI is an objective tool to measure the effectiveness of safety management system. The range of CSI value is between '0' to '1'. A value of '1' indicates no accident or injury at the site and thus it is a target value for the entire construction duration. The CSI may be calculated for different durations for example weekly, monthly, yearly etc.

PROPOSED INDEX

EVM is one of the popular tools being used in construction project management due to its simplicity. It is used as a reporting tool by project managers to inform the performance of a project to the top management. But, EVM has been setup to follow-up only time and cost, not safety performance at project. In the proposed index performance on cost, schedule, and safety management of a project are tried to be combined.

The computation of proposed index (Cost-Schedule-Safety Index CSSI) would be based on the following equation:

Cost Schedule Safety Index (CSSI) = CPI x SPI x CSI =CR x CSI

In other words, the index is the product of Cost Schedule Index (Critical Ratio) and Construction Safety Index. The value of CSI varies from '0' to '1'. So, CSI is highly sensitive to CSSI (see Figure 1). If the value of CSI = '0', it indicates that safety performance at project is negligible and thus safety performance is very poor. In such cases, even if the project is showing good values of SPI and CPI, the overall performance is poor. If safety is managed at site as per standards and legislations, the CSI will be '1' which indicates that the overall performance is very good. In such cases, CSSI is equal to the cost schedule index (critical ratio). The minimum and maximum value of CSSI is '0' and 'CR' (for a month) respectively for a particular month. The difference between CR and CSSI can be calculated on a monthly basis. It can be referred as 'Safety Performance Deficiency (SPD)' for a particular month. Project management should focus on nullifying the SPD at projects. The value of SPD also varies from '0' to value of CR for a particular month.

DISCUSSION

For the illustration of the proposed index we take an example of a construction site. The performance of this site measured in terms of cost and schedule of the project. The life and cost of the project are 13 months and Rs.517.70 million respectively. The EV, PV, AC and CSI have been measured on a monthly basis. The CPI, SPI, CR, CSI and CSSI are calculated and plotted on graph as shown in Figure 1. Since the work is ongoing, the compatibility issue for indices as CPI, SPI, and CSI are not explored as of now and any possible correlation among them are yet to be established.

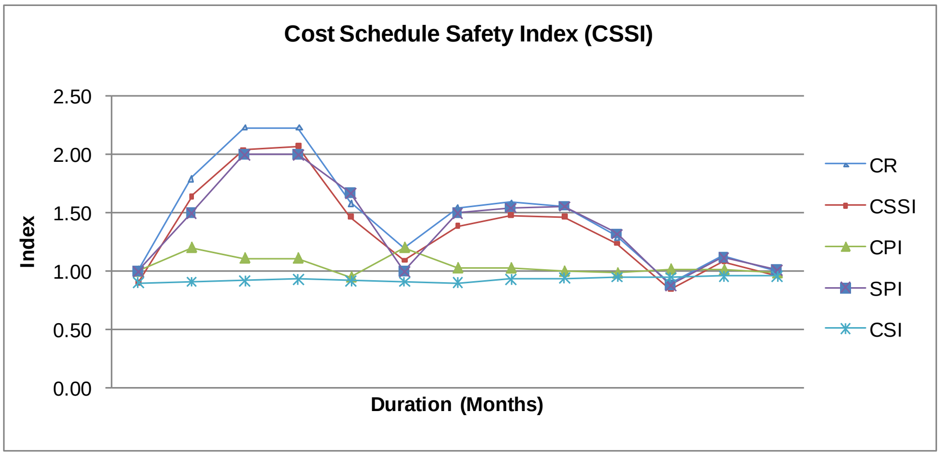

Figure 1. Cost performance, schedule performance, critical ratio (CR), construction safety, cost schedule safety indices.

Referring to Figure 1, it is observed that the value of CR is higher than all indices through out the project duration. CSI is also calculated on a monthly basis. By doing this, it is also possible to calculate and plot the value of CSSI along with CR. It is noted that the graph of CSSI is always lower than the graph of CR throughout the life of a project because the value of CSI is less than one. It also means that 100 percent safety performance was never achieved throughout the project life.

The interpretation and the behaviour of the earned value management performance indicator SPI over time has been criticized by different authors; If SPI=1 could mean that a task is completed it could also mean that the task is running according to plan. Towards the end of the project, the SV always converges to 0 indicating a perfect performance even if the project is late. Similarly the SPI always converges to 1 towards the end of the project, indicating 100 percent schedule efficiency even if the project is late. As a result, at a certain point in time the SPI becomes an unreliable indicator. The same limitations are also applicable with the proposed index (CSSI). It is also important to study the pattern of construction safety index (CSI) throughout life of the project because SPI and CPI are calculated on cumulative basis, but this is not the case with the construction safety index. The cost of safety is the part of cost of project. So it is also essential to study of interrelationship among cost safety index, CPI and SPI in various ongoing construction projects. The compatibility issue for indices as CPI, SPI, CSI and CSSI may be studied. The limitations of CSSI may be overcome by further research.

CONCLUSION

Safety management at site is critical and a challenging issue for top management. It is very essential to know the safety management of any project along with its earned schedule and cost of the project by its top management. The proposed index, CSSI (or

TPI) does represent safety management of project along with its earned cost and schedule of the project. This CSSI gives equal weight to cost, schedule, and safety parameters in project control. So, it may be considered as an important project controlling tool. By this index, top management will be able to differentiate project performance not only by its schedule and cost of project, but its safety management also. So it will be more useful to monitor safety management at site. The index is very simple, easy to calculate and easily understandable. It also presents graphical presentation of comparison of various similar projects. It may be calculated on a weekly or a monthly basis and may be reported to the top management. Decision makers, thus will have a clear picture on cost, schedule and safety parameters of a project. The CSSI can also be used to compare various projects and it would be possible to differentiate various projects easily in terms of cost, schedule and safety performance. This information and knowledge should prove to be useful to take strategic decisions by top management.

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