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# Development of a safety performance index assessment tool by using a fuzzy structural equation model for construction sites

Murat Gunduz[a,*], M. Talat Birgonul[b], Mustafa Ozdemir[c]

[a] Dept. of Civil Engineering, Qatar University, PO Box: 2713, Doha, Qatar
[b] Dept. of Civil Engineering, Middle East Technical University, Ankara, Turkey
[c] Botas Petroleum Pipeline Corporation, Bilkent, Ankara, Turkey

## ABSTRACT

The main goal of this study is to propose a safety performance index assessment tool to improve the construction safety. Formulation of the safety performance index of construction sites is achieved upon a validated multidimensional safety performance model. The contribution of this study could be summarized as incorporation of fuzzy set theory into structural equation modeling to develop a safety performance index assessment software tool. Case studies were conducted at 11 international construction sites and the results of their site safety performance indices were benchmarked. A short (simple) safety performance model was developed as an alternative to the full model (proposed model) to assess safety performance of construction sites. Results showed that short model predicts the safety performance with an acceptable accuracy and requires less time to complete. Finally, a safety performance index assessment software tool for construction sites was proposed by developing a site safety performance (SSP) application for mobile devices based on the validated multidimensional safety performance model. The paper attempts to numerically validate the influencing factors of construction safety with the help of a mobile device application. The paper also develops a mobile application tool to measure safety performance at any construction site.

## 1. 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 (GDP) [1], and also in terms of its impact on health and safety of the working population [2]. Although dramatic improvements have taken place in recent decades, prevention strategies lack to achieve higher safety performance and the safety record in the construction industry continues to be one of the poorest [3–7]. Persistent endeavors have been made to promote construction safety, but fatalities still plague the industry [8].

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 [9,10]. Drawing on the above strong endorsement to the need for a safety performance assessment tool, in this study, based on a validated multidimensional safety performance model, a safety performance index assessment tool is proposed to improve the construction safety. The contribution of this study could be summarized as incorporation of fuzzy set theory into structural equation modeling technique to develop a safety performance index assessment software tool.

The objectives of this paper can be summarized as: (1) to develop the formulation of the safety performance index of construction sites upon a validated multidimensional safety performance model, (2) to conduct case studies in international construction sites and perform assessment of their safety performance indices and benchmark the results, (3) to develop a short (simple) model as an alternative to the full model to assess safety performance ensuring simplicity, fastness and reasonable accuracy, (4) to propose a safety performance index assessment software tool for construction sites by developing a site safety performance (SSP) application for mobile devices based on the validated multidimensional safety performance model.

## 2. Literature review and significance of this study

Safety plays a vital role in construction especially since the sector is generally more hazardous than any other industries due to the use of heavy equipment, dangerous tools, constantly changing work environment and hazardous materials, all of which increase the potential for

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[*] Corresponding author.
*E-mail addresses:* mgunduz@qu.edu.qa (M. Gunduz), birgonul@metu.edu.tr (M. Talat Birgonul), mustafa.ozdemir@botas.gov.tr (M. Ozdemir).

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serious accidents and injuries [1]. Despite improvements over the years, accidents and injuries continue to plague the construction industry [8]. According to the researches conducted by the International Labour Organization ILO [11] and ILO [12], 4% of all global gross domestic product is spent on issues of removals, production interruptions, medical expenses and workers' compensation. According to the estimate of World Bank [13], the global gross domestic product in the year 2015 amounted to about 73.5 trillion US Dollars. This means, annual global cost of occupational accidents and diseases of all industries including construction reaches an approximated value of 3 trillion US Dollars.

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 [14].

Gunduz et al. [15] proposed and validated a multidimensional safety performance model for construction site by incorporating fuzzy set theory (FST) into structural equation modeling (SEM)s. In this integrated novel model, the disadvantage of low-point scaling of the previous models was eliminated. A comprehensive effort was made to discover the determinants of safety performance. The relative importance weights of the observed items were taken into account and a prospective method was recommended to improve safety performance of construction sites well before the undesirable safety outcomes. They suggested that a safety performance index assessment software tool might make a considerable contribution to the literature on construction safety. Based on validated multidimensional safety performance model proposed by Gunduz et al. [15], this study focuses on the formulation of the safety performance index of construction sites. A safety performance index assessment software tool for construction sites was proposed by developing a site safety performance (SSP) application for mobile devices based on the validated multidimensional safety performance model. The contribution of this study could be summarized as incorporation of fuzzy set theory into structural equation modeling technique to develop a safety performance index assessment software tool for mobile devices.

## 3. Research methodology

Quantitative methods tend to be predetermined. Such methods ask instrument-based questions, use performance data, and attitude data, and perform statistical analysis and interpretation [16]. A quantitative approach in research design was implemented through case studies, since case study method enables a researcher to closely examine the data within a specific context [17].

Research processes of this study are as follows: a) development of safety performance index formulae; b) conducting case studies in international construction sites; c) development of a short (simple) model as an alternative to the full model; d) discussion about the results of short (simple) model and the full model; and e) development of a safety performance index assessment software tool for construction sites.

## 4. Multidimensional safety performance model for construction sites by SEM

The authors developed and validated a multidimensional safety performance model for construction sites by structural equation modeling (SEM) [15]. In their study, through literature review and expert opinions, they collected together a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites. After determining the observable variables and latent dimensions affecting safety performance of construction sites, they administered a questionnaire survey to determine the relative importance effects (weights) of 168 observable variables in 16 latent dimensions on "safety performance of construction sites". 180 respondents fully completed the survey. In the questionnaire survey, data was collected from respondents by linguistic terms as "low, medium, high" for observable variables affecting safety performance of construction sites. The linguistic terms were defuzzified into concrete numbers as similar to Chen [18] and Yener [19] by using fuzzy set theory (FST). The authors formed a safety performance model and determined the research hypotheses accordingly. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. Results of the measurement model by SEM showed that, content validity was achieved, unidimensionality of both first-order and second-order factor structure was evidenced and held, convergent validity of both first-order factor structure was supported by high factor loadings and acceptable goodness of fitness indices, reliability was sustained by greater Cronbach's alpha and composite reliability values, discriminant validity was evidenced with all correlations significantly differed from unity and suggesting no multicollinearity. After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent variables and respective observable variables) and the structural model (associations between first-order and second-order latent variables) were achieved. Finally, the assessment of the structural model including the testing of hypothesized second-order factor structural model by SEM as a confirmatory assessment of structural validity, and the results of testing of the research hypotheses showed that, all of the research hypotheses were supported.

## 5. Relative weight calculations for the 16 latent dimensions of "safety performance of construction sites"

In this study, a "168 observable variables in 16 latent dimensions" measure is suggested as a scale of safety performance of construction sites. Gunduz et al. [15] found that the 168 observed variables had different factor loadings (FL) onto the latent dimensions, and the 16 latent dimensions were contributing differently to safety performance of construction sites. Second-order factor structural model for safety performance of construction sites with the standardized parameter estimates (path coefficients) of 16 latent dimensions calculated by are shown in Table 1.

In this study, these path coefficients are utilized in the calculation of relative weights of the 16 different latent dimensions when computing the safety performance index. As an example, the calculation of relative weight of the latent dimension G10 is explained as follows: for example, the relative weight of G10: the propriety of "Traffic and transportation control" was calculated as 0,0676; resulting from $0,94 / (0,79 + 0,83 + 0,88 + 0,91 + 0,85 + 0,85 + 0,83 + 0,90 + 0,94 + 0,94 + 0,65 + 0,93 + 0,88 + 0,94 + 0,93 + 0,86) = 0,0676$. The calculated relative weights for all of the latent dimensions of "safety performance of construction sites" are shown in Table 1.

