Development and Initial Validation of Sustainable Construction Safety and Health Rating System

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Abstract: This paper presents a study to develop and validate a sustainable construction safety and health (SCSH) rating system. The rating system provides an opportunity to rate projects based on the importance given to construction worker safety and health and the degree of implementation of safety and health elements. A Delphi survey using an expert panel of 12 experienced safety and health professionals representing different sectors of the construction industry was employed to develop the SCSH rating system. The study resulted in a rating system consisting of a total of 50 safety and health elements organized into 13 categories. Each category contains safety and health elements which carry credits based on their effectiveness in preventing construction worker injuries and illnesses. The rating system was initially validated based on data from 25 construction projects and found to accurately represent the safety performance of large projects. The SCSH rating system can be used as an effective tool to develop and plan construction safety and health programs and evaluate the potential safety performance of construction projects.

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Introduction

Efforts have been made over the past few decades to improve worker safety and health in the construction industry. Research has exposed the influence that owners, designers, constructors, and subcontractors have individually on construction worker safety and health. Some projects, especially petrochemical/industrial and DB projects, involve the owner, designer, constructor, and subcontractors working together to address safety and health during the project development process. Research aimed at identifying and assessing project safety performance when all four parties are involved and committed to worker safety is needed. All of the parties should strive to develop a positive safety culture and commit to creating an injury free work environment on all of the projects they perform. No industry-wide recognition such as a safety certification exists, however, for those projects that stand out in their commitment to reduce workplace fatalities and injuries. If present, such recognition would provide a motivation to project teams to sustain a high level of safety performance.

Another stimulus for this research is the minimal attention given to construction worker safety and health considerations in current sustainable design and construction practices. The United States Green Building Council's *Leadership in Energy and Environmental Design* (LEED) rating system, for example, is recognized throughout the construction industry as a standard by which buildings are rated for their sustainability. Formal consideration of construction worker safety and health in the LEED rating system, however, is minimal (Rajendran 2006). If an injury or fatality occurs during the construction of a building designed to be sustainable, is the project sustainable? Construction worker safety and health plays a major role in achieving sustainable socioeconomic development in the construction industry. The authors believe that the construction industry's current perspective of sustainability should include construction worker safety and health in addition to the safety and health of the facility occupants. It should be recognized that preserving the safety and health of the individuals who construct the facilities is part of sustainability. Sustainable practices should consider the entire facility lifecycle, from the project's initial conception through decommissioning, and aim to sustain all resources including human resources.

LEED's negligible consideration of construction worker safety and health, and a lack of a significant difference in safety performance between LEED and non-LEED projects (Rajendran 2006), prompts the development of a "sustainable construction safety and health" (SCSH) concept. The sustainable safety and health concept aims to sustain a construction worker's safety and health: from start to finish of a single project; for each future project a worker is involved in; and during the worker's remaining lifetime after retirement (Rajendran and Gambatese 2005). For example, the work lives of many construction workers have been shortened by repeated physical hazards posed by exposure to lead, silica, asbestos, and many other chemical and environmental hazards to which he or she was exposed (Hill 2003). The condition persists even after the exposure ends when the worker quits the job or is reassigned. The construction worker's health could have been sustained if he or she were properly protected from the exposure, or the hazard was eliminated, in the first place. Safety and health program elements exist that, if properly implemented in a project development process, can help sustain worker safety and health.

This study applies the concept of sustainability to construction

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worker safety and health with the development of a SCSH rating system. An SCSH rating system provides an opportunity to rate projects based on the importance given to safety and health and the degree of implementation of safety and health elements, and unifies and coordinates the safety and health efforts of the four primary parties in a project: owner, designer, general contractor, and subcontractors.

Construction Safety and Health Research and Practice

Previous research has identified ways to ensure and enhance construction worker safety and health on projects. Project owners can play a large role in worker safety through a variety of activities such as: setting project safety goals; selecting constructors based in part on safety performance; proactively participating in safety on the project; and addressing safety in the construction contract (Levitt and Samelson 1993; Hinze 1997; Huang 2003; Hinze and Godfrey 2003; Gambatese 2000). Research findings are continuing to reveal that the owner's role in jobsite safety is significant and cannot be understated or ignored.

