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aya hassan
aya.hassan@bue.edu.eg

Ali Hassan
ali.hassan@bue.edu.eg

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A hybrid model for assessing safety implementation and project success in the construction industry

Ali Hassan Ali [a,d,*], Ahmed Farouk Kineber [b], Mehrdad Arashpour [c], Aya Hassan [d], Mohammad Alhusban [e], Ahmad M. Zamil [f]

[a] *Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong SAR, China*
[b] *College of Project Management, Built Environment, Asset & Maintenance Management, School of Engineering and Technology, Central Queensland University, 120 Spencer Steet, Melbourne, VIC 3000, Australia*
[c] *Department of Civil Engineering, Monash University, Melbourne, VIC 3800, Australia*
[d] *Department of Civil Engineering, Faculty of Engineering, The British University in Egypt (BUE), El Sherouk City, Cairo, Egypt*
[e] *Department of Civil Engineering, Middle East University, Amman 3626, Jordan*
[f] *Department of Marketing, College of Business Administration, Prince Sattam bin Abdulaziz University, P.O. Box 165, Al-Kharj 11942, Saudi Arabia*

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ABSTRACT

Construction projects are prone to accidents and injuries, necessitating a focus on implementing safety programs. However, the implementation of such programs is influenced by various factors. Developing countries often have poor safety performance in their building sectors, with limited research in this area. This study aimed to identify essential safety program activities (SPAs) specific to the building sector. Through a literature review and survey, 25 SPAs were identified and validated via a pilot survey involving building sector experts. A questionnaire survey was conducted with 105 participants from the construction industry and academia. They were then categorized into four interconnected measurements using Exploratory Factor Analysis (EFA): Safety Program Management and Development (SPMD), Safety Culture Development (SCD), Safety Risk and Hazard Management (SRHM), and Safety Leadership, Responsibility, and Commitment (SLRC). The impact of safety implementation (SI) on overall project success (OPS) was analyzed using Partial Least Square- Structural Equation Modelling (PLS-SEM). Subsequently, Synthetic Fuzzy Evaluation (SFE) was employed to determine the criticality and importance of each SPA grouping for construction projects. The PLS-SEM analysis indicates that SI has a moderate impact on OPS, with an R^2 value of 45.4%. Moreover, the findings of the SFE highlight that the SLRC group is the most significant in enhancing the safety implementation of the construction industry.

1. Introduction

The construction industry is a crucial economic sector in many countries [1]. This industry, however, is associated with a high frequency of hazards [2]. Despite progress from occupational health and safety (OHS) regulations introduced in the 1970s, construction workers still face elevated rates of fatalities and injuries compared to other industries [3]. This is largely due to the inherent complexities of construction work - including continuous modifications, use of diverse resources, temporary and collaborative tasks, unconducive work environments, and involvement of multiple stakeholders [4].

According to the estimates provided by the [5], occupational-related fatalities resulting from slips, falls, and movements experienced an escalation from 805 in the year 2020–850 in 2021, corresponding to a 5.6 % increase. Globally, the construction industry witness over 60,000 work-related deaths annually [6]. Despite ongoing safety efforts, accident rates in the global construction industry remain unacceptably high. In the United States, construction accounted for 28 % of all work fatalities in 2018, representing the highest rate of any industry. The situation is similarly concerning in the United Kingdom, where the construction accident rate in 2019 is three times higher than the average rate across industries [7]. Therefore, the construction industry must implement operational safety measures to improve safety performance [8,9].

The situation is even worse in developing countries, where construction safety regulations are either non-existent or poorly enforced

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* Correspondence to: Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region of China and Department of Civil Engineering, Faculty of Engineering, The British University in Egypt (BUE), El Sherouk City, Cairo, Egypt.

E-mail addresses: ali-hassan.hassan@connect.polyu.hk, ali.hassan@bue.edu.eg (A.H. Ali), A.Farouk.kineber@gmail.com (A.F. Kineber), mehrdad.arashpour@monash.edu (M. Arashpour), aya.hassan@bue.edu.eg (A. Hassan), malhusban@meu.edu.jo (M. Alhusban), am.zamil@psau.edu.sa (A.M. Zamil).

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Nomenclature

Abbreviations	Term Meaning
SPAs	Safety Program Activities
EFA	Exploratory Factor Analysis
SPMD	Safety Program Management and Development
SCD	Safety Culture Development
SRHM	Safety Risk and Hazard Management
SLRC	Safety Leadership, Responsibility, and Commitment
SI	Safety Implementation
OPS	Overall Project Success
PLS-SEM	Partial Least Square- Structural Equation Modelling
SFE	Synthetic Fuzzy Evaluation
OHS	Occupational Health and Safety
AS	Average Scores

due to inadequate oversight. Existing regulations may also be outdated and irrelevant for modern practices [10]. Egypt's construction industry, among the emerging nations, is characterised by substandard safety program application by construction companies [8]. This led to more accidents, with a 19 % increase from 539 in 2015–645 in 2016. Consequently, there is a need for prompt actions to be taken or these numbers will continue rising [11].

Notwithstanding the significance of safety actions in the Egyptian construction industry, there is a lack of studies focusing on specific SPAs and their impact on safety performance. This represents a critical research gap that needs to be addressed. Compared to other countries like Malaysia, Saudi Arabia, Iraq and Pakistan which have comprehensively studied construction safety [4,10,12,13], Egypt requires more country-specific research due to its unique cultural and operational contexts.

This research aims to bridge the gap above by presenting a model that examines the influence of SPAs on SI to attain OPS in Egyptian construction projects. The study utilizes a hybrid PLS-SEM-SFE methodology to build the model, which is not extensively used before in the context of safety implementation in the Egyptian construction industry.

2. Activities that improve safety implementation

The construction industry is recognized as a high-risk sector due to its labor-intensive nature and the extensive use of heavy equipment [14]. Construction workers face severe risks like falls, encounters with careless machinery, and being struck by heavy equipment [15].

To address these safety challenges, safety program activities (SPAs) have emerged as an operational method to promote safety on construction sites and manage risks [12]. The implementation of robust safety programs is a practical approach to address common issues like lack of safety regulations, training, resources, commitment, and awareness [4].

Several prior studies have identified poor performance factors and actions affecting safety program implementation in construction projects. For instance, [16] studied 20 safety programs and found that key actions to improve construction safety performance include: employee observation programs, safety perception surveys, tracking first-aid incidents, supervisor involvement in safety policy, safety training for managers, owner involvement in safety activities, location-specific manager training, and adequate safety staffing.

[17] investigated 28 safety management system activities (SMSA) and found that the following SMSA influence construction safety implementation: incident investigation, pre-task hazard assessment, emergency planning, employee engagement programs, formal safety training, establishing safety procedures and goals, and incentive programs for safety performance.

Additionally, [18] analyzed 15 safety activities across 4 groups using the Analytic Hierarchy Process (AHP) in Saudi Arabia. The results showed that 7 factors accounted for 80 % of the AHP weight, indicating they were the most prominent for successful safety program implementation. These 7 factors were: i) proper regulations, ii) clear goals, iii) personnel attitudes, iv) collaboration, v) operational implementation, vi) safety training, and vii) organizational support. Based on a systematic literature review conducted to identify the key SPAs, a comprehensive list of the primary SPAs has been compiled and presented in Table 1.

3. Research methods

This study's research process comprised six distinct steps. Initially, a systematic literature review was conducted to identify SPAs. Following this, a pilot study was performed with construction industry experts to validate the identified SPAs. The third step involved distributing a questionnaire to practitioners in the construction industry to gather their opinions on the validated SPAs. Subsequently, the EFA approach was applied to categorize and group the SPAs. In Step 5, the PLS-SEM approach was used to test the correlations between SPAs and achieving SI to attain OPS. Finally, a SFE technique was applied to rank and assess the groups of SPAs. These six steps are demonstrated in Fig. 1.

