IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Safety and Security Engineering
Vol. 14, No. 4, August, 2024, pp. 1049-1060
Journal homepage: http://iieta.org/journals/ijsse

Development of Liquefied Petroleum Gas (LPG) Safety Risk Prediction Model for Hotel Sector in Sri Lanka

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https://doi.org/10.18280/ijsse.140404

Received: 4 June 2024
Revised: 22 July 2024
Accepted: 9 August 2024
Available online: 30 August 2024

Keywords:
Liquefied Petroleum Gas, risk causing factors, risk prediction index, safety risk prediction

ABSTRACT

The use of LPG has significantly risen among commercial enterprises in recent years because of its cost-effectiveness and environmental benefits compared to other fuels. LPG is potentially hazardous from the point of production until the end use due to its highly flammable mixture. Thus, an explosion or fire has become an inherent risk. Many accidents are reported in the kitchen and storage areas of hotels. It's essential to prioritize proactive safety tools over reactive safety measures to meet the high safety requirements. Therefore, this research aims to develop a model for predicting safety risks to enhance the safety of LPG facilities within the hotel sector in Sri Lanka. Safety risk-causing factors and relevant standard clauses were identified and related to a safety prediction rating for LPG facilities. Outputs of a validated multidimensional safety risk prediction model give the compliance level of LPG installations and are presented as a Safety Prediction Index (SPI). Safety recommendations are grouped according to the derived SPI ranges for LPG installations. The hotel sector can use this model to understand the prevailing level of risk and safety compliance of LPG installations.

1. INTRODUCTION

1.1 Benefits of using LPG

Liquefied Petroleum Gas (LPG) consists of a blend of hydrocarbon gases, mainly propane (C_3H_8) and butane (C_4H_{10}), and the exact composition may vary depending on the source and intended use [1]. Due to its high efficiency, it is economical and its excellent heating capacity helps to reach the required temperature in less time, saving a lot on fuel costs [2, 3]. It undergoes complete combustion, and produces no residue and particulate matter, which means minimum maintenance cost and lesser carbon footprint [4]. Therefore, the use of LPG has seen a tremendous increase in recent years for commercial businesses [5, 6].

The increasing use of LPG in households is driven by its cost-effectiveness, reduced emissions, and widespread availability. Gould and Urpelainen [7] highlighted the importance of clean cooking fuels after being adopted and thus, integrated LPG into daily routines. Currently, in Sri Lanka, LPG is used for industrial applications either as commercial cylinder manifolds or as bulk LPG storage supply systems. The annual total volume of industrial and domestic LPG consumption in Sri Lanka in 2022 was approximately 296,000 Metric Tons [8]. Ceramics manufacturing, rubber manufacturing, metal processing, and hotel segments are identified as the biggest Industrial LPG (ILPG) consumers in the country [9].

1.2 Risk of using LPG

LPG presents a high risk of catching fire due to its highly flammable nature [10]. LPG leak is identified as the consequence of the loss of primary containment (LOPC) in the system. Leak LPG evaporates and forms a large cloud of gas, which settles in low spots such as drains, LPG storage areas, or basements [11]. The primary health hazards associated with LPG usage include cold burns and respiratory problems [12, 13]. Occurring an explosion, fire has become an inherent risk of using LPG [14]. The proper installation, design of safety features, protection, storage, regular maintenance, and audits are all crucial for ensuring the safety of LPG distribution systems [15-17]. The use of LPG cylinder manifolds in hotel sector applications has further increased risk of fire. Out of the three risks identified in the literature, LOPC arises from the spillage of liquid from a pressurized container or a pipeline resulting in instant total dispersion and evaporation, and is identified as the main risk in the ILPG distribution system [11, 18]. Propane storage facilities in chemical process industries pose potential hazards such as Vapor Cloud Explosions (VCE), Flash Fires, and Boiling Liquid Expanding Vapor Explosions (BLEVE) [19, 20].