Of all the parties that play a role on a project, constructors commonly take the lead role in addressing construction worker safety and health. This is due primarily to the mandate of the Occupational Safety and Health Act (OSHA) that employee safety is the responsibility of the employer, and construction contract general conditions which typically state that the constructor has primary responsibility for safety on the project site (Toole 2002a). Much has been studied about the constructor's role in and impact on construction site safety and health. Several studies have identified elements for effective safety programs. In 1994, Meridian Research Group published a report citing various elements as essential to an effective construction safety program (Meridian Research 1994, as cited in Findley et al. 2004). These elements include among others: a written, comprehensive safety and health program/plan; safety and health responsibility and accountability clearly established and implemented; employee involvement in the design and operation of the safety and health program; and frequent worksite inspections. Liska et al. (1993) conducted an extensive research study that resulted in the identification of eight safety-related techniques (zero accident techniques) which, if implemented in a quality manner within a total safety program, will result in excellent project safety performance. The study concluded that of the eight techniques, the following five had the greatest impact on attaining a zero or near zero accident project: Pre-Project/Pre-Task Planning; Safety Orientation/Training; Safety Incentives; Alcohol and Substance Abuse Program; and Accident and Near Miss Investigation. Additional strategies for achieving excellence in construction safety performance at the project and company levels were reported by Jaselskis et al. (1996). Most recently, Hinze et al. (2001) presented nine best practices to be followed by constructors to make zero accidents a reality. This study was conducted to examine changes made since the initial zero accidents research was published (Liska et al. 1993). The nine elements that resulted from this research are Demonstrated management commitment; Staffing for safety; Safety planning Safety training and education; Worker participation and involvement; Recognition and rewards; Subcontractor management; Accident/incident reporting and investigations; and Drug and alcohol testing. Previous research has also resulted in guidance on how subcontractors can improve jobsite safety (for example, Hinze and Figone 1988; Hinze and Talley 1988; Hinze and Gambatese 2003; Fredericks et al. 2002; Abudayyeh et al. 2003; Fredericks et al. 2005).

A more recent focus of safety research has been on the influence that designers have on construction site safety. Eliminating the hazard is widely recognized as a far more effective way to improve safety than reducing the hazard or providing personal protective equipment to workers (Gambatese et al. 2005; Manuele 1997). Designers are in the best position to implement specific safety design recommendations, thereby preventing hazardous conditions on the site (Toole 2002b). Numerous examples exist of how architects and design engineers can be brought into the effort to improve construction site safety through the design and the design process (Gambatese et al. 1997; Behm 2005; Weinstein et al. 2005; Hecker et al. 2005).

Current construction safety and health literature provides evidence of how each party involved in a construction project can individually work to improve safety and health. Research is needed to develop a tool that can be used to organize the activities of each party into a proactive and collaborative safety and health effort and to evaluate the expected safety and health performance on projects.

SCSH Rating System Development

The research study involved two important phases: (1) development of the SCSH rating system, and (2) validation of the SCSH rating system. The objective of developing the SCSH rating system was to create a tool to assist the construction industry in incorporating construction worker safety and health into sustainability concepts and practice. To fulfill this objective, the following research questions were formulated:

- What are the important construction worker safety and health elements that should be part of the SCSH rating system?
- What is the effectiveness of these elements in preventing injuries and illnesses?
- What should be the structure of the SCSH rating system?

The elements contained within the SCSH rating system were initially drawn from literature and construction safety experts. Past research has focused on the owner, designer, contractor, and subcontractors, and reveals their impacts on construction site safety. These research studies were identified as a potential source from which critical elements for the SCSH rating system can be drawn. Studies that identified the roles and influence of these four parties on safety were reviewed. All of the major elements reported in the literature to improve safety performance were extracted and recorded (Rajendran 2006). A detailed presentation and description of these elements is beyond the scope of this paper and the reader is referred to the literature on this topic.

Research Methodology

The Delphi technique was chosen as the research methodology to develop the SCSH rating system. The Delphi technique is a series of sequential questionnaires or rounds, interspersed by controlled feedback, that seek to gain the most reliable consensus of opinion of a group of experts (Linstone and Turoff 1975). The Delphi technique is well suited to the research study since selection of safety and health elements for the rating system calls for value judgment from dispersed experts in the construction safety and health field. The purpose of the Delphi study was to extract safety and health program elements from the experts along with the

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experts' opinions of the effectiveness of each element in reducing construction site injuries and illnesses.

The success of a Delphi survey clearly rests on the combined expertise of the participants who make up the expert panel (Powell 2003). There are two key aspects to panel composition: panel size and panel member qualifications. Turoff (1970) recommends 10–50 participants on a Delphi panel, whereas Adler and Ziglio (1996) suggest that, with a homogenous group of experts, reasonable results can be obtained with 10–15 experts. It is generally regarded that as the number of members increases, the reliability of a composite judgment increases (Murphy et al. 1998). The actual size of the panel, however, commonly varies according to the scope of the problem and resources available (Fink et al. 1991, as cited in Powell 2003). The researchers decided to form a panel of at least 10–15 experts for the present study. This size was felt to be sufficient with a composition of highly qualified, diverse panelists containing at least one expert representing each of the different parties to a construction project.