3.1. Questionnaire survey development, sampling technique and sample size

Data collection involved a questionnaire survey comprising four sections. The first section introduced the study problem, followed by gathering respondents' background information. The third section involved evaluating SPAs and OPS factors. The final section included open-ended questions for any additional SPAs or OPS factors. Following [52–54], a Five-Point Likert Scale was employed to assess the effectiveness of the collected factors. The targeted participants for this survey were industry and academic professionals in Egypt. The survey tool underwent refinement based on pilot test results before primary data

Table 1
Safety activities with coding system.

Code	Activities	Reference
AT1	Assigning and accepting responsibility for safety	[14,19,20]
AT2	Conduction of safety training programs	[20–22]
AT3	Conduction of thorough hazard assessments	[12,23]
AT4	Creation of a committee for health and safety	[24–27]
AT5	Demonstration of visible commitment to safety	[12,20,28]
AT6	Designation of safety officers with the appropriate authority	[25,29]
AT7	Documentation of potential dangers	[12,30]
AT8	Education and training of workers on the safe usage of personal protective gear (PPG)	[31–34]
AT9	Encouraging employee participation in safety decision-making	[14,16,35,36]
AT10	Ensure safety precautions and procedures practices.	[25,37]
AT11	Establishment of routines for maintenance to prevent incidents	[34,38]
AT12	Establishment of safety regulations and policies	[35,36,39]
AT13	Examination for safety	[12,25]
AT14	Examination of incidents and almost-misses	[40–42]
AT15	Implementation of safety controls in engineering	[28,38,43]
AT16	Implementation of systems to track and address hazards	[30,44]
AT17	Institution of rules, regulations, and administrative controls for safety	[20,28]
AT18	Incentives for safety compliance	[16,28,37,45]
AT19	Orientation of new employees to safety procedures	[19,46]
AT20	Provision of medical assistance and program	[16,23,33]
AT21	Provision of PPG	[36,47]
AT22	Evaluation and assessment of safety plans and programs	[22,29,31]
AT23	Setting safety goals	[48–50]
AT24	Assessment of patterns of injury and sickness	[38,49,51]
AT25	Precautions against unforeseen events	[11,25,38]

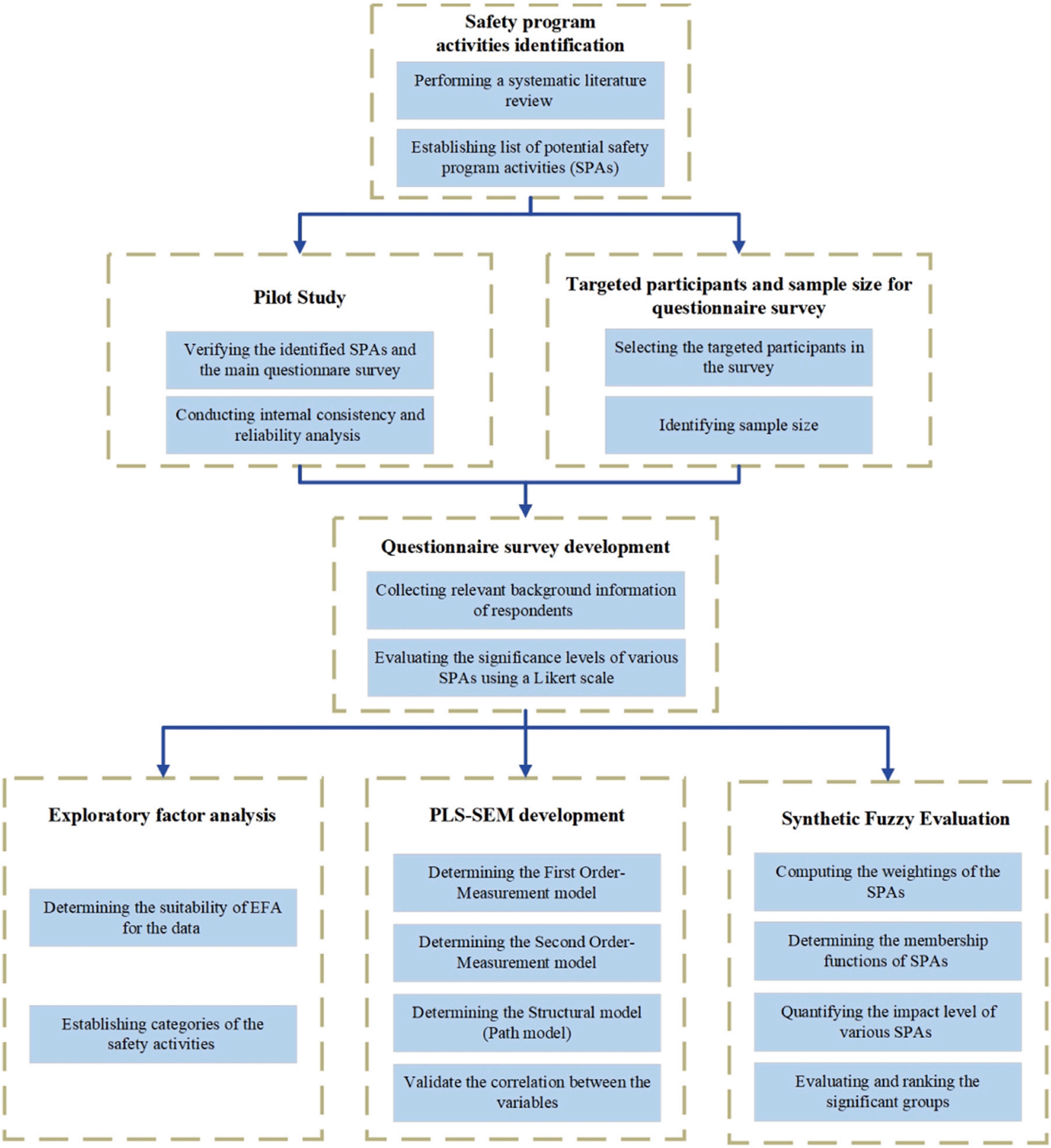


Fig. 1. Research design.

collection.

Random probability-based sampling was used to select participants from a larger population for research or survey purposes. Using random probability-based sampling, every member of the study population has an equal chance of being chosen. It ensures a representative population sample, which allows researchers to generalise their findings to the larger population [55].

[56] argued that the sample size should be sensibly selected in accordance with the research goals and the required accuracy and precision to obtain valid findings. This study established the sample size based on the PLS-SEM technique, which was chosen for the analysis. [57] suggests a PLS-SEM sample size of 100 or more. Similarly, [58] recommend at least 100 cases. However, [59] claim PLS-SEM can be used with just 33 cases. In this study, 105 valid responses were obtained from 170 questionnaires, achieving a 61.7 % response rate.

3.2. *Exploratory factor analysis (EFA)*

EFA is commonly employed in social and behavioural sciences to explore the structure of complex data sets, such as surveys or questionnaires. EFA can help researchers identify the underlying dimensions or factors that underwrite the observed data disparity and inform the development of theories or hypotheses about the constructs of interest [60]. Moreover, EFA numerical approach is applied to recognise the principal elements or constructs that explain patterns in observed data [61]. The procedures of EFA involve the following steps: (1) selection of variables and data preparation; (2) factor extraction; (3) factor rotation; and (4) factor loading [62]. SPSS statistical software was used to perform EFA, which identifies underlying elements within data and groups different SPAs.