## 6. The development of the formulation of the "safety performance index of construction sites"

To develop a safety performance index formula, the relationships between the 16 latent dimensions and "safety performance of construction sites" should be considered. Therefore, a similar methodology that Yoo and Donthu [20] and Avcılar [21] used in their studies was adopted in this study in the development of the formulation for safety performance index. Yoo and Donthu [20] and Avcılar [21] both performed second-order factorial confirmatory factor analyses to evaluate the effects of each different latent dimensions in the formulation of for a single "Multidimensional Brand Equity Index". According to their

**Table 1**
Dimensions of the second-order factor structural model for safety performance of construction sites with the standardized parameter estimates (path coefficients), errors and relative weights.

| Abbreviation | First order factors | Standardized parameter estimates | Standardized errors | Relative weights |
|---|---|---|---|---|
| G1 | "Scaffoldings and working platforms" | 0,79 | 0,38 | 0,0568 |
| G2 | "Ladders and stairs" | 0,83 | 0,31 | 0,0597 |
| G3 | "Working at height and protection against falling" | 0,88 | 0,23 | 0,0633 |
| G4 | "Lighting and electricity" | 0,91 | 0,17 | 0,0654 |
| G5 | "Housekeeping, order and tidiness" | 0,85 | 0,28 | 0,0611 |
| G6 | "Personal protective equipment (PPE)" | 0,85 | 0,27 | 0,0611 |
| G7 | "Fire prevention/protection" | 0,83 | 0,31 | 0,0597 |
| G8 | "Hand/power tools, machinery and devices" | 0,90 | 0,19 | 0,0647 |
| G9 | "Material handling (loading, transport, unloading, handling and storage)" | 0,94 | 0,11 | 0,0676 |
| G10 | "Traffic and transportation control" | 0,94 | 0,12 | 0,0676 |
| G11 | "First aid" | 0,65 | 0,57 | 0,0467 |
| G12 | "Excavation works" | 0,93 | 0,13 | 0,0669 |
| G13 | "Concrete and formwork" | 0,88 | 0,23 | 0,0633 |
| G14 | "Welding works" | 0,94 | 0,11 | 0,0676 |
| G15 | "Demolition works" | 0,93 | 0,13 | 0,0669 |
| G16 | "Workers" | 0,86 | 0,26 | 0,0618 |

methodology, it was suggested that the relative weight of a dimension was the division of the path coefficient for that dimension to the sum of the all latent dimensions' path coefficients.

The equations used in the development of the formulation of "Multidimensional Brand Equity Index" are shown below.

$$\text{Brand Equity Index} = \Sigma\,(\text{WD}_\text{i} * \text{MD}_\text{i}) \tag{1}$$

where: $\text{WD}_\text{i}$ = the weight of each dimension, $\text{MD}_\text{i}$ = the mean of dimension, WD = the weight of the dimension = (SFLD / SSFLD), SFLD = standardized factor loading of the dimension, SSFLD = summation of the standardized factor loadings of all latent dimensions.

In this study, a similar methodology was adopted in the development of the formulation of safety performance index. The developed formulation of the safety performance index of construction sites and explanations of terms included in the formula are presented below.

$$\text{Safety Performance Index}_{\text{of Construction Sites}} = \Sigma\,(\text{WMD}_\text{i} * \text{UWD}_\text{i}) \tag{2}$$

$$\text{Safety Performance Index}_{\text{of Construction Sites}} = \Sigma\,(\text{UWO}_\text{j} * \text{S}_{\text{Ej}} * \text{UWD}_\text{i}) \tag{3}$$

where: $\mathbf{WMD_i}$ = the weighted mean of the site observations of each latent dimension of "safety performance of construction sites" = [Σ ($\text{UWO}_\text{j}$ ∗ $\text{SE}_\text{j}$)] / [Σ $\text{UWO}_\text{j}$], where Σ $\text{UWO}_\text{j}$ = 1, **i** = 1, 2, …,16, **j** = 1, 2, …, total number of observed variables in the corresponding latent dimension, $\mathbf{UWO_j}$ = updated relative weight of the observed variable j = [1 / Σ ($\text{WO}_\text{j}$)] ∗ $\text{WO}_\text{j}$, $\mathbf{SE_j}$ = site evaluation of the observed variable $_\text{j}$ (scale: 0–100 where 0: conformity is minimum, 100: conformity is maximum), $\mathbf{WO_j}$ = relative weight of the observed variable $_\text{j}$ = $\text{FL}_\text{j}$ / Σ ($\text{FL}_\text{j}$), $\mathbf{FL_j}$ = factor loading of the observed variable $_\text{j}$, $\mathbf{UWD_i}$ = the updated relative weight of latent dimension i of "safety performance of construction sites" = [1 / Σ ($\text{WD}_\text{i}$)] ∗ $\text{WD}_\text{i}$], **n** = 16 (total number of latent dimensions (first-order factors) affecting safety performance of construction sites), $\mathbf{WD_i}$ = relative weight of latent dimension i of "safety performance of construction sites" = ($\text{SPCD}_\text{i}$) / Σ ($\text{SPCD}_\text{i}$), $\mathbf{SPCD_i}$ = standardized path coefficient of the latent dimension $_\text{i}$ of "safety performance of construction sites", $\mathbf{\Sigma\ SPCD_i}$ = summation of the standardized path coefficients of all latent dimensions of "safety performance of construction sites".

$$\begin{aligned}&\text{Safety Performance Index}_{\text{of Construction Sites}}\\&\quad = \Sigma\,([1/\Sigma\,((\text{SPCD}_\text{i})/\Sigma\,(\text{SPCD}_\text{i}))] * (\text{SPCD}_\text{i})\\&\qquad /\Sigma\,(\text{SPCD}_{\text{i)}})] * [1/\Sigma\,(\text{FL}_\text{j}/\Sigma\,(\text{FL}_\text{j}))] * (\text{FL}_\text{j}/\Sigma\,(\text{FL}_\text{j})) * \text{SE}_\text{j})\end{aligned} \tag{4}$$

## 7. Implementation of the safety performance index formula in case studies

Assessment of site performance was carried out by safety experts to calculate the safety performance of 11 different real international construction sites. The assessment forms (including the full list of 168 observed variables in 16 latent dimensions of safety performance) were filled out by the safety experts (minimum ten years of experience as a safety expert) according to a scale between 0 and 100, where 0: conformity is minimum, 100: conformity is maximum, NA: not applicable at the construction site. Out of 11 case studies conducted in 11 different real international construction sites, this paper briefly explains the calculations of the site safety performance index of case study #1 below as an example. Similarly, the calculations of the remaining 10 case studies were also performed but only the results of site safety performance indices by full and short model were reported in this paper.

## 8. Case study #1 (full model)

The site safety performance index of case study #1 was calculated as **82,16%**. Brief information regarding the calculation of the site safety performance index of case study #1 by full model was given in Table 2.

Explanations of the formulas in the Table 2 were listed as follows:

- Column $\text{FL}_\text{j}$: in this table, observed variables were listed in the descending order with respect to their factor loadings ($\text{FL}_\text{j}$).
- Column $\text{WO}_\text{j}$: relative weight of the observed variable j was calculated by the equation below:

$$\text{WO}_\text{j} = \text{FL}_\text{j}/\Sigma\,(\text{FL}_\text{j}) \tag{5}$$

where $\text{FL}_\text{j}$ = factor loading of the observed variable $_\text{j}$.