The expertise of the panel members for the development of the rating system was evaluated based on their professional accomplishments within the field of construction safety and health. Using information drawn from the literature, a list of eight criteria was produced to help the researchers define an "expert." For the present study, the criteria used to distinguish experts are education, authorship, conference presentation, work experience, professional licensure, safety association participation/affiliations, faculty positions, and book authorship. It was decided that participants who met at least three of the eight criteria would be included in the panel.

Using the criteria presented above, the researchers identified 20 prospective panel members from the safety and health profession within a wide range of occupations closely related to the construction industry. The potential experts were contacted and informed about the research, its objective, the Delphi process, and the time commitment required for the study. Fifteen out of the 20 members contacted responded positively to be part of the expert panel. Of the 15 participants: five (33%) are academics in the health and safety and/or construction disciplines; two (13%) work for general contractors; two (13%) work for an owner firm, one (6%) works for a subcontractor; one (6%) works for a safety and health regulatory agency; one (6%) is a DB professional; one (6%) works as a loss control consultant in an insurance company; one (6%) works as a safety and health consultant; and one (6%) is a safety and health professional who represents a workers' union.

Of the 15 experts who initially expressed interest, only twelve responded to the study's first round. Of the three who did not respond to round one, two were from academia and one from a general contracting firm. The professional accomplishments of the 12 panel members were gathered with the help of an online survey. The panel members are geographically spread across the United States, representing six different states and the district of Columbia, with the majority in Oregon. The safety and health experience of the panelists ranged from 4 to 50 years (mean = 19.7 years; median = 16.5 years). Except for two members who had no experience in construction, all others had more than 10 years of experience in the construction industry. The panelists possessed a variety of academic degrees and industrial certifications, and have published papers and given presentations at numerous construction industry conferences. Based on the demographics, all of the panelists were judged to be experts in the field of construction safety and health and, as a result, their inclusion in and contribution to the study justified.

Delphi Surveys

Delphi surveys of the expert panel were conducted to: (1) identify the elements needed to be part of the rating system; (2) allocate appropriate credits for the elements identified; and (3) develop a feasible structure for implementation of the rating system. The researchers conducted three rounds of surveys. It was decided to identify all of the possible elements in the first round, gaining consensus on the elements and their ratings as the rounds progressed, and finalizing the structure of the rating system in the third round.

Round I

The first round questionnaire was sent to the 15 experts who agreed to be part of the expert panel. The questionnaire was structured to contain open-ended questions to give the experts free reign to identify and elaborate on those safety and health elements they see as important and rate the elements based on their effectiveness in preventing construction worker injuries/illnesses. The questionnaire consisted of the following two questions:

1. What are the various construction worker safety and health elements/initiatives implemented on projects?
2. Rate each element/initiative you listed in Question 1 based on its effectiveness in preventing construction worker injuries/illnesses. Use a scale of 1–5 as follows: 1 = minimal impact/least effective, 2 = below average, 3 = moderate, 4 = above average, and 5 = large impact/most effective.

Twelve experts (80%) completed the first round questionnaire, contributing 329 safety and health elements. The remaining three experts were dropped from the study. The responses were reviewed to identify the unique elements provided by all of the experts, which resulted in a list of 74 unique safety and health elements. Six elements were added to the list from the literature and the researchers' personal research and industry experience, increasing the total to 80 safety and health elements. Using the ratings given by the experts, mean ratings for each of the 74 elements were calculated. The 80 elements identified from Round I were then sorted into 14 safety and health categories for simplicity and ease of review in Round II.

Round II

The 80 elements identified from Round I were presented to the 12 experts for further review. The experts were asked whether these elements were to be retained in the rating system, and whether they agreed with the mean rating obtained for each element in Round I. If the experts did not agree with the rating, they were asked to provide a new rating for the elements based on their effectiveness in preventing construction worker injuries/illnesses. Eleven of the 12 experts completed the second round questionnaire.

The level of agreement between the panelists was examined in two ways: one based on the mean rating received by the elements, and the other in terms of the elements to be retained in the rating system. Oertel (2001) suggested the use of *range*, the difference between the highest and lowest values, to evaluate agreement between the experts in a Delphi panel. This statistic was found to be a useful tool to analyze the level of agreement between the ratings received by an element. Agreement tended to be higher for the elements that had a higher mean rating, as illustrated by the fact that the percentage of items with a range of 2.0 or less in-

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creased from 64 to 96% when only the top 26 elements (mean rating ⩾ 4.0) were considered.