1.3 LPG-related incident control measures applicable to hotel segments

In numerous hotels around the world in recent years, there have been multiple reports of fire, explosions, and incidents related to cold burns [21, 22]. In terms of fire safety, hotels typically contain risky industrial equipment, particularly in their kitchens, including low to high-voltage electrical systems, gas connections, boilers, and storage tanks for flammable liquids like petroleum products and cooking oil [23]. A large number of LPG-related accidents are reported in kitchen and storage areas of hotels [22, 24]. Additionally, the close placement of numerous larger and more intricate units located in crowded areas within the hotel kitchen might amplify the potential risk of damage [25]. LPG standards in Sri Lanka, including SLS 1196 and SLS 712, are supplemented by international standards like National Fire Protection Association (NFPA), British Standards (BS), and European Directives (EN), which installers apply as needed; however, there are no mandatory requirements or regulatory authority. However, many approaches, strategies, regulations, and technology have been used to minimize the risk of industrial LPG systems in many countries [26].

The LPG industry must ensure that its business operations comply with all relevant laws, regulations, and standards [27]. In Sri Lanka, yet, there are many shortfalls that only the government and relevant authorities have the authority to enforce. The government should also support the industry's efforts for self-regulation. Especially for the hotel sector, there are no proper specific national procedures or local standards for LPG installations to minimize the risk. Further, there are no guidelines for industrial LPG uses to ensure safety in operations. The existing risk models mainly emphasize reactive measures based on consequences and are inadequate for representing multiple failure causes that deviate from standard requirements. The primary cause of failures is attributed to human error, with other factors like processes, management, and organization not being taken into account in risk prediction frameworks. One more drawback is that most of them provide descriptive explanations for accident causes without using any quantitative or mathematical accident prediction approach. This research paper is focused on presenting the development of a safety risk prediction model to serve as a holistic tool for LPG suppliers and hotel associations to manage and mitigate the inherent risks of LPG systems.

2. LITERATURE REVIEW

Risks can be broadly divided into system-related risks and process-related risks [28]. The main risks associated with the system are primarily from leaks in the LPG distribution system or losses in primary containment [29]. While safety concerns are acknowledged, gas leaks have become increasingly frequent and pose a significant threat to both human lives and property [30]. Sequential analysis models such as Fault Tree Analysis, Event Tree Analysis, Failure Mode and Effect Analysis, Cause Consequence Analysis, and Domino theory have certain gaps and limitations. Calculating the risk levels of LPG sites requires considering subject-specific risk factors and relevant standards. It is crucial to address the deficiencies in existing models in various sectors such as construction and LPG safety by prioritizing the identification, prediction, and prevention of hazards.

The safety of ILPG distribution systems in hotels relies heavily on the correct installation, inclusion of safety features during the design, protection during storage, regular maintenance, and thorough audits [15, 17]. Use of ILPG manifolds in hotel applications has further increased the risk of fire. LOPC arises from the spillage of liquid from a pressurized container or from a pipeline resulting in instant total dispersion and evaporation, which is identified as the main risk in the industrial LPG distribution system [11, 31]. To understand the potential fire and explosion risks of hotel industrial LPG distribution system, factors such as geographical location of the ILPG supply system and surrounded environmental information [32, 33], Plot plan, Process and Instrumentation Diagrams (P&IDs), Process Flow Diagrams (PFDs) [26, 34, 35] Installation layout, Operation procedures, physical and Chemical specification of the material [33, 36], etc., are to be examined.

In determining safety distances for industrial LPG pipelines, considerations of the possible outcomes of unintended fuel gas discharges from pressurized transmission systems are important [37]. The separation distances aim to safeguard the LPG facility from fire radiation involving other structures and to reduce the chances of ignited LPG escaping and dispersing or diluting [38, 39].