3.3. *Development of PLS-SEM*

This study aims to explore the impact of SPAs on SI and assess the correlation between SI and OPS through a scientific methodology. To achieve this objective, PLS-SEM was employed for the analysis. PLS-SEM is a statistical method used to study correlations among constructs in Structural Equation Modeling (SEM). Unlike traditional SEM, which relies on a covariance matrix, PLS-SEM uses a set of regression equations to measure correlations among dependent and independent factors or variables [13]. The PLS-SEM method is particularly useful in situations where the sample size is relatively small or the data is not normally distributed or highly skewed. It is also suitable for studies that aim to predict outcomes and test hypotheses regarding the underlying data structure [63]. The PLS-SEM method involves two stages: the measurement model and the structural model [64].

3.4. *Synthetic fuzzy evaluation*

SFE is a decision-making technique used to evaluate complex systems with multiple criteria. This technique utilizes fuzzy logic, a mathematical tool for handling uncertainty and imprecision, to measure the relative significance of each criterion and its impact on the overall evaluation [65]. The SFE approach aims to offer a structured and transparent method for evaluating complex systems with multiple criteria, considering the inherent uncertainties and imprecisions in the evaluation process [66]. SFE provides several advantages over traditional evaluation methods, including flexibility, the ability to handle uncertainty, transparency, adaptability, and integration [67].

4. Results

4.1. *Respondents' profile*

Fig. 2 illustrates the demographic information of the respondents, providing a comprehensive overview of key demographic data.

4.2. *Exploratory factor analysis for SPAs*

The first step in conducting EFA involves selecting variables and preparing the data for analysis. This was accomplished by identifying the SPAs and evaluating them through a questionnaire survey. The subsequent step involved extracting the factors, for which Principal Component Analysis (PCA) was employed to estimate factor loadings [68]. According to [60], the total number of factors that could be extracted is guided by a scree plot, which is a commonly used method in EFA. The scree plot is a graphical tool used to determine the number of factors to retain, plotting the eigenvalues of each factor in descending order against the total factors [60]. Fig. 2 depicts the initial eigenvalues obtained and the Scree plot. Once the factors have been extracted, they need to be rotated to facilitate interpretation. Rotation aims to achieve a simpler structure where variables load predominantly on one factor [68]. According to [69], varimax rotation is a popular method for

Fig. 2. Respondents profile.

rotating the factor matrix in EFA. Therefore, this study utilized varimax rotation.

Table 2 displays four main components with eigenvalues exceeding 1.0. These components collectively accounted for 73.692 % of the variance. Component 1, Safety Program Management and Development (SPMD) explained 58.998 % of the variance. Components 2 and 3, Safety Culture Development (SCD) and Safety Risk and Hazard Management (SRHM), explained 5.593 % and 4.654 % of the variance, respectively. The fourth component, Safety Leadership, Responsibility, and Commitment (SLRC) contributed 4.446 % to the variance. Fig. 4 illustrates the categorization along with activity and category coding systems for SPAs.

[66] claimed that the adequacy of the factor solution was assessed using the Kaiser-Meyer-Olkin (KMO) test, Bartlett's sphericity test, and commonalities. The KMO measures data appropriateness for factor analysis by determining the proportion of variance generated by underlying factors. A KMO of 0.6 or above is acceptable. The results showed a KMO of 0.925, exceeding the threshold. Bartlett's sphericity test assesses whether the correlation matrix differs from the identity matrix, indicating factor analysis suitability. A p-value <0.05 indicate correlation and suggest component analysis. In this case, Bartlett's test had a p-value of 0.000, below the threshold. Communities measure the overall variation in each underlying factors. Variables with low starting communalities (< 0.3) may not be suitable for factor analysis due to little variation explained by the model. The findings show all commonalities above 0.3, which is acceptable.

4.3. PLS-SEM for SPAs

Fig. 3 presents a guide to applying PLS-SEM, which consists of three models: the first-order measurement model, second-order measurement model, and the path or structural model. Each model has different types of tests that serve specific goals.

4.3.1. First-order construct analytical model

First-order measurement models in PLS-SEM measure constructs using observed items, which can be reflective or formative. Reflective items indicate the construct, while formative items define it. These models assess the reliability and validity of each construct and their corresponding items [70]. The first-order measurement models include: (1) Convergent validity, which examines the consistency of indicators measuring the same latent variable; and (2) Discriminant validity, which assesses the degree of uncorrelation between constructs [71]. To assess convergent validity, the authors use several tests and measures, including:

- **Average Variance Extracted (AVE):** This measure indicates the total variance described by each concept compared to the total variance resulting from the statistical error. The AVE (0.5) values are generally acceptable for convergent validity [72]
- **Composite Reliability (CR):** This measure assesses the construct's internal reliability of the construct by calculating the ratio of actual score discrepancy to observed score variance. CR values of 0.7 or higher are generally acceptable for convergent validity [73].
- **Cronbach's Alpha:** This measure is commonly applied to assess inner reliability within PLS-SEM. The values of Cronbach's alpha 0.7 or higher are generally measured as satisfactory for convergent validity [64]. However, CR is often considered more precise than Cronbach alpha.
- **Factor Loadings:** factor loadings represent the direction and strength of correlation among each item and its respective construct. Generally, factor loadings of 0.4–0.5 or higher are acceptable for convergent validity [74].

According to the results presented in Table 3 and Fig. 6, all factor loadings were deemed acceptable except for SRHM1 and SLRC1. These two factors were excluded from the model due to their low factor loadings (below 0.4), indicating a minimal impact on the respective constructs.

In contrast, the authors use Cross-Loading and Fornell and Larcker's Criterion to assess discriminant validity. This test evaluates the construct's distinctiveness relative to other constructs in the model. Discriminant validity is often assessed by comparing the square of the correlation between AVE on an individual construct and other constructs in the model. Discriminant validity requires AVE values greater than the squared correlations [63]. According to Table 4 and Table 5, the model demonstrates discriminant validity in this study.

4.3.2. Second-order analytical model construct

The second-order measurement model creates a higher-level, more abstract construct from the first-order constructs. Unlike the first-order model, the "items" observed for the second-order constructs are the first-order constructs themselves [73]. Second-order models are used when the first-order constructs represent related concepts that can be combined into a single higher-order construct [74,75]. In this study, a second-order model was used to assess the statistical significance of the four first-order constructs (i.e. SPMD, SCD, SRHM, SLRC) and their relationship to SI.

- Beta and p-values: Beta values represent the strength of relationships between constructs, while p-values indicate the statistical significance of these relationships. Meaningful beta values are typically 0.1 or higher, and statistically significant p-values are usually less than 0.05 [76]. In Fig. 7, all constructs' Beta and p-values meet their criteria, indicating acceptance.

4.3.3. Structural model

In the PLS-SEM structural model, R^2 and Q^2 are two critical measures used to evaluate the power of the goodness-of-fit and predictive model.

- R^2 shows the percentage of variation in the dependent variable explained by the independent variables in the model. Higher R^2 values indicate better model fit [74]. This study's R^2 is 0.454, meaning the model's independent variables explain 45.4 % of the

Table 2
Rotated Varimax matrix.