The level of agreement on retaining the elements was determined based on the percentage of participants recording "yes" to whether the element should be retained. Among all 80 elements, the agreement ranged from 18 to 100%. Fifteen safety and health elements received a 100% retainage consensus. A low of 18% was received by two elements. When the top 26 elements (mean rating ⩾ 4.0) were examined, the trend considerably changed, ranging from 64 to 100%.

For the purposes of this study, the researchers used the following criteria to retain or omit elements for the subsequent rounds and final rating system:

- Elements with a level of agreement of 60% or more and a mean rating ⩾ 4.0 were "retained and required."
- Elements with a level of agreement of 60% or more and a mean rating ⩽ 4.0 were retained and rated.
- Elements with a level of agreement of less than 60% and a mean rating ⩾ 4.0 were retained and rated.
- Elements with a level of agreement of less than 60% and a mean rating ⩽ 4.0 were "omitted" from subsequent rounds.

The retained and required elements were considered to be very effective in reducing safety hazards, with agreement from a majority of the experts. Hence, these elements would be a prerequisite for any project to get rated through the SCSH rating system. The category retain and rated, however, means that the elements which satisfy this criterion are elective elements and may or may not be chosen to fulfill the credits to get certified. If the project team wants to pursue higher levels of certification, the elective credits need to be included.

Based on the Round II results, 58 elements received a level of agreement of 60% or more. Of these 58 elements, 26 elements received a mean rating of 4.0 or more and were labeled retain and required. Thirty-two of the 58 elements received a mean rating less than 4.0 and were identified as retain and rated. The remaining 22 elements from the sample of 80 in Round II did not achieve the required consensus of 60% or more. In addition to the low level of agreement, all of these 22 elements received ratings lower than 4.0 and, therefore, were omitted. As a result, this process left 58 elements of which the experts suggested to consolidate six elements within other already existing elements. Ultimately there were 52 elements at the end of Round II sorted into 13 categories. It is interesting to note that all elements under the category "incentive/disincentive programs" were omitted based on the above process.

Round III

The purpose of the third and final round survey was to: (1) confirm consensus on the 52 elements and ratings from Round II, and (2) gain expert input on the structure for the rating system and method for implementation. The experts were asked to reconsider these remaining elements and rate them similar to Round II. The mean, median, range, and the level of agreement received from the responses in Round III were calculated. It was found that, of the 52 elements, none of the elements received a mean rating of less than 3.0, which was an improvement compared to Round II where there were several elements with mean ratings less than 3.0. This is an indication of agreement between the experts that all of the elements retained at the end of Round II have a significant impact on improving safety. The mean ratings of the elements ranged from 4.8 received by the element "clear project safety responsibility and accountability," to the lowest mean rating of 3.0 received by the element "stretch and flex program for all workers."

A subsequent analysis was performed to evaluate the level of agreement between the experts for the elements in Round III. Thirty of the 52 elements had a level of agreement of more than 90%. In order to retain or drop elements from the final rating system, the three decision criteria used in Round II were also used for Round III. Based on the Round III results, 50 elements (96%) received a level of agreement of 60% or more. Of these 50 elements, 25 (50%) received a mean rating of 4.0 or more. These 25 elements were labeled as retain and required. The remaining 25 elements received a mean rating of 4.0 or lower and were identified as retained and rated. Two of the original 52 elements did not achieve the required consensus of 60% or more. When examining these two elements, it was found that in addition to the low level of agreement, these elements received ratings lower than 4.0. These two elements were therefore dropped from the final SCSH rating system, leaving a total of 50 elements in the rating system.

A summary list of the SCSH rating system elements is presented in Appendix I which shows all of the 50 safety and health elements along with their corresponding credits. The mean ratings received during Round III added up to a total of 198.2 credits. For the purposes of implementation in practice, the researchers normalized the rating system to a total of 100 credits. The 50 elements were organized into 13 safety and health categories (see Appendix I). In order to get certified, a project must fulfill all of the 25 required elements to some degree that adds up to 54.5 credits. A project that incorporates more elements, or incorporates elements to a greater extent, would receive more credits. The premise of the rating system is that a higher number of total credits received by a project would indicate a lower potential for hazards that lead to construction worker injuries, illnesses, and fatalities. The rating system has four levels of certification (certified, silver, gold, and platinum) to differentiate between extent and level of effort with respect to safety on a project. The credit range for different levels of certification is certified for 54–60 credits; silver for 61–75 credits; gold for 76–90 credits, and platinum for 91–100 credits. The credit range was chosen by the researchers and did not involve any scientific or statistical methodologies.

A detailed SCSH rating system guide was prepared to assist industry practitioners in using the rating system. The guide contains one page for each of the 50 elements (see example in Appendix II) that describe the purpose, requirements, submittals, and method for calculating applicable credits.

