A FUZZY STRUCTURAL EQUATION MODEL FOR DEVELOPMENT OF A SAFETY PERFORMANCE INDEX

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Abstract - In this research, a framework is to be proposed to model the safety performance in construction sites. Determinants of safety performance are to be defined through extensive literature review and a multidimensional safety performance model is to be developed. In this context, a questionnaire is to be administered to construction companies with sites. The collected data through questionnaires including linguistic terms are then to be defuzzified to get concrete numbers by using fuzzy set theory which provides strong and significant instruments for the measurement of ambiguities and provides the opportunity to meaningfully represent concepts expressed in the natural language. The validity of the proposed safety performance model, relationships between determinants of safety performance are to be analyzed using the structural equation modeling (SEM) which is a highly strong multivariable analysis technique that makes possible the evaluation of latent structures. After validation of the model, a safety performance index assessment tool is to be proposed by the help of software. The proposed safety performance assessment tool will be based on the empirically validated theoretical model.

Keywords - Fuzzy Set Theory, Safety Performance Assessment, Safety Index, Structural Equation Modeling (Sem), Construction Sites.

I. INTRODUCTION

In the developed as well as developing part of the world, construction industry is considered to be one of the most significant industries in terms of its contribution to Gross Domestic Product and also in terms of its impact on health and safety of the working population (Farooqui et al. (2008)).

The construction industry is one of the most hazardous industrial fields (Grimaldi and Simonds (1984); Suazo and Jaselskis (1993)). Construction sites are in a constant state of change, dictating frequent inspections (Jannadi and Assaf (1998)). Construction site safety is of utmost importance due to nature of construction industry (Priyadarshani et al. (2013)). However, in a market driven society where more concern is for completion of projects to the required quality at minimum time and cost, safety is a secondary concern (Priyadarshani et al. (2013)). Although dramatic improvements have taken place in recent decades, the safety record in the construction industry continues to be one of the poorest (Huang and Hinze (2006)).

Some construction companies realize the importance of reducing their accident rates not only for humanitarian reasons, but also due to the many financial benefits which flow from the safe conduct of the work. Other companies do not have a strong belief in safety. This has serious repercussions when any unfortunate incidents occur. Good management should always insist that every engineer, supervisor and laborer must be familiar with all basic safety aspects and practices that guard those around the construction sites from accidents and injuries (Jannadi and Assaf (1998)).

The current research plans to examine the relationships between determinants of safety performance in construction sites. Its objectives are to identify the determinants of safety performance, study the relationships between determinants of safety performance and propose a safety performance index assessment tool for construction sites.

II. BACKGROUND TO THE RESEARCH AND PROBLEM STATEMENT

To control and improve safety performance in construction sites, a key ingredient is an effective measure of safety performance. Both Tarrants (1980) and Laufer (1986) agree that measurement of safety performance is necessary for the following reasons: as a basis for casual factor detection, to locate and identify problem areas, as a basis for trend comparison, to describe the current safety state of an organization, as a basis for predicting future accident problems, as a basis for evaluating accident prevention program effectiveness, as a basis for making decisions regarding the allocation of accident prevention resources, to assess accident costs, to establish long-term accident control, and as a basis for quantifying probable risk of injury or other loss.

Despite the importance of safety performance, Helander (1991) reported that very little research focusing on the construction industry has been performed on this subject. Smith et al. (1999) agrees that there is a need to develop evaluation tools for

construction sites to enable them to assess their overall safety performance. The need for measuring safety performance was stipulated in many previous research studies. Several methods on measuring the safety performance on a construction site in the literature have been as follows:

In the "TR safety observation method" (Laitinen et al. (1999)), the safety of the work environment and of the work is observed so as to get a sufficiently reliable picture of the current level of safety at the construction site. The observer walks around the construction site and marks down the items of observations. The aim is to have at least one hundred separate items. The items to be observed are grouped into six entries on the measurement form: 1) working, 2) scaffolding and ladders, 3) machinery and equipment, 4) protection against falling, 5) electricity and lighting and 6) order and waste disposal. The observations are marked as 'correct/incorrect': the target is marked as right if it reaches the level of safety standards; otherwise it is marked as incorrect. The safety level of the construction site is a percentage calculated from the number of correct observations. A high safety index as an observation result indicated a low accident rate, and vice versa (Laitinen et al. (1999); Antti-Poika and Laitinen (2004); Laitinen and Paivarinta (2010)). TR method has a 2-point scale, where the score is either correct or incorrect, is not sensitive enough to show small changes (Duff, (2000)), and there is a disadvantage in that the use has only limited possibilities for evaluating hazards. Also the safety level formula of TR method does not take into account the relative importance weights of observed items.