As an example: relative weight of the observed variable G1F5 was calculated as:

$$\text{WO}_{\text{G1F5}} = (\text{FL}_{\text{G1F5}})/\Sigma\,(\text{FL}_\text{j});$$

where j = total number of observed variables in the corresponding latent dimension.

$$\text{WO}_{\text{G1F5}} = 0,\ 71/7,\ 79 = 0,\ 0911$$

- Column $\text{UWO}_\text{j}$: updated relative weight of the observed variable $_\text{j}$ was calculated by the equation below:

$$\text{UWO}_\text{j} = [1/\Sigma\,(\text{WO}_\text{j})] * \text{WO}_\text{j} \tag{6}$$

As an example: updated relative weight of the observed variable G1F5 was calculated as:

**Table 2**
Brief information regarding the calculation of the site safety performance index of case study #1 by full model.

| Observed variable j | $FL_j$ | $WO_j = FL_j / \Sigma (FL_j)$ | $UWO_j = [1 / \Sigma (WO_j)] * WO_j$ | $SE_j$ | $WMD_i = \Sigma(UWO_j * SE_j)$ | Dimension i | $SPCD_i$ | $WD_i = (SPCD_i) / \Sigma (SPCD_i)$ | $UWD_i = [1 / \Sigma (WD_i)] * WD_i]$ | $SPI = \Sigma(UWO_j * SE_j * UWD_i)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Factor loading of the observed variable j | Relative weight of the observed variable j | Updated relative weight of the observed variable j | Site evaluation of the observed variable j (scale: 0–100) | The weighted mean of the site observations of each dimension | | Standardized path coefficient of dimension i | Relative weight of dimension i | Updated relative weight of dimension i | Safety performance index of construction site |
| G1F5 | 0.71 | 0.0911 | 0.0911 | 90 | 8.2028 | G1 | 0.7900 | 0.0568 | 0.0568 | 0.4659 |
| G1F1 | 0.70 | 0.0899 | 0.0899 | 100 | 8.9859 | | | | | 0.5103 |
| G1F3 | 0.69 | 0.0886 | 0.0886 | 90 | 7.9718 | | | | | 0.4527 |
| G1F11 | 0.68 | 0.0873 | 0.0873 | 95 | 8.2927 | | | | | 0.4710 |
| G1F2 | 0.66 | 0.0847 | 0.0847 | 87 | 7.3710 | | | | | 0.4186 |
| G1F6 | 0.66 | 0.0847 | 0.0847 | 75 | 6.3543 | | | | | 0.3609 |
| G1F8 | 0.65 | 0.0834 | 0.0834 | 60 | 5.0064 | | | | | 0.2843 |
| G1F7 | 0.64 | 0.0822 | 0.0822 | 50 | 4.1078 | | | | | 0.2333 |
| G1F9 | 0.64 | 0.0822 | 0.0822 | 50 | 4.1078 | | | | | 0.2333 |
| G1F12 | 0.61 | 0.0783 | 0.0783 | 80 | 6.2644 | | | | | 0.3558 |
| G1F4 | 0.58 | 0.0745 | 0.0745 | 75 | 5.5841 | | | | | 0.3171 |
| G1F10 | 0.57 | 0.0732 | 0.0732 | 85 | 6.2195 | | | | | 0.3532 |
| Sum | 7.79 | 1.00 | 1.00 | | 78.47 | | | | | 4.4565 |
| G2F7 | 0.80 | 0.113 | 0.1153 | 85 | 9.7983 | G2 | 0.8300 | 0.0597 | 0.0597 | 0.5847 |
| G2F6 | 0.78 | 0.1124 | 0.1124 | 75 | 8.4294 | | | | | 0.5030 |
| G2F2 | 0.75 | 0.1081 | 0.1081 | 90 | 9.7262 | | | | | 0.5804 |
| G2F3 | 0.71 | 0.1023 | 0.1023 | 75 | 7.6729 | | | | | 0.4578 |
| G2F5 | 0.70 | 0.1009 | 0.1009 | 50 | 5.0432 | | | | | 0.3009 |
| G2F1 | 0.67 | 0.0965 | 0.0965 | 80 | 7.7233 | | | | | 0.4608 |
| G2F4 | 0.67 | 0.0965 | 0.0965 | 85 | 8.2061 | | | | | 0.4896 |
| G2F9 | 0.67 | 0.0965 | 0.0965 | 70 | 6.7579 | | | | | 0.4032 |
| G2F8 | 0.63 | 0.0908 | 0.0908 | 70 | 6.3545 | | | | | 0.3792 |
| G2F10 | 0.56 | 0.0807 | 0.0807 | 60 | 4.8415 | | | | | 0.2889 |
| Sum | 6.94 | 1.00 | 1.00 | | 74.55 | | | | | 4.4485 |
| Global sum | | | | | | Σ | 13.9100 | 1.0000 | 1.0000 | 82.1587 |
| | | | | | **Site safety performance index of case study #1** | | | | | **82.1587** |

**Table 3**
The calculations of the scenario 1 (full model).

| Observed variable j | $FL_j$ | $WO_j = FL_j / \Sigma (FL_j)$ | $UWO_j = [1 / \Sigma (WO_j)] * WO_j$ | $SE_j$ | $WMD_i = \Sigma(UWO_j * SE_j)$ | Dimension i | $SPCD_i$ | $WD_i = (SPCD_i) / \Sigma (SPCD_i)$ | $UWD_i = [1 / \Sigma (WD_i)] * WD_i]$ | $SPI = \Sigma(UWO_j * SE_j * UWD_i)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Factor loading of the observed variable j | Relative weight of the observed variable j | Updated relative weight of the observed variable j | Site evaluation of the observed variable j (scale: 0–100) | The weighted mean of the site observations of each dimension | | Standardized path coefficient of dimension i | Relative weight of dimension i | Updated relative weight of dimension i | Safety performance index of construction site |
| G1F5 | 0.71 | 0.0911 | 0.1109 | 90 | 9.9844 | G1 | 0.7900 | 0.0568 | 0.0568 | 0.5670 |
| G1F1 | 0.70 | NA | NA | NA | NA | | | | | |
| G1F3 | 0.69 | NA | NA | NA | NA | | | | | |
| G1F11 | 0.68 | 0.0873 | 0.1063 | 95 | 10.0938 | | | | | 0.5733 |
| G1F2 | 0.66 | 0.0847 | 0.1031 | 87 | 8.9719 | | | | | 0.5095 |
| G1F6 | 0.66 | 0.0847 | 0.1031 | 75 | 7.7344 | | | | | 0.4393 |
| G1F8 | 0.65 | 0.0834 | 0.1016 | 60 | 6.0938 | | | | | 0.3461 |
| G1F7 | 0.64 | 0.0822 | 0.1000 | 50 | 5.0000 | | | | | 0.2840 |
| G1F9 | 0.64 | 0.0822 | 0.1000 | 50 | 5.0000 | | | | | 0.2840 |
| G1F12 | 0.61 | 0.0783 | 0.0953 | 80 | 7.6250 | | | | | 0.4331 |
| G1F4 | 0.58 | 0.0745 | 0.0906 | 75 | 6.7969 | | | | | 0.3860 |
| G1F10 | 0.57 | 0.0732 | 0.0891 | 85 | 7.5703 | | | | | 0.4299 |
| Sum | 7.79 | 0.82 | 1.00 | | 74.87 | | | | | 4.2522 |

$(UWO_{G1F5}) = [1/\Sigma (WO_j)] * WO_{G1F5}$;

where j = total number of observed variables in the corresponding latent dimension.