The 50 safety and health elements are similar to those elements identified in previous research. All of the zero accident techniques identified in previous studies by Liska et al. (1993), Hinze et al. (2001), Jaselskis et al. (1996) are included in the SCSH rating system with the exception of safety incentives (recognition and rewards) as mentioned previously. While worker safety incentives were identified as positive influences on safety in previous research, the scores given to this element by the Delphi panel experts did not warrant its inclusion in the rating system. This is perhaps a reflection of the varied opinions on the effectiveness of safety incentives in enhancing and maintaining a positive safety culture.

SCSH Rating System Validation

The objective of this phase of the study was to conduct a preliminary validation of the SCSH rating system by testing the presence of any correlation between total SCSH credits and the safety performance of a project. For the purpose of the study, safety performance was defined in terms of the total OSHA recordable injury rate (TRIR). TRIR includes all OSHA recordable incidents which are defined as those incidents that resulted from an exposure or event in the workplace and that required some type of medical treatment or first-aid. The total OSHA recordable incident rate is the number of recordable incidents per 100 workers per year (200,000 worker-hours). The rating system would be considered to accurately reflect safety performance if the TRIR decreased as the total number of credits increased (i.e., a negative correlation).

A detailed questionnaire survey was conducted to gather information for the validation study. The questionnaire consisted of three major sections, requesting information on project demographics, safety performance, and the safety efforts implemented on the project. The questionnaire was sent to 25 construction firms and five owner/developer firms with offices across the United States. 10 of the firms were those with which the researchers have personal contact and which had expressed an interest in helping out with the research (convenience sample). The remaining 20 firms were randomly selected from the Engineering News-Record list of top 400 contractors. The survey respondents were asked to compile the survey information for as many projects as possible, limited to projects constructed in the past 2 years or which were near completion at that time. The respondents were asked to select the project(s) randomly instead of selecting only the projects with good safety performance.

Results

12 of the 30 firms contacted (40%) responded to the questionnaire survey and provided information on a total of 25 projects. All of the projects were constructed (some in progress) within the previous 2 years. The study sample included projects built in 13 states geographically dispersed throughout the United States. 23 of the projects were new construction, and two were mixed new and remodel projects. The sample projects consisted of eight facility types that included: high-rise residential and hotel buildings (8), health care facilities (5), industrial (4), higher education university buildings (3), transportation (2), office building (1), parking structure (1), and (1) animal shelter.

The cost of the sample projects ranged from \$4.9 million to \$11.5 billion (mean=\$578.9 million; median=\$89.0 million) and the size ranged from 22,000 to 1,200,000 ft^2 (mean =366,000 s f; median=307,000 s f). The unit cost of the projects ranged from \$79.4 to \$475.6/ft^2 (mean=\$360/s f; median=\$181/s f). The data received for 21 projects included the total number of workers for the entire project duration, which ranged from 45 to 2,544 workers (mean=618 workers; median =200 workers). The total number of worker-hours expended on the sample projects ranged from 9,500 to 30,419,929 h (mean =1,678,429 worker h; median=320,000 worker hours).

In terms of height, the sample projects ranged from 1 to 65 stories (mean=14.3 stories; median=5 stories). Of the 25 projects, 14 projects were funded by the private sector and 11 by the public sector. It should be noted that for 15 of the 25 projects (60%), the construction work was in progress at the time of the study. Included in the 15 incomplete projects were nine projects that were at least 60% complete, and the remaining six projects were less than 25% complete.

The data provided on all of the 25 projects included the number of OSHA recordable injuries and the total worker-hours ex-

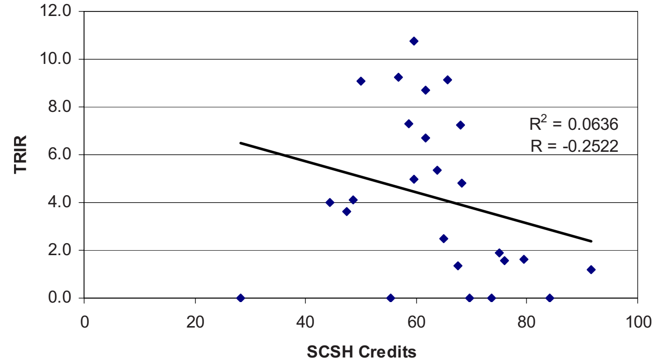

Fig. 1. Correlation between TRIR and SCSH credits for all sample projects (n=25)

pended on the projects. One project did not have the information on total worker-hours, but the project did not have any OSHA recordable injuries. Hence, the TRIR for the project was assumed to be 0. For the 25 projects, the TRIRs ranged from 0 to 10.8 (mean=4.2; median=4.0), with five projects (20%) reporting no injuries.