SPAs	Components			
	1	2	3	4
AT1		0.7		
AT2		0.754		
AT3		0.76		
AT4		0.76		
AT5				0.584
AT6			0.783	
AT7		0.769		
AT8		0.785		
AT9		0.667		
AT10			0.618	
AT11	0.536			
AT12	0.582			
AT13	0.644			
AT14	0.643			
AT15	0.633			
AT16	0.746			
AT17		0.523		
AT18		0.631		
AT19		0.547		
AT20	0.54			
AT21	0.849			
AT22	0.824			
AT23			0.61	
AT24				0.55
AT25	.			0.612

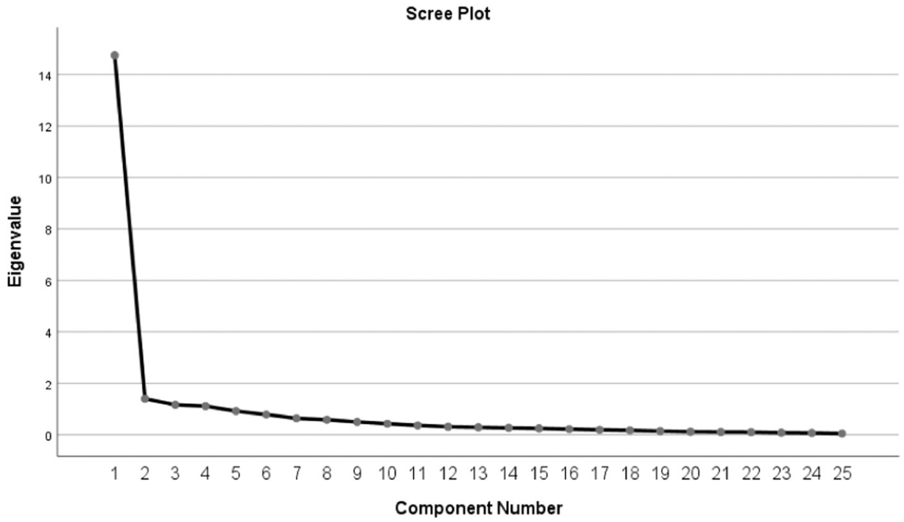


Fig. 3. SPSS scree plot.

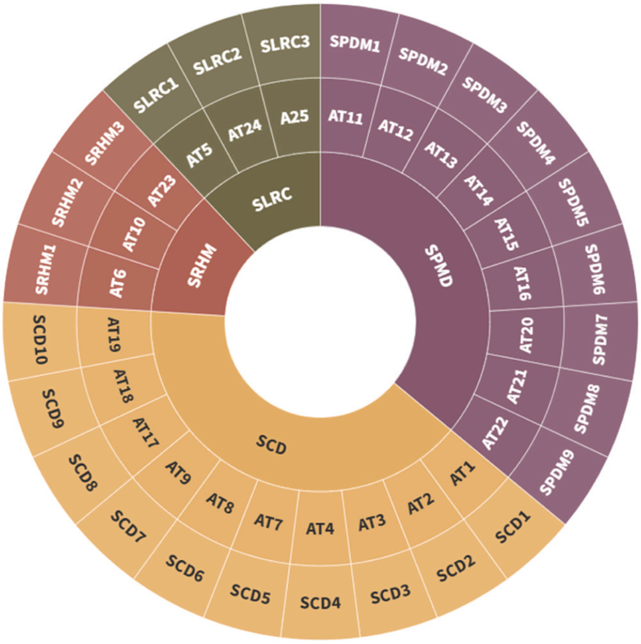


Fig. 4. Categorization along with assigned items.

dependent variable's variation. This percentage indicates a moderate relationship between SI and OPS.

- Q^2 measures how much variance the model's exogenous constructs can predict in endogenous variables. Q^2 higher values indicating better predictive power. According to [63], Q^2 values greater than zero show the model's predictive power, while values around or beyond 0.25 suggest robust predictive relevance. Q^2 for SI and OPS in this study is 0.987 and 0.438, respectively, which exceed 0.25. Thus, the model is robustly predictive.

4.4. Synthetic fuzzy evaluation for SPAs

4.4.1. The mean scores for SPAs

The initial step in applying SFE involved computing average scores (AS) for the entire SPAs. The AS for SPAs can be estimated using Eq. 1. Next, Eq. 2 was employed to calculate the total AS for each group. Finally, to compute the overall AS for all groups, Eq. 3 was used. The calculation for AS for all SPAs, including their respective groups, as well as the overall AS for the entire groups, is presented in Fig. 8.

$$\mathrm{AS} = \frac{\sum \mathrm{w}}{\mathrm{N}} = \frac{5\mathrm{n}_5 + 4\mathrm{n}_4 + 3\mathrm{n}_3 + 2\mathrm{n}_2 + 1\mathrm{n}_1}{\mathrm{N}} \tag{1}$$

$$\mathrm{Total}_{\mathrm{AS}} = \sum \mathrm{AS}_{\text{same group}} \tag{2}$$

$$\mathrm{Overall}_{\mathrm{AS}} = \sum \mathrm{Total}_{\text{As for all groups}} \tag{3}$$

Where: "**AS**" represent the average score for each SPA, "**n**" represents the rating system for SPAs, ranging from 1 to 5, "**N**" represents the total number of participants. The "**Total$_{AS}$**" is the sum of all the average scores for the SPAs in the same group. the "**Overall$_{AS}$**" is the sum of all the "Total$_{AS}$" values for all groups.

4.4.2. The Weightings for SPAs and SPAs' Groups

The weightings of each SPA are determined based on the average score (AS) using Eq. 4. In contrast, the weightings of the four SPA groups are computed using Eq. 5. The calculation of weightings for all SPAs, including their respective groups, is illustrated in Fig. 8.

$$\mathrm{W}_{\text{Each SPA}} = \frac{\mathrm{AS}_{\text{Each SPA}}}{\mathrm{Total}_{\text{As for the same group}}} \tag{4}$$

$$\mathrm{W}_{\text{Each SPA Group}} = \frac{\mathrm{Total}_{\text{As for each group}}}{\mathrm{Overall}_{\mathrm{AS}}} \tag{5}$$

Where: "**W$_{Each\ SPA}$**" represent the weightings score for each SPA and "**W$_{Each\ SPA\ Group}$**" represent the weightings score for each SPA group. (Fig. 9)

4.4.3. The membership function for each SPA (MFL3)

The first step in developing the SPA set membership functions (MFL3) is determining each SPA's membership function. This forms the basis for calculating the group membership functions. Eq. 6 is used to compute the SPA membership function from Likert Scale-based expert ratings, resulting in a (1×5) matrix as per Eq. 7. The MFL3 calculations for all SPAs are presented in Table 6.

Table 3
Convergent validity tests.

Constructs	Item	Factor loadings	Condition	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)	Condition
Safety Program Management and Development (SPMD)	SPDM1	0.862	Agreed	0.946	0.955	0.705	Accepted
	SPDM2	0.885	Agreed				
	SPDM3	0.868	Agreed				
	SPDM4	0.878	Agreed				
	SPDM5	0.853	Agreed				
	SPDM6	0.859	Agreed				
	SPDM7	0.621	Agreed				
	SPDM8	0.844	Agreed				
	SPDM9	0.854	Agreed				
Safety Culture Development (SCD)	SCD1	0.883	Agreed	0.954	0.96	0.708	Accepted
	SCD2	0.893	Agreed				
	SCD3	0.853	Agreed				
	SCD4	0.81	Agreed				
	SCD5	0.856	Agreed				
	SCD6	0.792	Agreed				
	SCD7	0.795	Agreed				
	SCD8	0.828	Agreed				
Safety Risk and Hazard Management (SRHM)	SCD9	0.837	Agreed	0.751	0.732	0.5	Accepted
	SCD10	0.859	Agreed				
	SRHM1	**0.376***	**Deleted**				
	SRHM2	0.781	Agreed				
	SRHM3	0.866	Agreed				
Safety Leadership, Responsibility and Commitment (SLRC)	**SLRC1**	**0.33***	**Deleted**	0.752	0.764	0.551	Accepted
	SLRC2	0.883	Agreed				
	SLRC3	0.874	Agreed				
Overall Project Success (OPS)	OPS1	0.912	Agreed	0.925	0.947	0.817	Accepted
	OPS2	0.913	Agreed				
	OPS3	0.908	Agreed				
	OPS4	0.882	Agreed				

*Deleted items.