The Injury Exposure Assessment (IEA) method allows an estimation to be made of the risk of an accident occurring during the building implementation phase (Seixas et al. (1998)). An observer visits a building site and then scores the various dangers using a checklist, taking into account the presence and degree of protection. The degree of protection is estimated using a weighting between 0 and 10. A '0' means no protection while '10' stands for fully protection. The results are then subsequently added together for each danger. By means of this method, the observer can evaluate whether there may be a risk situation. The IEA method was tested on three building sites and tests showed that there were large and significant differences in the assessments made by different observers. This seems to partly depend on the level of expertise of the observer, so testing randomly chosen observations has its drawbacks. High risk situations which do not happen very often will probably remain undiscovered using this method. Complexity of the IEA makes it unsuitable for use by construction site employees.

Checklist of safety indicators is a method for making safety quantifiable and for using the results to implement improvements so that the safety levels of a company can be increased (Trethewy (2003)). In total, 58 indicators have been developed for various phases of a building project. The indicators are scored on a six-point scale varying from zero (0) to excellent (5). These 58 indicators are divided over the phases from design to implementation as follows: drafting and feasibility phase (2 indicators), design and planning phase (10 indicators), selection and invitation-to-tender phase (4 indicators), implementation phase divided into 4 sub-phases (38 indicators), completion, maintenance (4 indicators).

Accident Rate (AR), Incident Rate (IR), Experience Modification Rate (EMR) and Score Card (SC) systems are some retrospective safety evaluation methods introduced for better safety management. Although Tam and Fung (1998) mentioned use of AR is superior to other indices, as the accident rates remain quite constant throughout the years and are easily obtainable, it has been regarded as an unsound basis for comparison ((Priyadarshani et al. (2013)). Accuracy of IR depends on how honest a contractor is in revealing accidents, illnesses, fatalities and injuries. EMR is the ratio between actual claims filed and expected claims for a particular type of construction (Ng et al. (2005)). EMR formulae are relatively complex and different versions of calculations exist in practice making it an inappropriate measure of safety performance for all types of companies (Hinze et al. (1995)). Retrospective methods are used to understand the causes and to reduce the number of accidents, but the results are limited by imperfections in accident recording and in research and analysis of accident causes (Frijters et al. (2008); Frijters and Swuste (2011)). Although there are some benefits from using outcome indicators, their use does not lead to improvement in safety outcomes. The main reason for this is outcome indicators are reactive and well after the event (Ahmad et al. (1999)).

There is a need for valid and user-friendly assessment methods for construction site safety so that everyone becomes aware of the dangers on the construction site and takes the necessary precautions (Frijters et al. (2008); Frijters and Swuste (2011)).

Drawing on the above strong endorsement to the need for a safety performance assessment tool, this research is to focus on developing and validating a multidimensional theoretical safety performance model for construction sites. The determinants of safety performance and relationships between them are to be identified and studied. The significance of this research is that it firstly plans to develop an empirically validated theoretical model; then with the help of this model, a practical safety performance

index assessment tool is to be proposed to improve the construction safety.

III. RESEARCH OBJECTIVES

The principal aim of this research is to examine the relationships between determinants of safety performance in construction sites. A framework is to be proposed to model the safety performance in construction sites such that the safety performance determinants are empirically valid and the relationships between them are justified. Based on the validated model, a safety performance index assessment tool is to be proposed by developing a software program. This aim is to be realized through the following objectives:

- to identify the determinants of safety performance,
- to study the relationships between determinants of safety performance,
- to develop and validate a multidimensional theoretical safety performance model,
- to propose a safety performance index assessment tool by developing a software for construction sites based on the empirically validated theoretical model.