Using the provided project information, the total number of SCSH credits was calculated for all of the 25 sample projects. The total SCSH credits for the sample projects ranged from 28.2 to 91.5 credits (mean=63.2 credits; median=63.7 credits). Using the SCSH rating system, the study sample consisted of five uncertified projects (20%), five certified projects (20%), 10 silver projects (40%), four gold projects (16%), and one platinum project (4%).

Analysis and Discussion

Using Microsoft Excel, a scatter plot was developed between the SCSH credits and TRIR values for the 25 sample projects (see Fig. 1). A trend line was added to the graph to examine any trends in the data set. Both variables are normally distributed and Pearson's correlation was used to determine the relationship between the variables. A weak correlation ($R=-0.252$) was found between the SCSH credits and TRIR values, and the result is not significant (two tailed, $p=0.224$). The R^2 was very low (0.064), indicating that the SCSH credits do not predict the TRIR values for the projects. When examining the plot it was noticed that Project C with 28.2 SCSH credits and a TRIR of zero was pulling the trendline toward a positive slope. This project was considered an outlier since the project consisted of a simple facility of only 20,000 sf compared to the mean for the data set of 366,000 sf. In addition, the project did not report the total worker-hours worked. Hence, Project C was removed from the analysis.

A similar analysis was conducted to examine the correlation when controlling for project size. For the purpose of the analysis, project size was defined in terms of the number of worker-hours on the project. Some of the projects in the sample had just begun and only 9,500 h had been worked. The researchers decided to analyze the trend between SCSH credits and TRIR for projects on which more than 100,000 worker-hours were worked, and then for projects with more than 200,000 worker-hours. 19 projects were part of the sample that had worked more than 100,000 worker-hours. It was found that the R^2 (0.37) and R-value (−0.61) improved significantly for just these 19 projects. There were 13 projects that had worked more than 200,000 worker-

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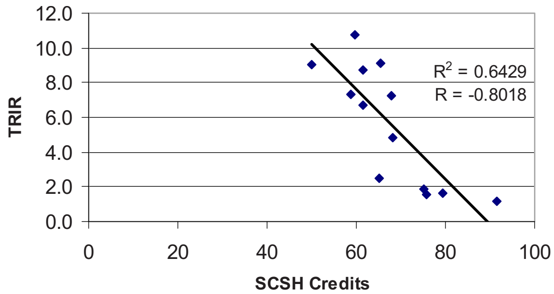

Fig. 2. Correlation between TRIR and SCSH credits for projects with >200,000 worker-hours (n=13)

hours, and the R^2 and R-value for these projects were 0.64 and −0.803, respectively (see Fig. 2). This result was found to be significant (two-tailed, p=0.001). Based on these additional analyses, it can be seen that the correlation between SCSH credits and TRIR improves for larger projects.

Similar analyses were performed with respect to other project characteristics. Of the 25 sample projects, seven projects were delivered using the design-bid-build (DBB) method of project delivery, seven using design-build (DB), and nine using the construction manager/general contractor method. It was interesting to find that projects delivered using DBB had a slight positive correlation (R=0.20), while projects delivered using the DB method had a moderate negative correlation (R=−0.53).

For both private and public projects, the correlation coefficient had a negative value. When Project C, a publicly funded project, was removed from the list of public projects, the R-value increased to −0.61, indicating moderately strong correlation between SCSH credits and TRIR among publicly funded projects. The SCSH rating system worked better for projects using unionized labor (R=−0.58) than for those that used nonunion labor (R=−0.12).

In terms of the facility type, all types of facilities had a negative correlation between SCSH credits and TRIR. It was found that the SCSH rating system would work very well for education projects (R=−0.99) and transportation facilities (R=−1.0), although the number of projects of these types in the sample was small. A similar trend was found for industrial (R=−0.74) and residential (R=−0.79) facilities. The correlation analysis was also performed for projects from individual builders. Only three builders contributed an adequate number of projects to be included in this part of the analysis. It was found that all of the three builders' projects had a negative correlation between SCSH credits and TRIR. One builder had an R-value of −0.92 and an R^2 value of 0.85, the strongest correlation of the three builders.

Validation Study Limitations

Limitations in the interpretation and generalization of the study findings exist as a result of the research methods and data sample used. The limitations that are present in this study include:

1. The survey questions required the respondents to rate the extent of implementation of some of the elements on a scale of one to five. The response to these questions is dependent upon the judgment of the respondents, which may vary between survey respondents.
2. A second limitation is associated with the study inferences. The TRIR used for the study is observational data and cannot be used to make cause and effect statements. The strongest statement that can be made from the study is that there is an "association" between the TRIR and the SCSH credits.
3. Another limitation is the small sample size of projects used in the model validation effort. The small sample size limits the ability to generalize the results to the entire construction industry. The results of the validation provide only an initial assessment of the SCSH model and further study needs to be conducted to fully validate the accuracy of the model.
4. While the survey requested information about safety activities implemented by the owner, designer, contractor, and subcontractors, in some cases only one firm completed the entire survey. For these cases, the reliability of the information provided depends on the respondent's level of knowledge of the activities undertaken by the other firms.