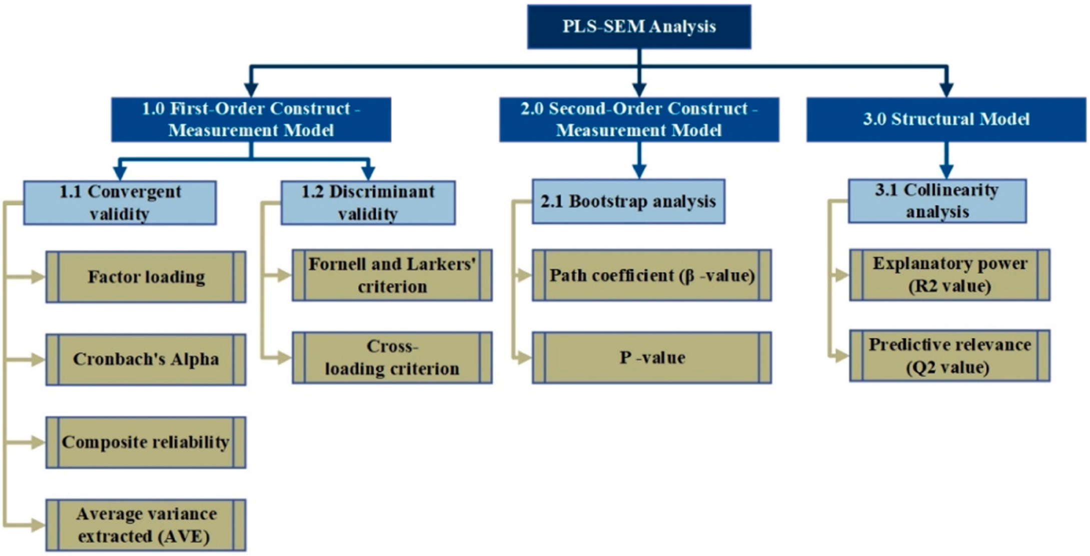


Fig. 5. Structure of PLS-SEM procedures.

$$\mathrm{MFL1}_{\text{Each SPA}} = \frac{\text{Percentage of Least Effective (LE)}}{\text{LE}} + \frac{\text{Percentage of Quite Effective (QE)}}{\text{QE}} + \frac{\text{Percentage of Moderate Effective (ME)}}{\text{ME}} + \frac{\text{Percentage of Effective (E)}}{\text{E}} + \frac{\text{Percentage of Very Effective (VE)}}{\text{VE}} \tag{6}$$

Where: ''**MFL1** $_{\textbf{Each SPA}}$'' represent the membership function level for each SPA, while "**LE, QE, ME, E, VE**" denote the respective percentages of survey participants who provided ratings of 1, 2, 3, 4, or 5 for the importance of a particular SPA.

$$R_{1\times 5} = \left(r_{SPA_{i1}},\ r_{SPA_{i2}}, r_{SPA_{i3}},\ r_{SPA_{i4}},\ r_{SPA_{i5}}\right) \tag{7}$$

Where: "$\mathbf{R}_{1\times5}$" denotes an evaluation or rating vector of dimensions 1×5 based on Likert scale. "$\mathbf{r}_{\mathbf{SPA}_{i1}}, \mathbf{r}_{\mathbf{SPA}_{i2}}, \mathbf{r}_{\mathbf{SPA}_{i3}}, \mathbf{r}_{\mathbf{SPA}_{i4}}, \mathbf{r}_{\mathbf{SPA}_{i5}}$" are the evaluation scores or ratings assigned to alternative i based on Likert scale ratings from experts.

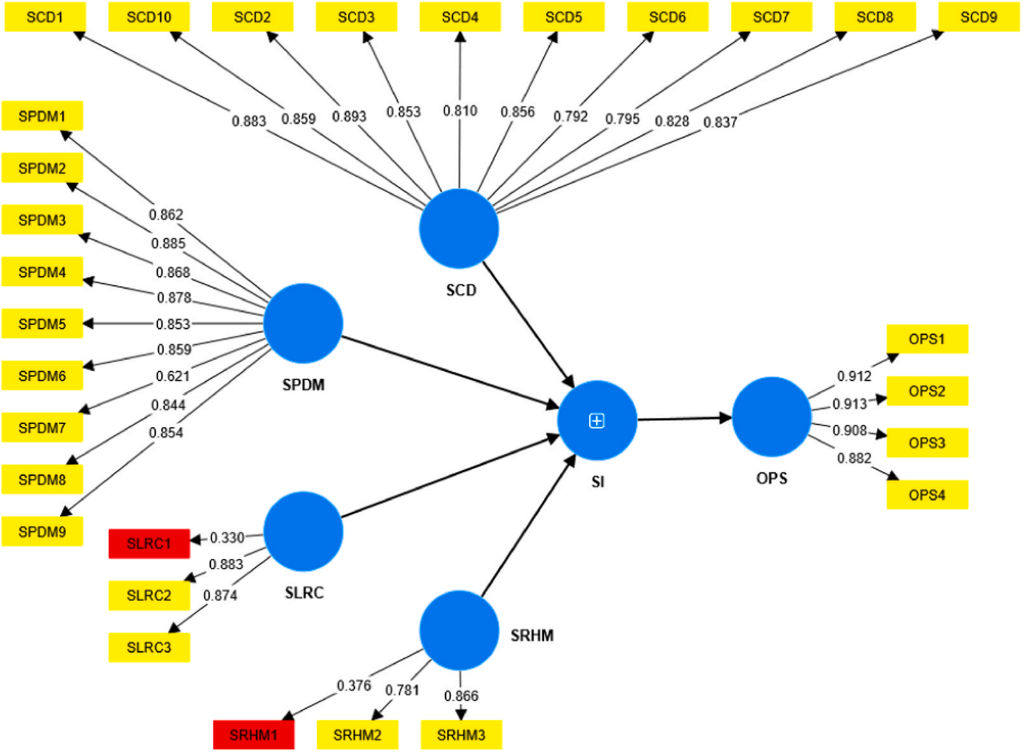


Fig. 6. Factor loading values in First-Order model.

Table 4
Discriminant validity (cross loadings).

Constructs/Items	OPS	SCD	SLRC	SPDM	SRHM
OPS1	**0.912**	0.579	0.538	0.581	0.586
OPS2	**0.913**	0.542	0.547	0.591	0.523
OPS3	**0.908**	0.587	0.539	0.592	0.501
OPS4	**0.882**	0.567	0.507	0.612	0.543
SCD1	0.621	**0.883**	0.614	0.785	0.71
SCD2	0.555	**0.893**	0.591	0.764	0.686
SCD3	0.462	**0.853**	0.552	0.734	0.626
SCD4	0.482	**0.81**	0.585	0.674	0.611
SCD5	0.487	**0.856**	0.573	0.747	0.623
SCD6	0.421	**0.792**	0.547	0.656	0.639
SCD7	0.488	**0.795**	0.596	0.693	0.683
SCD8	0.608	**0.828**	0.607	0.812	0.735
SCD9	0.55	**0.837**	0.589	0.821	0.701
SCD10	0.598	**0.859**	0.647	0.85	0.815
SLRC2	0.5	0.617	**0.883**	0.562	0.619
SLRC3	0.571	0.589	**0.874**	0.558	0.546
SPDM1	0.595	0.797	0.583	**0.862**	0.764
SPDM2	0.509	0.796	0.508	**0.885**	0.722
SPDM3	0.474	0.766	0.482	**0.868**	0.748
SPDM4	0.522	0.765	0.543	**0.878**	0.803
SPDM5	0.624	0.809	0.606	**0.853**	0.784
SPDM6	0.591	0.747	0.562	**0.859**	0.756
SPDM7	0.296	0.557	0.512	**0.661**	0.621
SPDM8	0.647	0.752	0.572	**0.844**	0.746
SPDM9	0.657	0.771	0.602	**0.854**	0.764
SRHM2	0.38	0.521	0.491	0.627	**0.781**
SRHM3	0.636	0.813	0.614	0.849	**0.866**

4.4.4. *The membership function for each SPA group (MFL2)*

Eq. 8 is employed to calculate MFL2 for each individual SPA group. MFL2 for each SPA group is estimated based on multiplying the weightings of each SPA in the same group by their corresponding MFL3 values. The MFL2 values for the groups are presented in Table 7.