$0,0911 = 1/1*0,0911$

### *8.1. Scenario 1*

As can be understood from the formula, if some of the items were evaluated as Not Applicable, then $\Sigma (WO_j)$ would be smaller than 1, resulting in an updated relative weight of the observed variable $(UWO_{G1F5})$.

To illustrate abovementioned scenario 1: if site evaluation of the observed variable $SE_{G1F1}$ and $SE_{G1F3}$ were NA; then as shown in the Table 3, $\Sigma (WO_j)$ becomes 0,82.

Updated relative weight of the observed variable G1F5 was calculated as:

$UWO_{G1F5} = [1/\Sigma (WO_j)] * WO_{G1F5}$;

where j = total number of observed variables in the corresponding latent dimension. $UWO_{G1F5} = 1/0,82*0,0911 = 0,1109$

- Column $SE_j$: this column shows the site evaluations of the observed variables. Scale is between 0 and 100, where; 0 = conformity is minimum, 100 = conformity is maximum, NA: not applicable.
- Column $WMD_i$: the weighted mean of the site observations of each latent dimension was calculated by the equation below:

$$WMD_i = \Sigma (UWO_j * SE_j) \tag{7}$$

As an example: the weighted mean of the site observations of latent dimension G1 was calculated as:

$$(WMD_1) = UWO_1*SE_1 + UWO_2*SE_2 + \ldots + UWO_{12}*SE_{12}$$

$$78,47 = 8,2028 + 8,9859 + 7,9718 + 8,2927 + 7,3710 + 6,3543 + 5,0064 + 4,1078 + 4,1078 + 6,2644 + 5,5841 + 6,2195.$$

- Column $SPCD_i$ demonstrated standardized path coefficient of latent dimensions.
- Column $WD_i$: relative weight of latent dimension $_i$ was calculated by the equation below:

$$WD_i = (SPCD_i)/\Sigma (SPCD_i) \tag{8}$$

As an example: relative weight of latent dimension 1 was calculated as:

$0,0568 = 0,798/13,91.$

- Column $UWD_i$: updated relative weight of latent dimension $_i$ was calculated by the equation below:

$$UWD_i = [1/\Sigma (WD_i)] * WD_i] \tag{9}$$

As an example: updated relative weight of latent dimension 1 was calculated as:

$UWD1 = [1/\Sigma(WD_i)] * WD1]$; where $i = 1, 2, \ldots, 16$.
$0,0568 = 1/1*0,0568.$

### *8.2. Scenario 2*

As can be understood from the formula, if latent dimension G2 was evaluated as Not Applicable (NA), then $\Sigma (UWD_i)$ would be smaller than 1 resulting an updated relative weight of the latent dimension (UWD1) greater than the relative weight of the latent dimension (WD1).

To illustrate abovementioned scenario 1: if site evaluation of latent dimension G2 was NA; then as shown in the Table 4, $\Sigma (UWD_i)$ becomes 0,9403.

Updated relative weight of the latent dimension G1 was calculated as:

$UWD1 = [1/\Sigma (WD_i)] * WD1]$; where $i = 1, 2, \ldots, 16$.

$0,0604 = 1 / 0,9403 * 0,0568$, showing updated relative weight of latent dimension G1.

- **Full Model Safety Performance Level**: for the full model, the safety performance levels of latent dimensions were calculated as follows:

$$\text{Safety performance level of latent dimension}_i = WMD_i/100 = \Sigma (UWO_j * SE_j)$$

As an example: safety performance level of latent dimension 1 was calculated as 78,47 / 100 = 78,47%

- Column SPI: safety performance index of construction site was calculated by the formula below:

$$SPI = \Sigma (UWO_j * SE_j * UWD_i) \tag{10}$$

where **i** = 1, 2, …, 16 and, **j** = total number of observed variables in the corresponding latent dimension

$$SPI = (0,0911*90*0,0568) + \ldots + (0,0833*95*0,0618) = 82,16\%$$

## 9. Benchmarking of construction sites of case studies #1 to #11 according to safety performance

The site safety performance indices of 11 case studies conducted in this study were demonstrated in Fig. 1 in descending order. According to the results, the highest safety performance index in all the cases is calculated as 91,58% for case study 11, whereas the lowest safety performance index is calculated as 35,92% for case study 7. The high number of near miss cases/incidents/accidents, and low-conformity of the safety dimensions in case study 7 reasonably explains and supports this remarkable difference in site safety performance between these two cases.

## 10. Proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions)

In the previous parts, to assess the safety performance of 11 different international construction sites, investigations were made by safety professionals of construction companies. The evaluation forms including the full list of 168 observed variables in 16 latent dimensions of safety performance were filled at the construction sites by safety engineers of the companies working for the case study projects. The site safety performance indices of 11 case studies were calculated accordingly.

In this part, since it is quite harder and more time consuming for safety engineers to evaluate 168 observed variables in 16 latent dimensions, a relatively short and simple model was proposed consisting of the top three most important observed variables taking into account of their factor loadings calculated previously for each 16 latent dimensions. This short model consisted of 48 observed variables in 16 latent dimensions.

## 11. Case study #1 (short model)

Proposed short model was implemented to the first case study project and the site safety performance index of case study #1 was calculated as **84,39%**, while taking into account the top three most important observed variables for each 16 latent dimensions. Brief

**Table 4**
The calculations of the scenario 2 (full model).

| Observed variable j | $FL_j$ | $WO_j = FL_j / \Sigma (FL_j)$ | $UWO_j = [1 / \Sigma (WO_j)] * WO_j$ | $SE_j$ | $WMD_i = \Sigma(UWO_j * SE_j)$ | Dimension i | $SPCD_i$ | $WD_i = (SPCD_i) / \Sigma (SPCD_i)$ | $UWD_i = [1 / \Sigma (WD_i)] * WD_i]$ | $SPI = \Sigma(UWO_j * SE_j * UWD_i)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Factor loading of the observed variable j | Relative weight of the observed variable j | Updated relative weight of the observed variable j | Site evaluation of the observed variable j (scale: 0–100) | The weighted mean of the site observations of each dimension | | Standardized path coefficient of dimension i | Relative weight of dimension i | Updated relative weight of dimension i | Safety performance index of construction site |
| G1F5 | 0.71 | 0.0911 | 0.0911 | 90 | 8.2028 | G1 | 0.7900 | 0.0568 | 0.0604 | 0.4954 |
| G1F1 | 0.70 | 0.0899 | 0.0899 | 100 | 8.9859 | | | | | 0.5427 |
| G1F3 | 0.69 | 0.0886 | 0.0886 | 90 | 7.9718 | | | | | 0.4815 |
| G1F11 | 0.68 | 0.0873 | 0.0873 | 95 | 8.2927 | | | | | 0.5009 |
| G1F2 | 0.66 | 0.0847 | 0.0847 | 87 | 7.3710 | | | | | 0.4452 |
| G1F6 | 0.66 | 0.0847 | 0.0847 | 75 | 6.3543 | | | | | 0.3838 |
| G1F8 | 0.65 | 0.0834 | 0.0834 | 60 | 5.0064 | | | | | 0.3024 |
| G1F7 | 0.64 | 0.0822 | 0.0822 | 50 | 4.1078 | | | | | 0.2481 |
| G1F9 | 0.64 | 0.0822 | 0.0822 | 50 | 4.1078 | | | | | 0.2481 |
| G1F12 | 0.61 | 0.0783 | 0.0783 | 80 | 6.2644 | | | | | 0.3784 |
| G1F4 | 0.58 | 0.0745 | 0.0745 | 75 | 5.5841 | | | | | 0.3373 |
| G1F10 | 0.57 | 0.0732 | 0.0732 | 85 | 6.2195 | | | | | 0.3756 |
| Sum | 7.79 | 1.00 | 1.00 | | 78.47 | | | | | 4.7393 |
| G2F7 | 0.80 | NA | NA | NA | NA | G2 | 0.8300 | NA | NA | |
| G2F6 | 0.78 | NA | NA | NA | NA | | | | | |
| G2F2 | 0.75 | NA | NA | NA | NA | | | | | |
| G2F3 | 0.71 | NA | NA | NA | NA | | | | | |
| G2F5 | 0.70 | NA | NA | NA | NA | | | | | |
| G2F1 | 0.67 | NA | NA | NA | NA | | | | | |
| G2F4 | 0.67 | NA | NA | NA | NA | | | | | |
| G2F9 | 0.67 | NA | NA | NA | NA | | | | | |
| G2F8 | 0.63 | NA | NA | NA | NA | | | | | |
| G2F10 | 0.56 | NA | NA | NA | NA | | | | | |
| Sum | 6.94 | – | – | | – | | | | | – |
| Global sum | | | | | | Σ | 13.9100 | 0.9403 | 1.0000 | 82.6413 |
| | | | | | **Site safety performance index of case study #1** | | | | | **82.6413** |