Conclusions

In this paper, the development and validation of a SCSH rating system was described. The SCSH rating system was developed with the help of a Delphi survey of construction safety and health experts from industry and academia. A key aspect of the research is the application of the sustainability concept to construction worker safety and health. This concept, defined as SCSH, can be implemented in the industry with the help of the SCSH rating system.

According to the expert panel, in order to have comprehensive SCSH performance, a total of 50 elements should be implemented through the combined efforts of the project team. The most important elements (top 3) are (1) clear project safety authority, responsibility, and accountability; (2) employee empowerment to stop work authority; and (3) contractor selection based on safety. While still effective elements, the least important elements (last 3) are (1) *task-based* hazard database; (2) hearing conservation program; and (3) stretch and flex programs for all workers. Project safety incentive programs were not considered integral to good safety performance as they may lead to more underreporting and do not necessarily prevent injuries and illnesses.

Rather than having the constructor play the sole role in safety, all parties should be involved in project safety efforts to have sustainable safety results. Addressing safety in the design of a project is an activity that can have a significant impact on safety performance and was one of the highly rated elements. According to the SCSH rating system, in order to get a project certified, project teams must consider safety during the planning and design stages of the project.

With respect to the 25 sample projects, the SCSH rating system provides an accurate representation of safety performance due to the presence of the negative correlation between the SCSH credits and the TRIR. The correlation improved (i.e., R-value decreased significantly toward negative one) when only projects that had expended more than 200,000 worker-hours were considered. The SCSH rating system showed a stronger negative correlation with TRIR for projects delivered through DB than for projects delivered using DBB. The SCSH credits for residential, transportation, education, and industrial facility types had a moderate negative correlation with TRIR although the small sample size limits the application of this conclusion beyond the sample projects. The correlation between SCSH credits and TRIR differed from one builder to another and did not indicate a perfect relationship for all of the three major builders in the study. However, the correlation coefficient was negative for all three.

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Recommendations

The 50 elements that are part of the SCSH rating system were derived based on the expert opinion from the Delphi survey. As discussed previously, the final rating system elements and their corresponding credits are affected by the expert's personal experience and professional knowledge of the various elements' effectiveness in improving worker safety and health. In some cases the elements, including those that are deemed required, would be difficult or impractical to implement. For example, the element "OSHA 10 hour certification for all workers" would not be feasible for all projects given the fact that some workers may only work fewer than 10 h on a project. Another such example would be having an owner/constructor safety representative for the project. Small owners often cannot afford to have a safety representative or some projects would not have the need for a full-time safety representative. Research should be performed, for example, to identify criteria for projects in terms of cost or number of employees to require safety representatives. From a mandatory credit perspective, the elements "safety inspection" and "drug and alcohol testing program" ended up as elective elements. Others may disagree and feel that these should be mandatory.

The researchers argue that projects cannot be labeled sustainable if consideration is not given to safety and health over the entire life cycle of a building, including construction. In order to have sustainable safety and health, the SCSH rating system should include elements that deal with safety and health of the facility maintenance personnel as well. The current rating system has one element, "life cycle safety review," that addresses this issue. Additional research should be expended to expand the rating system in this vane.

One key recommendation as a result of this research study is the development of a separate planning tool and/or rating system aimed specifically at designers. Formally addressing construction worker safety in the design of a project is a relatively new concept in the construction industry. Efforts should be made to develop a detailed construction safety and health planning tool that would guide designers to consider worker safety and health during design. However, there is a lack of knowledge about whether implementing certain elements will improve worker safety and health. This gap in knowledge can be filled by the development of a designer safety and health rating system that will rate designers based on safety and health efforts expended by an individual or company-wide. Having such a resource could provide an incentive to designers to incorporate safety in the design phase of a project.