Table 5
Discriminant validity (Fornell-Larcker).

Constructs	OPS	SCD	SLRC	SPDM	SRHM
OPS	0.904				
SCD	0.63	0.899			
SLRC	0.59	0.702	0.742		
SPDM	0.657	0.841	0.657	0.893	
SRHM	0.596	0.814	0.667	0.84	0.707

$$
\begin{aligned}
D_{\text{Each SPA Group}} &= \sum\nolimits_{i=1}^{n} W_{i\ \text{for each SPA in the same group}} \\
&\quad \times R_{i\ \text{For each SPA in the same group}} \\
&= W_{i\ \text{for each SPA in the same group}} \times \begin{vmatrix} MFL1_{SPA_{i1}} \\ MFL1_{SPA_{i2}} \\ \dots \\ MFL1_{SPA_{in}} \end{vmatrix} \\
&= W_{i\ \text{for each SPA in the same group}} \\
&\quad \times \begin{vmatrix} SPA_{1_{i1}} & SPA_{2_{i1}} & SPA_{3_{i1}} & SPA_{4_{i1}} & SPA_{5_{i1}} \\ SPA_{1_{i2}} & SPA_{2_{i2}} & SPA_{3_{i2}} & SPA_{4_{i2}} & SPA_{5_{i2}} \\ \dots & \dots & \dots & \dots & \dots \\ SPA_{1_{in}} & SPA_{2_{in}} & SPA_{3_{in}} & SPA_{4_{in}} & SPA_{5_{in}} \end{vmatrix}
\end{aligned}
\tag{8}
$$

Where: ''$\boldsymbol{D}_{\textbf{Each SPA Group}}$'' represents the matrix collection corresponding to different SPA. ″ × ″ denotes the fuzzy multiplication operator, and ''$\mathbf{R}_{\textbf{i for each SPA in the same group}}$″ signifies the fuzzy matrix associated with the evaluations or assessments for each SPA within the same group.

4.4.5. *The overall membership function for all SPAs' groups (MFL1)*

Eq. 9 computes MFL1 for all SPA groups by multiplying the weightings of each group by their respective MFL2 values, then summing all the values. The computation of MFL1 for all groups is demonstrated below.

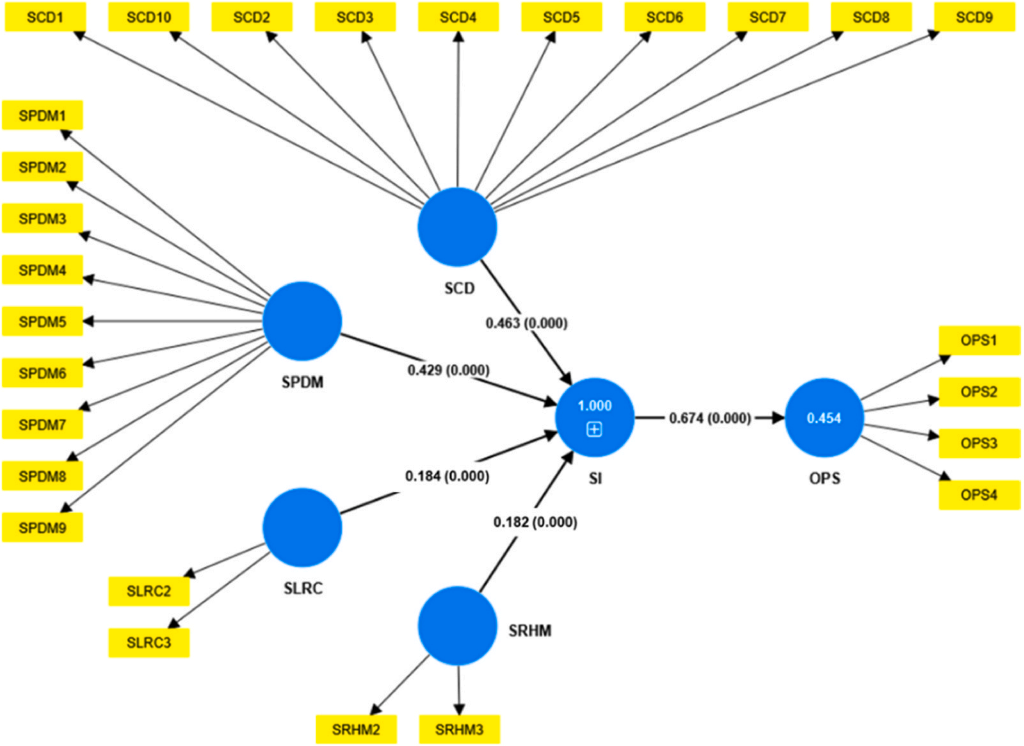
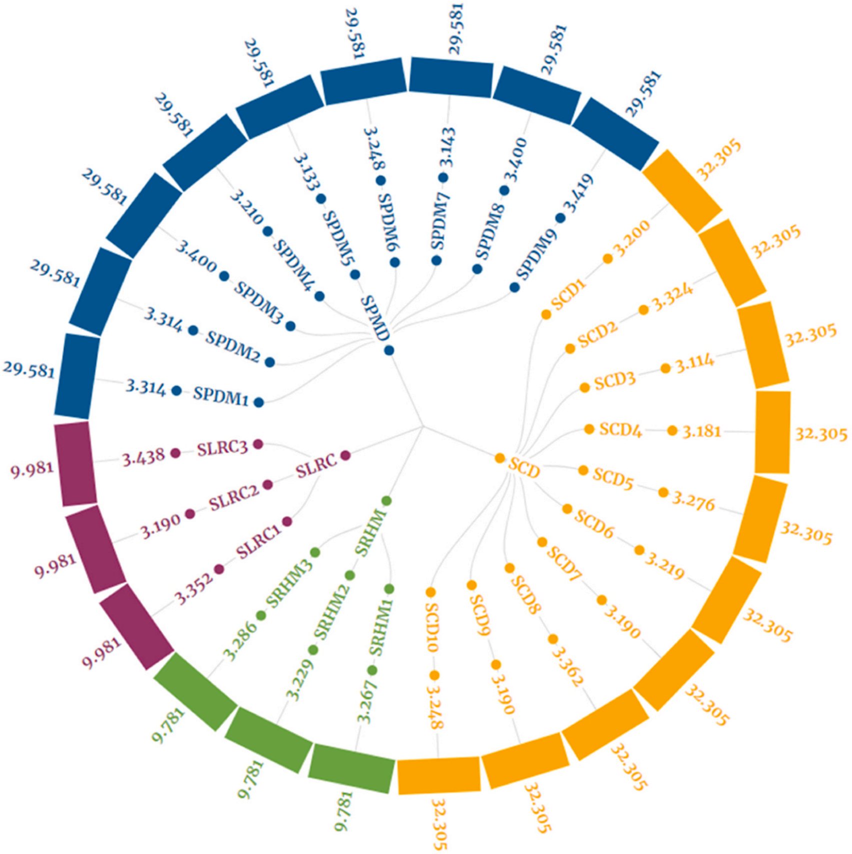


Fig. 7. Second-order measurement model bootstrapping.



$$\text{Overall}_{AS} = \sum \text{Total}_{AS\ for\ SLRC}, \text{Total}_{AS\ for\ SRHM}, \text{Total}_{AS\ for\ SCD}, \text{Total}_{AS\ for\ SPMD} = 81.648$$

Fig. 8. AS, total AS, and overall AS for SPAs.