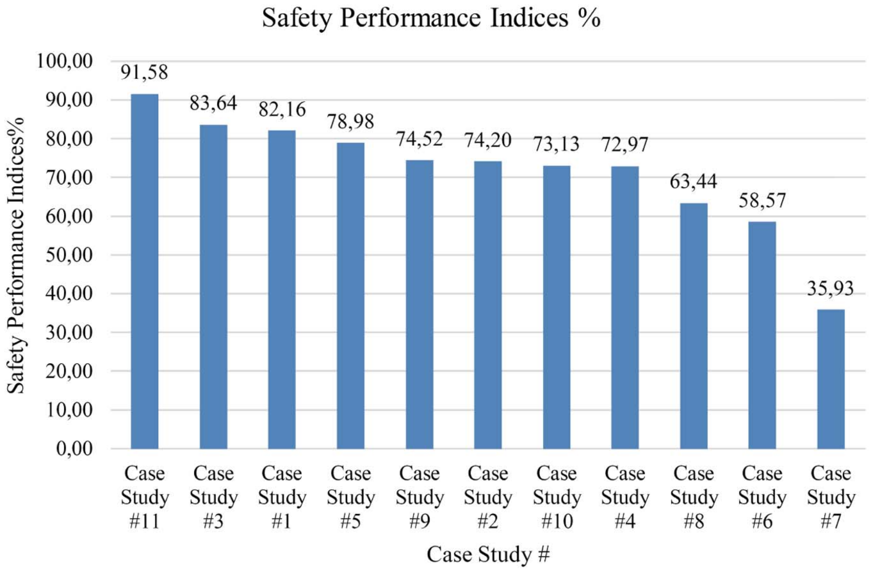


**Fig. 1.** Calculated safety performance indices for case studies #1 to #11 (in descending order).

information regarding the calculation of the site safety performance index of case study #1 by short model was given in Table 5.

- **Short Model Safety Performance Level**: For the short model, the safety performance levels of latent dimensions were calculated as follows:

$$\text{Safety performance level of latent dimension}_i = WMD_i/100 = \Sigma\,(UWO_j * SE_j)$$

As an example: safety performance level of latent dimension 1 was calculated as 93,33 / 100 = 93,33%.

- Column SPI: safety performance index of construction site was

**Table 5**
Brief information regarding the calculation of the site safety performance index of case study #1 by short model.

| Observed variable j | $FL_j$ | $WO_j = FL_j / \Sigma (FL_j)$ | $UWO_j = [1 / \Sigma (WO_j)] * WO_j$ | $SE_j$ | $WMD_i = \Sigma(UWO_j * SE_j)$ | Dimension i | $SPCD_i$ | $WD_i = (SPCD_i) / \Sigma (SPCD_i)$ | $UWD_i = [1 / \Sigma (WD_i)] * WD_i]$ | $SPI = \Sigma(UWO_j * SE_j * UWD_i)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Factor loading of the observed variable j | Relative weight of the observed variable j | Updated relative weight of the observed variable j | Site evaluation of the observed variable j (scale: 0–100) | The weighted mean of the site observations of each dimension | | Standardized path coefficient of dimension i | Relative weight of dimension i | Updated relative weight of dimension i | Safety performance index of construction site |
| G1F5 | 0.71 | 0.3381 | 0.3381 | 90 | 30.4286 | G1 | 0.7900 | 0.0568 | 0.0568 | 1.7282 |
| G1F1 | 0.70 | 0.3333 | 0.3333 | 100 | 33.3333 | | | | | 1.8931 |
| G1F3 | 0.69 | 0.3286 | 0.3286 | 90 | 29.5714 | | | | | 1.6795 |
| SUM | 2.10 | 1.00 | 1.00 | | 93.33 | | | | | 5.3007 |
| G2F7 | 0.80 | 0.3433 | 0.3433 | 85 | 29.1845 | G2 | 0.8300 | 0.0597 | 0.0597 | 1.7414 |
| G2F6 | 0.78 | 0.3348 | 0.3348 | 75 | 25.1073 | | | | | 1.4981 |
| G2F2 | 0.75 | 0.3219 | 0.3219 | 90 | 28.9700 | | | | | 1.7286 |
| SUM | 2.33 | 1.00 | 1.00 | | 83.26 | | | | | 4.9682 |
| G16F3 | 0.80 | 0.3361 | 0.3361 | 75 | 25.2101 | G16 | 0.8600 | 0.0618 | 0.0618 | 1.5586 |
| G16F2 | 0.79 | 0.3319 | 0.3319 | 50 | 16.5966 | | | | | 1.0261 |
| G16F5 | 0.79 | 0.3319 | 0.3319 | 75 | 24.8950 | | | | | 1.5392 |
| SUM | 2.38 | 1.00 | 1.00 | | 66.70 | | | | | 4.1239 |
| Global sum | | | | | | Σ | 13.9100 | 1.0000 | 1.0000 | 84.3945 |
| | | | | | **Site safety performance index of case study #1** | | | | | **84.3945** |

calculated by the formula below:

$$SPI = \Sigma\,(UWO_j * SE_j * UWD_i) \tag{10}$$

where: $\mathbf{i} = 1, 2, \ldots, 16$ and, $\mathbf{j} = 1, 2, 3$.

$$SPI = (0,3381*90*0,0568)+\ldots+(0,3319*75*0,0618) = 84,\ 39\%$$

## 12. Discussion about the results of short (simple) model and the full model

In this part, results of the short (simple) model and the full model were compared for case studies #1 to #11. To illustrate: The site safety performance index of case study #1 for short model was calculated as 84,39%. As known, it was found to be 82,16% in the full model. The reasons for the difference between the full and short model results were due to the followings.