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Appendix 1. SCSH Rating System Elements (R = Required, E = Elective)

Project team selection		6.6 possible credits	
R	Element 1.1	Constructor selection	2.3
R	Element 1.2	Subcontractor selection	2.3
E	Element 1.3	Designer selection	2.0
Safety and health in contracts		5.5 possible credits	
R	Element 2.1	Safety and health in contracts	2.2
E	Element 2.2	Safety hazard identification in construction drawings	1.6
E	Element 2.3	Specification of less hazardous materials	1.7
Safety and health professionals		8.1 possible credits	
R	Element 3.1	Competent personnel for all high hazard tasks	2.4
E	Element 3.2	Owner safety representative	1.8
E	Element 3.3	Constructor safety representative	2.0
E	Element 3.4	Subcontractor safety representative	1.9
Safety commitment		4.3 Possible credits	
R	Element 4.1	Management commitment to safety and health	2.3
R	Element 4.2	Owner/representative commitment to safety and health	2.0
Safety planning		27.8 Possible credits	
R	Element 5.1	Safety and health during conceptual planning phase	2.3
R	Element 5.2	Constructability review	2.3
R	Element 5.3	Designing for worker safety and health	2.2
R	Element 5.4	Life cycle safety design review (LCS)	2.0
R	Element 5.5	Safety checklist for designers	2.1
R	Element 5.6	Constructor site specific safety plan	2.0
R	Element 5.7	Subcontractor site specific safety plan	2.1
R	Element 5.8	Job hazard analysis	2.3
R	Element 5.9	Pre-task planning	2.3
R	Element 5.10	Look ahead schedule	2.1
R	Element 5.11	On and off site traffic plan	2.1
R	Element 5.12	Good housekeeping plan	2.2

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E	Element 5.13	Personnel protection equipment (PPE) plan	1.8
Training and education		15.3 possible credits	
R	Element 6.1	Safety training for designers	2.0
R	Element 6.2	Safety orientation for all workers	2.0
E	Element 6.3	Safety training for all field supervisors	2.0
E	Element 6.4	OSHA 10 h training for all workers	1.8
E	Element 6.5	Assessment of all equipment operators skills and training	1.8
E	Element 6.6	Toolbox meetings	1.8
E	Element 6.7	Regular safety training for all project personnel	2.0
E	Element 6.8	Constructor mentors subs to improve safety performance	1.9
Safety resources		1.8 possible credits	
E	Element 7.1	Task-based hazard exposure database	1.8
Drug and alcohol program		1.8 possible credits	
E	Element 8.1	Drug and alcohol testing program	1.8
Accident investigation and reporting		3.7 possible credits	
R	Element 9.1	Accident and near miss investigation	2.0
E	Element 9.2	Accident and near miss investigation with pre-task/JHA	1.7
Employee involvement		4.2 possible credits	
R	Element 10.1	Employees empowered with stop authority	2.3
E	Element 10.2	Employee safety committee and leadership team	1.9
Safety inspection		3.8 possible credits	
E	Element 11.1	Safety inspections	2.0
E	Element 11.2	Safety Violations identified and corrected	1.8
Safety accountability and performance measurement		8.0 possible credits	
R	Element 12.1	Project accountability and responsibility	2.4
R	Element 12.2	Supervisors evaluated based on safety performance	2.2
E	Element 12.3	Safety performance evaluation using safety metrics	1.9
E	Element 12.4	Contractor evaluation based on safety performance	1.5
Industrial hygiene practices		9.1 possible credits	
R	Element 13.1	Engineering controls for health hazards	2.1
E	Element 13.2	Hearing protection program	1.6
E	Element 13.3	Respiratory protection program	1.9
E	Element 13.4	Stretch and flex program	1.5
E	Element 13.5	Ergonomic task analysis and remediation	2.0
Project total		100 possible credits	

Certified 54–60 credits; **Silver** 61–75 credits; **Gold** 76–90 credits; **Platinum** 91–100.0 credits. All Required elements to be fulfilled for all levels of certification.

Appendix 2. SCSH Rating System Example Credit Allocation Methodology

1.0 Project team selection

Element 1.1	Constructor selection
Possible credits	2.3
Type	Required

Purpose: Employ a constructor with a good safety record.

Requirements: The owner should select a constructor based in part on past safety performance. Criteria used for selection should include the following: experience modification rating (EMR); incident rates (OSHA recordable rate and lost time rate); claims rate; number of OSHA citations in the past 3 years; personal interview/personal knowledge of the constructor's safety performance; and review of the constructor's safety program.

Submittals: The calculation sheet provided below should be submitted with signatures from the owner and the constructor.

Criteria	Used in Selection?		Points (Yes=1; No=0)
EMR	☐ Yes	☐ No	
Incident Rates	☐ Yes	☐ No	

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OSHA citations	☐ Yes	☐ No
Personal interviews/knowledge	☐ Yes	☐ No
Safety programs review	☐ Yes	☐ No
Claims rate	☐ Yes	☐ No

Total points received =	
Total points possible =	6
% of criteria fulfilled = Points received/Points possible =	
Credit received = Possible credits * % of criteria fulfilled =	

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