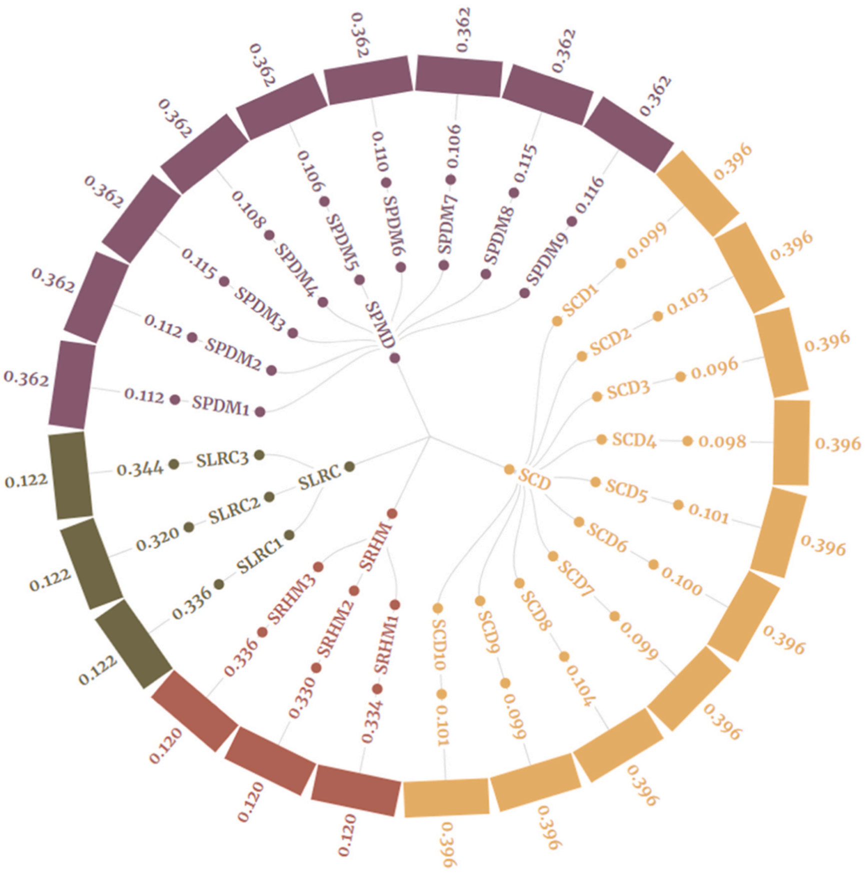


Fig. 9. Weights for all SPAs and their groups.

Table 6
MFL3 for All SPAs.

SPAs Code	MFL3				
SPDM1	0.06	0.25	0.20	0.31	0.18
SPDM2	0.10	0.16	0.28	0.23	0.23
SPDM3	0.05	0.26	0.21	0.22	0.27
SPDM4	0.16	0.15	0.25	0.19	0.25
SPDM5	0.11	0.25	0.20	0.27	0.17
SPDM6	0.08	0.26	0.19	0.30	0.18
SPDM7	0.09	0.24	0.27	0.27	0.14
SPDM8	0.07	0.23	0.22	0.21	0.28
SPDM9	0.07	0.24	0.16	0.28	0.26
SCD1	0.18	0.14	0.17	0.30	0.20
SCD2	0.08	0.23	0.23	0.23	0.24
SCD3	0.13	0.13	0.35	0.25	0.13
SCD4	0.11	0.16	0.32	0.23	0.17
SCD5	0.10	0.14	0.30	0.27	0.18
SCD6	0.05	0.21	0.38	0.20	0.16
SCD7	0.12	0.18	0.25	0.28	0.17
SCD8	0.07	0.17	0.30	0.25	0.21
SCD9	0.12	0.21	0.22	0.25	0.20
SCD10	0.10	0.21	0.20	0.30	0.18
SRHM1	0.09	0.23	0.23	0.25	0.21
SRHM2	0.12	0.18	0.22	0.30	0.18
SRHM3	0.11	0.19	0.21	0.27	0.22
SLRC1	0.13	0.10	0.24	0.32	0.20
SLRC2	0.10	0.19	0.30	0.23	0.18
SLRC3	0.05	0.22	0.25	0.22	0.27

Table 7
MFL2 for All SPAs' groups.

SPAs Groups	MFL2				
SPMD	0.09	0.24	0.23	0.26	0.23
SCD	0.11	0.19	0.29	0.27	0.19
SRHM	0.11	0.21	0.23	0.28	0.21
SLRC	0.10	0.18	0.27	0.27	0.23

$$\begin{aligned} D_{\text{Overall for All Groups}} &= \sum\nolimits_{i=1}^{n} W_{\text{All Groups}} \times R_{\text{All Groups}} \\ &= W_{\text{i for each SPA group}} \times \begin{vmatrix} MFL2_{SPA_{i1}} \\ MFL2_{SPA_{i2}} \\ \dots \\ MFL2_{SPA_{in}} \end{vmatrix} \\ &= W_{\text{i for each SPA group}} \\ &\quad \times \begin{vmatrix} SPA1_{i1} & SPA2_{i1} & SPA3_{i1} & SPA4_{i1} & SPA5_{i1} \\ SPA1_{i2} & SPA2_{i2} & SPA3_{i2} & SPA4_{i2} & SPA5_{i2} \\ \dots & \dots & \dots & \dots & \dots \\ SPA1_{in} & SPA2_{in} & SPA3_{in} & SPA4_{in} & SPA5_{in} \end{vmatrix} \end{aligned} \tag{9}$$

$$\begin{aligned} D_{\text{overall}} &= \begin{pmatrix} 0.362 & 0.396 & 0.120 & 0.122 \end{pmatrix} \\ &\quad \times \begin{pmatrix} 0.09 & 0.24 & 0.23 & 0.26 & 0.23 \\ 0.11 & 0.19 & 0.29 & 0.27 & 0.19 \\ 0.11 & 0.21 & 0.23 & 0.28 & 0.21 \\ 0.10 & 0.18 & 0.27 & 0.27 & 0.23 \end{pmatrix} \\ &= \begin{pmatrix} 0.10 & 0.21 & 0.26 & 0.270.21 \end{pmatrix} \end{aligned}$$

Table 8
Evaluation and ranking for each SPA group.

Groups	Evaluation (E)	Rank
SLRC	3.49	1
SPMD	3.45	2
SRHM	3.42	3
SCD	3.39	4

4.4.6. The final evaluation matrix

Once MFL1 is calculated, the final evaluation matrix level for each SPA group is computed using Eq. 10. Table 8 summarizes the final estimation matrix for the SPA groups and their ranking.

$$\mathrm{E}_{\text{Each Group}} = \sum\nolimits_{i=1}^{n} MFL1_{i\ \textit{for each SPA group}} \times \mathrm{LS}_{\text{i for each SPA group}} \tag{10}$$

Where: ''$\mathbf{E}_{\textbf{Each Group}}$'' represents the evaluation for each group, '' $\boldsymbol{MFL1}_{\boldsymbol{i}\ \textbf{\textit{for each SPA group}}}$'' is the first-level membership function fuzzy matrix, and '' $\boldsymbol{LS}_{\boldsymbol{i}\ \textbf{\textit{for each SPA group}}}$″is the five Likert scales.