As demonstrated in Tables 2 and 5; full model included 168 observed variables in 16 latent dimensions but short model consisted of 48 (top three most important observed variables taking into account of their factor loadings calculated previously for each 16 latent dimensions) observed variables in 16 latent dimensions. As an example, in the full model, latent dimension G1 has 12 observed variables but in the short model, latent dimension G1 has three observed variables. Factor loadings and site evaluations of the observed variables were the same for both models. In addition, relative weights of the latent dimensions were the same for both models. But, since the remaining nine observed variables were not taken into account in the short model, the values of the updated relative weights of the observed variables of G1F5, G1F1, and G1F3 were different from the full model. In the full model the updated relative weights were calculated as: $UWO_{G1F5} = 0{,}0911$, $UWO_{G1F1} = 0{,}0899$, and $UWO_{G1F3} = 0{,}0886$. Whereas in the short model they were calculated as: $UWO_{G1F5} = 0{,}3381$, $UWO_{G1F1} = 0{,}3333$, and $UWO_{G1F3} = 0.3286$. According to the Eq. (4), the differences in the updated relative weights of the observed variables lead to difference in the calculated safety performance indices.

Deviation of the result of the short model from the result of the full model was calculated by the following equation:

**Table 6**
The results of comparison between short model and full model.

| Case study # | Full model result % | Short model result % | Deviation % |
|---|---|---|---|
| Case study #1 | 82,16 | 84,39 | 2,71 |
| Case study #2 | 74,20 | 76,42 | 2,99 |
| Case study #3 | 83,64 | 85,31 | 2,00 |
| Case study #4 | 72,97 | 75,47 | 3,43 |
| Case study #5 | 78,98 | 82,27 | 4,17 |
| Case study #6 | 58,57 | 60,90 | 3,98 |
| Case study #7 | 35,93 | 39,04 | 8,66 |
| Case study #8 | 63,44 | 64,53 | 1,72 |
| Case study #9 | 74,52 | 76,47 | 2,62 |
| Case study #10 | 73,13 | 75,06 | 2,64 |
| Case study #11 | 91,58 | 91,29 | − 0,32 |

$$\text{Deviation} = (\text{Short Model Result} - \text{Full Model Result})/\text{Full Model Result} \tag{11}$$

$$\text{Deviation for}_{\text{Case study}\#1} = (84,\ 39\% - 82,\ 16\%)/82,\ 16\%)$$

$$\text{Deviation for}_{\text{Case study}\#1} = \mathbf{2,\ 71}\%$$

According to the assessment carried out by the safety experts of 11 different real international construction sites, calculations of the safety performances were performed by the full and short model. Comparison of the results between short model and full model was shown in Table 6. The average deviation of the short model results from full model result was calculated as + 3,14%. It is quite reasonable to utilize the proposed short model taking into account its simplicity, fastness and reasonable accuracy.

According to the results, the highest safety performance index in all the cases is calculated as 91,58% (full model) and 91,29% (short model) for case study 11, whereas the lowest safety performance index is calculated as 35,93% (full model) and 39,04% (short model) for case study 7 as shown in in Table 6. The high number of near miss cases/incidents/accidents, and low-conformity of the safety dimensions in case study 7 as compared to case study 11 reasonably explains and supports this remarkable difference in site safety performance between these two cases.

**Table 7**
The breakdown of the case study projects according to their types.

| Case study # | Project type |
|---|---|
| Case study #1 | Construction of natural gas pipeline project |
| Case study #2 | Construction of natural gas pipeline project |
| Case study #3 | Supply and installation of compressor station project |
| Case study #4 | Supply and installation of compressor station project |
| Case study #5 | Construction of natural gas pipeline project |
| Case study #6 | Construction of natural gas pipeline project |
| Case study #7 | Construction of natural gas pipeline project |
| Case study #8 | Construction of natural gas pipeline project |
| Case study #9 | Supply and installation of compressor station project |
| Case study #10 | Construction of building structures |
| Case study #11 | Construction of underground natural gas storage project |

## 13. Validation of results of both models

Both models were tested and validated in 11 different real international construction sites. The breakdown of the case study projects according to their types was demonstrated in Table 7.

As can be seen from Table 7, one of the projects was construction of an underground natural gas storage project. One of them was construction of building structures. Six of the projects were construction of natural gas pipeline projects. Three of the projects were the supply and installation of compressor station projects.

## 14. The performance of short model versus full-fledged model

For the full-fledged model, it is quite hard and time consuming for safety engineers to evaluate 168 observed variables in 16 latent dimensions. Therefore, a relatively short and simple model was proposed consisting of the top three most important observed variables taking into account of their factor loadings calculated previously for each 16 latent dimensions. This short model just consisted of 48 observed variables in 16 latent dimensions.

As previously mentioned, assessment of site performance was carried out by safety experts to calculate the safety performance of 11 different real international construction sites. Both models were performed in these real international construction sites and results showed that the average duration of the filling the assessment forms by the safety experts in the short model was nearly below one-third of the duration that was spent in the full-fledged model.

Also, according to the results, short model estimated the result with an average deviation of 3,14%. Therefore, within a reasonable accuracy, short model showed higher performance both in terms of duration of filling and simplicity.

## 15. The development of site safety performance (SSP) application for mobile devices

The development of a site safety performance (SSP) application for mobile devices was briefly explained it this part.

### 15.1. Native, mobile-web and hybrid mobile platforms

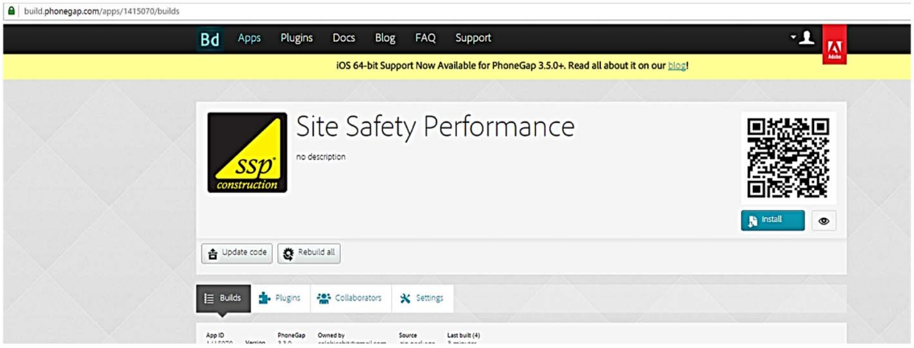
Mobile applications can be broadly classified into three categories namely native mobile, mobile-web and hybrid mobile applications [22]. The native mobile applications are built specifically for a particular mobile device and its operating system [23]. A mobile-web application is normally downloaded from a central web server. The hybrid mobile application, from the user interface, looks like browser based, with a native application wrapped around it providing access to device native functionality [24].

### 15.2. Cross-platform software development kits (SDKs)

Cross-platform mobile development has become more popular approach to deliver applications to various mobile platforms [25]. Using the SDKs, one can develop mobile-web, hybrid and native applications reducing a lot of the effort, time and resources required to develop applications for multiple platforms [22]. Some of the most widely used cross-platform SDKs and HTML5 frameworks used to develop such applications are as follows: a) PhoneGap, b) Appcelerator's Titanium, c) Airplay SDK, d) Adobe Air, e) Rho Mobile.

### 15.3. PhoneGap

PhoneGap, first released in 2005 by Nitobi Inc. [26], is an open source cross-platform mobile application development framework which through the use of HTML5, CSS and JavaScript allows for the development of applications for iOS, Android and Windows devices. The final product of a PhoneGap application is a binary application archive that can be distributed through standard application ecosystems. Applications developed by PhoneGap can be distributed to various vendor application stores and installed on an end-user's device like any other native application. Some of the benefits PhoneGap Build provides are; It does not involve installing and maintaining multiple native software development kits, it maximizes the developer's productivity while minimizing production time, team members can be added to work collaboratively and roles can be developed within PhoneGap Project [26]. Considering PhoneGap's advantages of being a standards-based, open source development framework, free to download, with community-built development tools and plugins [23] and being the most popularly growing platform [27], in this study, PhoneGap is selected to develop a hybrid mobile application. In this study, a site safety performance (SSP) web application software was developed by using the HTML5, CSS3 and JavaScript coding languages. Then a site safety performance (SSP) mobile application was developed by using PhoneGap built on the previously developed SSP web application software. The barcode page for SSP Mobile application by PhoneGap Build was generated in Fig. 2.