The primary cause of process-related risk stems from operational procedure deviations, maintenance, design, competency, as well as process safeguarding and installation issues [26]. To assess the risk of the LPG distribution system, it's essential to consider factors such as the geographical location and environmental conditions of the distribution site, plot plan, P&IDs, PFDs, installation layout, operational procedures, and the physical and chemical properties of LPG [16, 17]. Silva [40] has evaluated the practical problems of present cylinder manifolds and identified related problems for both system and process-related risks including limitations in consumption rate, High replacing frequency, Cylinder sweating, LPG leftover cylinders, non-availability of liquid withdrawal facility, High rate of accessory damages due to high rate of regulator replacement, Barriers to increasing the number of cylinders in the manifold, and vulnerability for leaks in the system.

3. RESEARCH METHODOLOGY

The study relies on qualitative data collected from experts in the field. Since the objective of the research is to develop a risk prediction model, qualitative LPG safety performance-related data will be gathered in the first phase and transformed into quantitative variable factors as initial inputs to the developed formula. Since the validity and reliability are both enhanced in mixed methods, this is encouraged in use in many operational safety prediction models [41].

3.1 Data collection

Data collection was carried out in two steps as follows:

Step 1: A thorough literature review was conducted to explore safety risk-causing factors in ILPG installations in the hotel segment and the relevant standards used to minimize operational risks. Ten main risk-causing factors and seventy-eight sub-factors were identified based on 82 relevant journal publications. The relevant papers were extracted using keywords from available journal papers in databases including Scopus/ Google Scholar. Further, the literature review on available LPG-related standards such as SLS, NFPA, Code of Practice (COP) & Litro Gas Standard Internal Standard 1 was carried out to determine to related safety standards and clauses under each risk-causing factor. A total of 217 relevant safety standards and clauses were selected concerning identified risk-causing factors.

A content analysis was carried out to form similar groups among 78 identified risk-causing factors, using the NVivo software tool. It extracted 10 main groups (main factors) and 78 sub-groups (sub-factors).

Literature findings were further validated by focus group interviews. Twenty experts participated in this discussion and their profile is shown in Table 1. Experts confirmed the factors established through literature and further added two specific main factors and seven sub-factors related to the Sri Lankan context (refer to Table 2).

Table 1. Profile of experts

Expert Name	Description	Years of Experience in the LPG Field
FG1_E1	LPG consultant	10 - local and 10 - foreign experience
FG1_E2	LPG consultant	30
FG1_E3	LPG consultant	27
FG1_E4	LPG consultant	35
FG1_E5	LPG consultant	30
FG1_E6	LPG consultant	31
FG1_E7	LPG consultant	20
FG1_E8	LPG consultant	10
FG1_E9	LPG consultant	35
FG1_E10	LPG consultant	30
FG2_E11	Engineer	11
FG2_E12	Safety Manager	8
FG2_E13	LPGProject Engineer	18
FG2_E14	HSE Manager	22
FG2_E15	Safety Engineer	30
FG2_E16	Process Engineer	24
FG2_E17	LPG consultant	13
FG2_E18	Project Manager	10
FG2_E19	Technical Manager	10
FG2_E20	Engineer	20

Table 2. Risk causing factors

No.	Main Factor	Sub Factors
1	Location of the cylinder manifold	13
2	Manifold Design	7
3	Operations	8
4	Audit Assessments and Monitoring	9
5	Cylinder Stack Sizes	2
6	Ventilation	7
7	Electrical and Pneumatic Installation	8
8	Fire Protection	7
9	Maintenance of ILPG Supply System	6
10	Training & Emergency Procedures	11
11	Cylinder stacking requirement	3
12	Vehicle Movement	4

Experts were further involved in establishing the assessment criteria for each factor. A scale of 0 to 4 was used to define safety distinguish levels under different safety conditions as illustrated in Table 3. Since safety cannot be compromised in most of the factors, the scale has two options of either 0 (not complied at all) or 4 (fully complied). For example: the availability of an emergency responsive plan.