5. Discussion

Project success may be greatly increased by using SI between practitioners and their important activities. Revisions to SEM models and the statistical values derived from these model evaluations provide a solid foundation for comprehending relationships across the models included. During the process of study and modification, several intriguing discoveries are made. Compared to other industries, the building sector has less general characteristics, such as product quality, productivity, and functionality [77].

Additionally, in order to improve the performance of the construction project, it is important to investigate the influence of SI on building success. The influence of SI on the project's performance was ascertained through the investigation of the relationship between the independent and dependent variables. The results indicate that 45.5 % of the project's success is attributable to the SI's implementation. Owing to time, cost, and quality issues, the adoption of SI also has a substantial association with the OPS when the value of $\beta = 0.674$, which is significant when the firm or organization raises 1 unit of SI, would also enhance the project's success by 0.674.

The results showed that certain of the SI implementation's outputs would assist those working on the project in properly managing it to satisfy the client's objectives for timeliness, quality, and cost. Based on the aforementioned findings, we may infer that the success of the project will be influenced by the SI's output, which measures the organization's effectiveness in overseeing the project—which is precisely defined—-while taking time, money, and quality into account. Every project success finding in this investigation matched expectations.

The current result showed that the activities for safety implementation in construction projects are strongly influenced by the establishment of routines for maintenance to prevent incidents which could improve the company's performance. The current result is comparable to existing literature [8,78–80]. Safety activities positively influence financial/economic, competitiveness and safety performances. Hence, they indicate the compatibility between employee protection and the company's competitiveness [78].

Safety implementation activities in construction projects are also influenced by establishing safety regulations and policies [30,81]. Using factor analysis, [37] identified twelve barriers to safety activities in the construction industry, which are further abridged into four groups: i) poor safety awareness, ii) poor safety governance, iii) poor working conditions and iv) obstructive organisation norms. Therefore, a system of safety regulation (or governance) at the national level must be established to resolve these barriers and enhance the construction industry's safety performance. This study further revealed that the activities for safety implementation in construction projects are closely related to the examination for safety [82,83].

Examination of safety tends to be accompanied by continuous improvement (CI). For instance, an experiential analysis of the correlation between safety and lean construction in the industrialised housing industry revealed by [84] revealed that the prediction of rates of accidents could be lessened through the implementation of lean. Thus, CI programs are correlated with considerable improvement in safety activities and lower accident rates, irrespective of the company's production level. Evaluating and implementing new safety training techniques for construction industry workers can enhance safety competencies and improve motivational innovation concerning the construction industry's safety performance [85].

Additionally, the effectiveness of participatory human factors safety training and examination provides a promising substitute for inactive learning approaches. Thus, its inspiring effect complements other safety training activities [85]. [86] argued that learning from accidents, the flow of safety information, and resilient safety information culture concerning safety performance in construction could improve learning from incidents and safety performance in construction by developing strategies to ensure non-defective safety data and smooth data flow in a robust organisational context. Learning from incidents and near-misses could improve the safety performance of construction employees [87]. Therefore, the underlying safety activities factors in Component 1 are essential to enhance the safety performance of construction employees.

The top critical benefits of safety controls comprised employee risk reduction, safer operational environments, considering safety management as an integral part of construction project management, and improved project management [88]. However, the significant hurdles to safety controls are placing safety at the lower priority because of cultural disparity in companies, high rates of worker turnover, tight work schedules, obstacles by subcontractors, lethargic participation in implementing safety management system by project stakeholders [88]. Hence, safety controls in engineering need to be examined to enrich the literature with knowledge of the benefits of implementing safety activities in the construction industry.

Activity is everyone's job in the construction industry since risk management in construction is challenging [89]. It is essential to consider safety in awarding contracts and developing project timelines, and risk management must be iterative. Thus, top-down control of safety commitment should be communicated to and incorporated by construction workers and managers all over the project site [89]. An improved understanding of how contracting relationships, employees' remuneration and liability insurance measures affect safety could move risk management determinations from employee attitude to a broader focus on how these safety activities concerning medical assistance and program and relationships influence incentives and disincentives for projects' site safety and workers health [89].

Thus, the effectiveness of macro factors on the application of medical safety care management in construction systems [90]. Assessment and evaluation of safety activities program and plans implementation in the construction industry is another critical safety activity, as revealed by proposed SEM model. However, proper evaluation of safety plans and programs requires health and safety implementation technologies in the construction industry [91]. Embracing and implementing novel solutions is an efficient way to improve the construction industry's safety performance [91].

The application of technology as a precautionary measure or stemming the observed lop-sided rate of employee injuries and deaths in the construction industry compared to other industries has drawn attention over the last twenty years [91]. The literature has highlighted the need to increase awareness concerning the practicality and value of technology for health and safety activities management in construction and factors that prevent or limit technology application to evaluate and assess safety in the construction industry [91].

6. Conclusion

Safety performance in construction globally remains a significant concern, especially due to financial constraints. Developed nations have made considerable advancements in enhancing safety, contrasting with the slower progress in developing nations. This study focusses on Egypt's construction sector, known for its inadequate safety culture and limited safety research. The primary aim is to identify significant SPAs crucial for enhancing safety within the industry.

This study conducted a systematic literature review resulting in the identification of 25 significant SPAs. Subsequently, data collection via a survey tool was performed with 105 participants. The SPAs were then grouped into four categories using EFA: (1) SPMD; (2) SCD; (3) SRHM; and (4) SLRC. Following this, PLS-SEM was executed to develop a mathematical model to examine the relationships between different variables. Based on the R^2 result, the model's independent variables explain 45.4 % of the dependent variable's variation, indicating a moderate relationship between SI and OPS. Lastly, the clusters were subjected to SFE for evaluation, prioritization, and ranking concerning their importance. The results show that SLRC achieved the first rank, followed by SPMD, SRHM, and SCD, respectively.

7. Implications and contribution

This study presents a novel perspective on construction safety management in Egypt, representing one of the initial empirical investigations in this field. Previous research has often neglected safety implementation in construction engineering management, particularly in identifying SPAs and OPS. This study establishes a crucial theoretical foundation, contributing to existing knowledge on the utilization of SPAs in construction. It underscores the importance of implementing SPAs in developing nations like Egypt, where safety practices are still developing. The findings highlight the complex nature of activities that support the widespread adoption of SI in construction. Overall, this research enhances our understanding of the intricate relationship between SPAs, SI, and OPS.

On the other hand, this study offers a valuable practical contribution to safety practices in the construction industry, specifically focusing on small and medium-sized organizations, aiming to enhance safety measures. By leveraging this knowledge, such firms can improve their competitiveness and secure previously unattainable projects due to safety issues. Furthermore, this study's results provide significant insights to professionals, clients, and construction management regarding the SPAs that drive the effective adoption of safety practices in the construction industry.

CRediT authorship contribution statement

Aya Hassan: Data curation, Investigation. **Mohammad Alhusban:** Funding acquisition, Supervision. **Ahmad M Zamil:** Funding acquisition, Supervision. **Ali Hassan Ali:** Conceptualization, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Ahmed Farouk Kineber:** Conceptualization, Investigation, Methodology, Writing – original draft. **Mehrdad Arashpour:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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