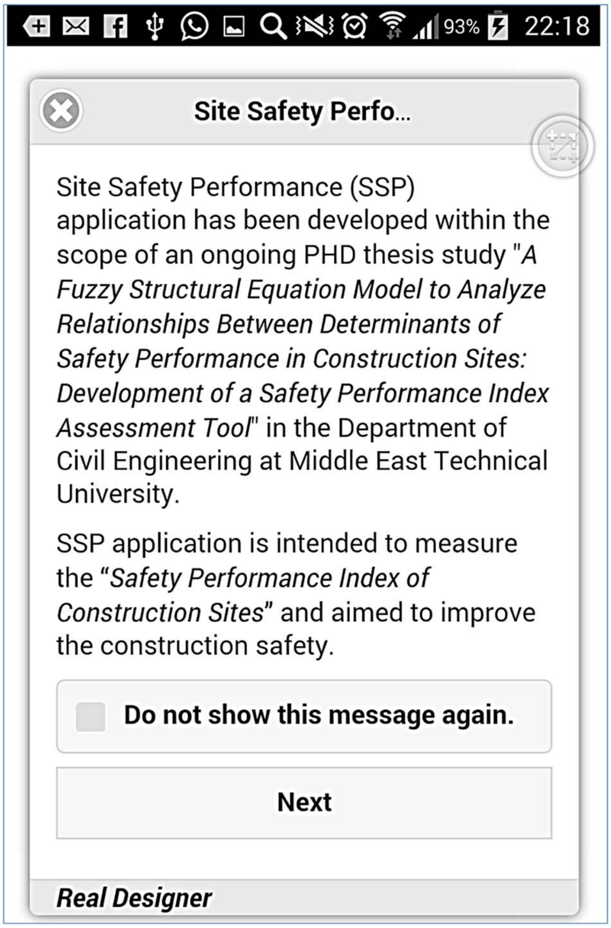


iOS 64-bit Support Now Available for PhoneGap 3.5.0+. Read all about it on our blog!

Site Safety Performance

no description

**Fig. 2.** Developed SSP mobile application by PhoneGap Build.



**Site Safety Perfo...**

Site Safety Performance (SSP) application has been developed within the scope of an ongoing PHD thesis study "*A Fuzzy Structural Equation Model to Analyze Relationships Between Determinants of Safety Performance in Construction Sites: Development of a Safety Performance Index Assessment Tool*" in the Department of Civil Engineering at Middle East Technical University.

SSP application is intended to measure the "*Safety Performance Index of Construction Sites*" and aimed to improve the construction safety.

☐ **Do not show this message again.**

**Next**

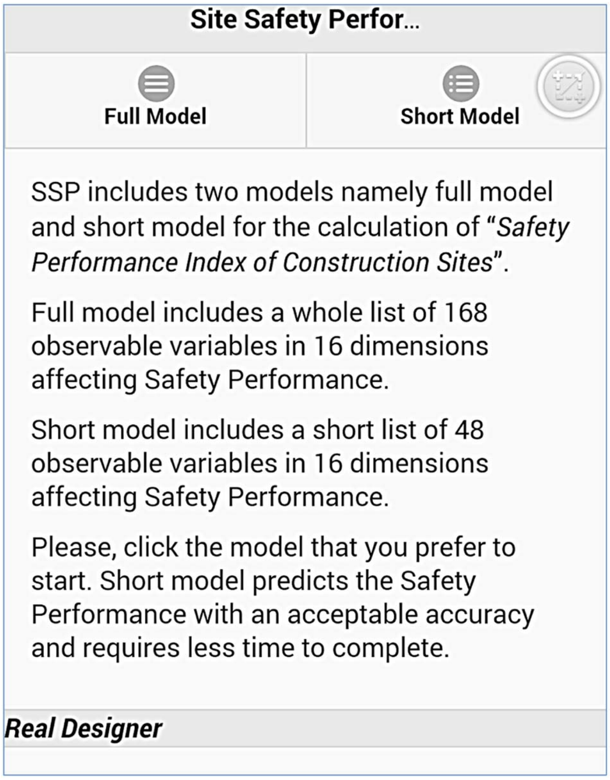
***Real Designer***

Fig. 3. The introduction page of site safety performance (SSP) mobile application.

### 15.4. Application compilation for site safety performance (SSP) mobile application

After preparing the site safety performance (SSP) web content, the files were organized in the folder structure. PhoneGap accepts user login developed on GitHub or using AdobeID. GitHub is a repository service where users can upload their contents and use them by providing their Uniform Resource Locator (URL) references. The developed SSP mobile web content is uploaded to GitHub and then called directly to PhoneGap. After clicking 'Upload a .zip file' and uploading the .zip file including all web-contents and configurations for site safety performance (SSP) application, the barcode page and download link (https://build.phonegap.com/apps/1415070/download/android?qr_key=atwQ3RsRQ65JKy3yfc3-.) for SSP Mobile application by PhoneGap Build was generated.

When the site safety performance (SSP) mobile application is started by triggering the program's shortcut, an introductory page is displayed on the screen of the mobile phone as shown in Fig. 3. If the mobile device is tilted 90 degrees in clockwise or counter-clockwise direction, SSP application adapts itself and shows the tilted view. After triggering the next button in Fig. 3, SSP model selection page opens as shown in Fig. 4. In the model selection page of SSP application, explanations are given to describe the models to be selected. When the full model button is triggered, the full model page is displayed on the screen. In the full model page of SSP mobile application, explanations are made as seen in Fig. 5. When the short model button is triggered, the short model page is displayed on the screen. When the results button is triggered in full model menu, the results page is displayed on the screen. Explanations and results are demonstrated in Fig. 6. When the results button is triggered in short model menu, the results page is displayed on the screen. In the results page of SSP mobile application, following explanations are made and results are demonstrated as similar to the full model. When back button is forced, program saves the data and closes down. If SSP mobile application is restarted, users can continue to make evaluation of the observable variables. SSP mobile application never expires. Data and results are always available, when a change is made in the evaluation of any observable variable, the results are calculated and changed accordingly and can be reached from results page simultaneously.



**Site Safety Perfor...**

**Full Model** **Short Model**

SSP includes two models namely full model and short model for the calculation of "*Safety Performance Index of Construction Sites*".

Full model includes a whole list of 168 observable variables in 16 dimensions affecting Safety Performance.

Short model includes a short list of 48 observable variables in 16 dimensions affecting Safety Performance.

Please, click the model that you prefer to start. Short model predicts the Safety Performance with an acceptable accuracy and requires less time to complete.