Proposal of such a framework would have considerable contribution to the literature in the construction safety. In this research, the authors are to adopt an integrated approach and are to attempt to incorporate fuzzy set theory into structural equation modeling technique to the collection and analysis of the questionnaire survey data. This research is to represent a first attempt to propose a safety performance index assessment tool for construction sites based on the empirically validated theoretical model.

IV. LITERATURE REVIEW REGARDING DETERMINANTS (VARIABLES AND GROUPS) OF SAFETY PERFORMANCE IN CONSTRUCTION SITES

This section presents the findings of literature review to meet research objectives. The literature review was carried out through books, journals, conference papers, theses and the web. More than 250 publications related to safety performance have been analyzed and 23 studies have been deeply analyzed directly associated with the current research topic. In these referenced studies, dated between 1994 and 2013, a total of 91 categories, 20 headings, 18 divisions, 45 criteria, 102 groups, 804 items, 185 factors, 122 questions, 40 sub-items, 251 considerations, 20 main factors, and 85 sub-factors (a grand total of 1783 determinants) have been listed as safety performance determinants in construction sites. In this research, abovementioned determinants have been screened through expert opinions and least significant findings have been removed before the preparation of a questionnaire template. Firstly, a total of 98 variables in 16 groups affecting safety performance of construction sites have been achieved. After determining the variables and groups affecting safety performance of construction sites, a questionnaire form has been prepared and interviews about this template have been made with 15 different construction safety professionals. Taking account of the valuable feedbacks of these construction safety professionals, an additional literature review has been made to satisfy the lacking items in the questionnaire template. Additional 6 studies have been deeply analyzed directly associated with the current research topic. By adding these additional referenced studies, dated between 1994 and 2014, a total of 91 categories, 59 headings, 18 divisions, 45 criteria, 148 groups, 885 items, 226 factors, 363 questions, 40 sub-items, 251 considerations, 20 main factors, and 85 sub-factors (a grand total of 2231 determinants) have been listed as safety performance determinants in construction sites. Finally, a total of **168** variables in **16** groups affecting safety performance of construction sites have been figured out.

V. RESEARCH METHODOLOGY

A questionnaire survey ((Inquire of groups and variables by taking into account their "Probability of an Incident" and "Impact of an Incident" by using 3 point likert scale) is to be administered to construction companies having construction sites as a data collection tool. Data is to be collected in linguistic terms as “Low, Medium, “High”. These linguistic terms are to be defuzzified into concrete numbers by using fuzzy set theory. Fuzzy set theory provides strong and significant instruments for the measurement of ambiguities and provides the opportunity to meaningfully represent ambiguous concepts expressed in the natural language.

Structural equation modeling, which is a highly strong multivariable analysis technique that makes possible the evaluation of latent structures, is to be used as a research analysis tool. The validity of the hypotheses and proposed model is to be tested by statistical analyses using structural equation modeling based on data collected through the questionnaire survey.

VI. THEORETICAL REVISION OF FUZZY SET THEORY

A similar methodology that Chen (1997) and Yener (2007) used is to be adopted in this research in the utilization of fuzzy technique. Combination of trapezoidal and triangular membership functions is to be defined and corresponding fuzzy numbers are to

be selected. These linguistic terms are then to be defuzzified into concrete numbers as similar to Chen (1997) and Yener (2007) by using fuzzy set theory.

After gaining the concrete numbers from this part, data output would be ready for utilization and analysis in the development and validation of the multidimensional theoretical safety performance model through Structural Equation Modeling.

VII. THEORETICAL REVISION OF STRUCTURAL EQUATION MODELING

Structural equation modeling is to be utilized to achieve objectives of the current research proposal to study the relationships between determinants of safety performance, and to develop and validate a multidimensional theoretical safety performance model. SEM was selected as an analysis and testing tool for the current research because of its unique features over other multivariate techniques.

Safety performance variables in the questionnaire are to be the observed variables of safety performance, forming the measurement model. SEM enables multiple determinants of safety performance to be analyzed simultaneously. Safety performance is a latent variable that cannot be directly observed and measured. Because SEM can reveal the interdependencies of observed variables and latent variables simultaneously, interdependencies of safety performance determinants can be fully modeled and tested. A second order factor analytical model, consisting of both measurement and structural models are to be tested and validated and the relationships between determinants of safety performance are to be analyzed by SEM. Various structural equation modeling software packages are commercially available, according to their observed analysis capabilities, the relevant software package is to be selected for the current research.

VIII. PROPOSAL OF A SAFETY PERFORMANCE MODEL IN CONSTRUCTION SITES AND DETERMINATION OF THE HYPOTHESES BASED ON THIS MODEL

As previously mentioned, a total of 98 variables in 16 groups affecting safety performance of construction sites were achieved through literature review and expert opinions. After making the interviews about the preliminary questionnaire form with 15 different construction safety professionals, conducting additional literature review, and figuring out a total of 168 variables in 16 groups affecting safety performance of construction sites, a final safety performance model have been formed in Figure 1.

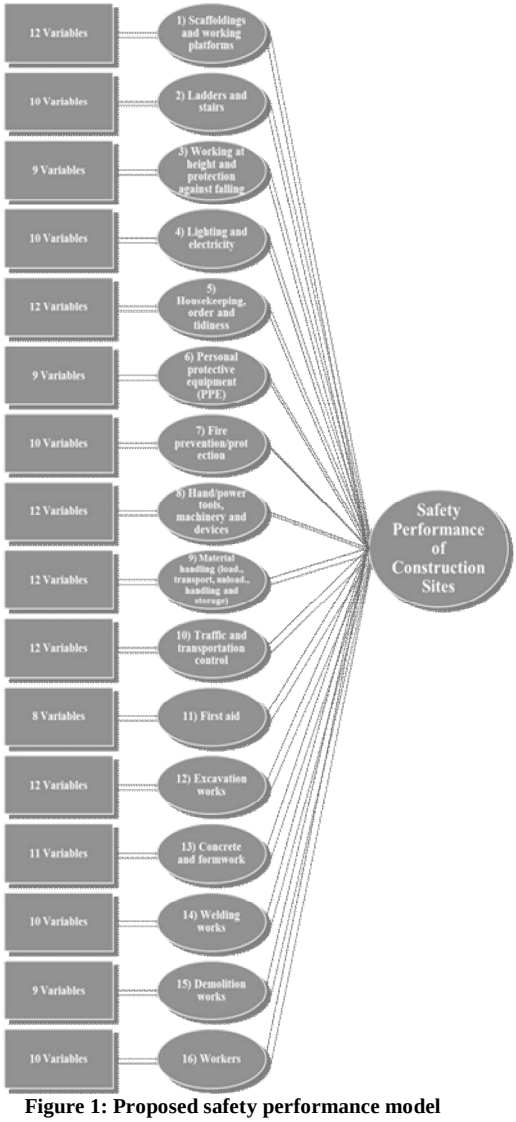


Figure 1: Proposed safety performance model

CONCLUSION

This paper focuses on developing and validating a multidimensional theoretical safety performance model for construction sites due to the strong need for a safety performance assessment tool. The main aim of this research is to examine the relationships between determinants of safety performance in construction sites. To achieve this aim a total of 168 variables in 16 groups affecting safety performance of construction sites have been figured out through literature review.

The significance of this research is that it firstly plans to develop an empirically validated theoretical model; then with the help of this model, a safety performance index assessment tool is to be proposed to improve the construction safety.

Planned future studies in this research are listed as follows: 1) Development and administration of the questionnaire form to construction companies with construction sites is to be completed. 2) Data

collection and preparation for analysis (Implementation of fuzzification- defuzzification operations (i.e., conversion of linguistic values to numerical values) is to be completed 3) Implementation of reliability, validity, factor, exploratory factor, confirmatory factor, second order confirmatory factor, structural equation model analyses and model fit evaluations (By SPSS Statistics, SPSS Amos and Lisrel computer programs) is to be completed. 4) Evaluation of effect coefficients of variables and groups on Safety Performance and interpretation of hypothesis testing results are to be completed 4) Development of a safety performance assessment tool (on windows-mac-android-ios platforms) by facilitating the acquired structural equation model and effect coefficients.

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