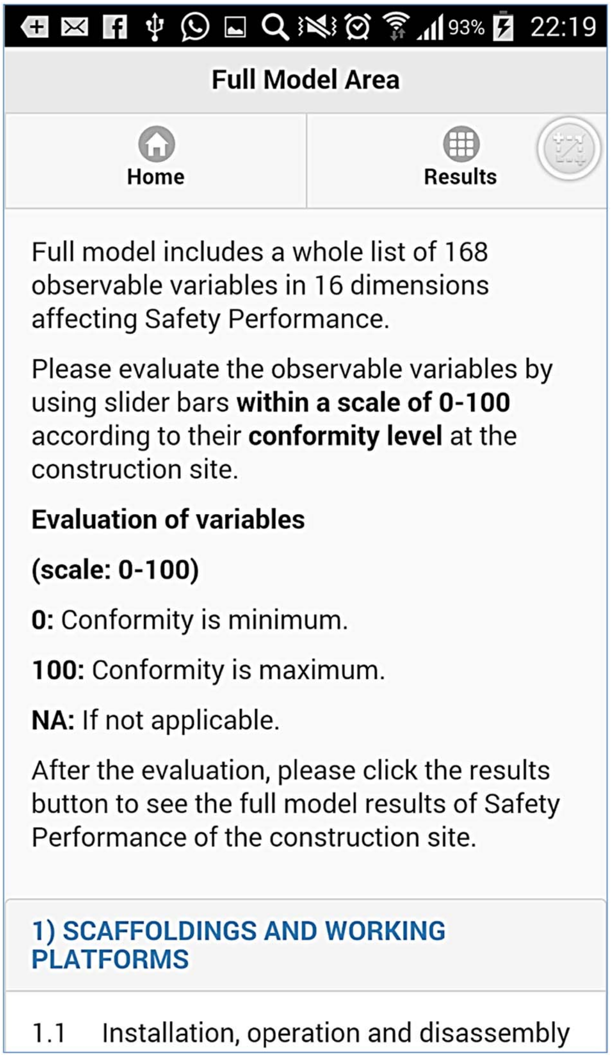
***Real Designer***

Fig. 4. The model selection page of site safety performance (SSP) mobile application.

## 16. Conclusion

This paper focused on the formulation of the safety performance index of construction sites based on validated multidimensional safety performance model. A safety performance index assessment tool was proposed by developing a site safety performance application for mobile devices. PhoneGap was selected to develop a hybrid mobile application. A brief explanation of the development procedure of the site safety performance (SSP) application for mobile devices by PhoneGap was made. Snapshots of the pages of SSP application for mobile devices were demonstrated. This application would work with any construction type. This tool can be used at any stage of the construction. The end-user is to decide the required level of percentage index calculated by the model. The output of the study was validated with 11 international construction projects as case studies.

A proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions) was explained. Results of safety performance by the short (simple) model and the full model were compared for all of the case studies. Deviations of the results of the short model from the results of the full model were calculated. The average deviation of the short model results from full model results was found to be +3.14%. It was found quite reasonable to utilize the proposed short model considering its advantages over the full model. Firstly; since the short model includes only 48 observed variables, it is



Full model includes a whole list of 168 observable variables in 16 dimensions affecting Safety Performance.

Please evaluate the observable variables by using slider bars **within a scale of 0-100** according to their **conformity level** at the construction site.

**Evaluation of variables**

**(scale: 0-100)**

**0:** Conformity is minimum.

**100:** Conformity is maximum.

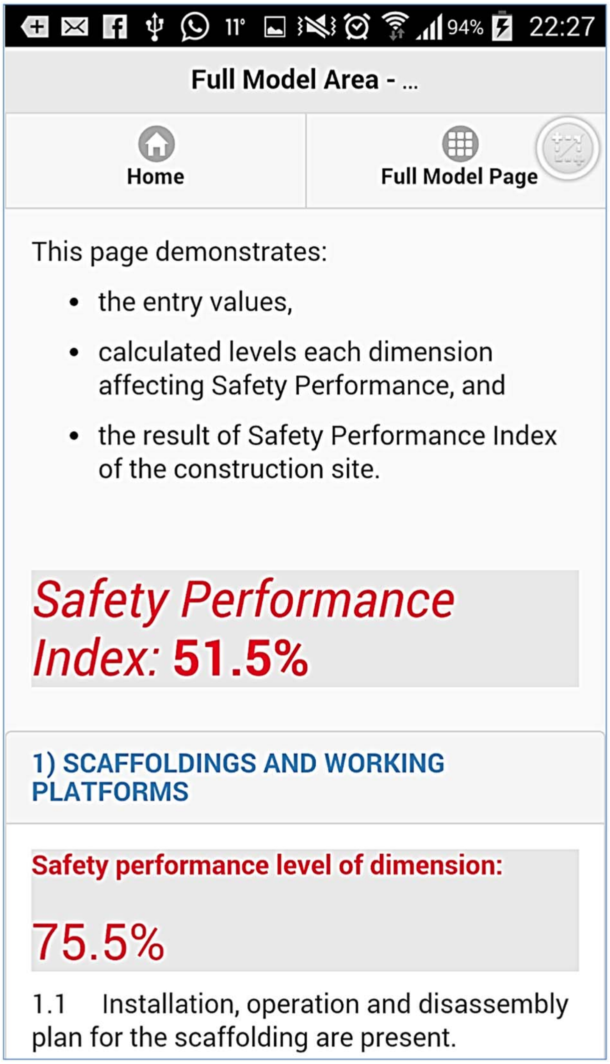
**NA:** If not applicable.

After the evaluation, please click the results button to see the full model results of Safety Performance of the construction site.

1) SCAFFOLDINGS AND WORKING PLATFORMS

1.1 Installation, operation and disassembly

**Fig. 5.** The full model page of site safety performance (SSP) mobile application.



This page demonstrates:

- the entry values,
- calculated levels each dimension affecting Safety Performance, and
- the result of Safety Performance Index of the construction site.

*Safety Performance Index:* **51.5%**

1) SCAFFOLDINGS AND WORKING PLATFORMS

**Safety performance level of dimension:**

75.5%

1.1 Installation, operation and disassembly plan for the scaffolding are present.

**Fig. 6.** The results page of full model of SSP mobile application.

quite simple to fill it out. It requires less effort as compared to the full model. Secondly; since the short model have considerably less number of observed variables, it requires less time to fill it out. By using short model, the results are achieved faster as compared to the full model. Thirdly; since the average deviation of the short model results from full model results was found to be + 3.14%, short model calculates the result within a reasonable accuracy by experience. Consequently, the proposed short model supplies the simplicity, fastness and moderate accuracy. According to the results, the highest safety performance index in all the cases is calculated as 91,58% (full model) and 91,29% (short model) for case study 11, whereas the lowest safety performance index is calculated as 35,93% (full model) and 39,04% (short model) for case study 7. The high number of near miss cases/incidents/accidents, and low-conformity of the safety dimensions in case study 7 as compared to case study 11 reasonably explains and supports this remarkable difference in site safety performance between these two cases.

The limitation of this paper is that the models were tested only in 11 real international construction projects as case studies. Therefore, more data could to be collected to evaluate the performance of the short model and determine whether it can be used to replace the full-fledged model.

## 17. Recommendations for future study

In this study, it was assumed that, safety engineers had considerable experience and knowledge in construction site safety in evaluating the forms. But in the real life, it is advisable that, to assure the calibration among evaluators, future studies shall develop user manuals explaining how to evaluate observed variables occurring at the site in a scale between 0 and 100. This will result in a better calibration among the evaluators, which can enhance the quality of the results of different sites and different projects. Cloud-support can be integrated to the developed mobile applications to save the results online servers and make available from everywhere to reach the benchmarking of the safety performance results of different projects effectively. This paper opens up possibilities where future researchers can produce more powerful, versatile and user-friendly software that can produce fast and reliable results.

## 18. Data availability

Data generated or analyzed during the study are available from the corresponding author by request.

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