Step 2: A questionnaire survey was carried out with ILPG experts in the field to assess risk levels of those factors concerning the hotel segment in Sri Lanka.

In the questionnaire survey, data was collected from the respondents with the aid of linguistic scale terms such as "Low, Medium, High," for identifying 85 risk-causing factors in LPG installations (refer to Table 2). Then, the respondents were asked to select the appropriate scale for the "expected probability" and "expected impact" of each risk factor. The questionnaires were sent to the professionals in the LPG field. Five hundred questionnaires were distributed to Consultants, Site Managers, Engineers, Safety Professionals, LPG accessory suppliers, and LPG installation contractors. The recipients were chosen at random from the database maintained by LPG suppliers.

3.2 Development of the risk prediction model

The development of a risk prediction model involves several steps and techniques. In the research, the main steps in fuzzy system design include analyzing the problem, identifying linguistic variables and values, defining fuzzy sets, identifying fuzzy rule sets, and choosing appropriate methods for fuzzification, fuzzy inference, and defuzzification The IBM SPSS Statistics software was employed for data validation and analysis, and Structural Equation Modeling was utilized to establish the relationship between observable/latent variables based on the hypothesis definition. The following overview outlines the methodology steps undertaken.

Step 1: Converting the linguistic scale using fuzzy logic

Linguistic scale values (i.e. low, medium, and high) used to assess the impact and probability of risk-causing factors were converted to quantitative numbers using fuzzy logic techniques. In this step, the "Mandani-style if-and-then fuzzy rules" were used to convert linguistic terms to crisp values. The methods used by Han [42] and Dikmen et al. [43], were applied to define linguistic terms for potential risk levels under different risk situations as explained in Table 4. Since Mandani-style rules have more intuitive and easier-to-understand rule bases, they are well-suited to expert system applications where the rules are created from human expert knowledge and also it is more acceptable and widespread [44, 45].

Table 3. Sample of assessment criteria

Main Factor	Sub Factor	Standard Requirement	Criteria				
			0	1	2	3	4
Location of manifolds	Floor conditions	Floor should be concreted compacted, paved, level and free from debris	Unpaved, uneven floor and available debris		Concreted and free from debris		Fully complied to the clause
Training and emergency procedures	Emergency responsive plan		Not available				Available

Table 4. Linguistics terms used for risk assessment

Rule	Description	Linguistic Term
1	If the expected probability for an incident is ***low*** and the expected impact of the incident is also ***low***	Very low
2	If the expected probability for an incident is ***low*** and the expected impact of the incident is ***medium***	Low
3	If the expected probability for an incident is ***low*** and the expected impact of the incident is ***high***	Medium
4	If the expected probability for an incident is ***medium*** and the expected impact of the incident is ***low***	Low
5	If the expected probability for an incident is ***medium*** and the expected impact of the incident is ***medium***	Medium
6	If the expected probability for an incident is ***medium*** and the expected impact of the incident is ***high***	High
7	If the expected probability for an incident is ***high*** and the expected impact of the incident is ***low***	Medium
8	If the expected probability for an incident is ***high*** and the expected impact of the incident is ***medium***	High
9	If the expected probability for an incident is ***high*** and the expected impact of the incident is ***high***	Very high

Table 5. Linguistic terms

Linguistic Term	Fuzzy Numbers	Defuzzification Values
Very low (VL)	(0,0,0,0.3)	0.075
Low (L)	(0,0.3,0.3,0.5)	0.275
Medium (M)	(0.2,0.5,0.5,0.8)	0.5
High (H)	(0.5,0.7,0.7,1)	0.725
Very high (VH)	(0.7,1,1,1)	0.925

Table 5 shows the respective fuzzy numbers for derived linguistic terms (Table 4), their corresponding fuzzy numbers, and defuzzification values that were calculated based on the method used by Chen [46].

Step 2: Establishing relationships of risk-causing factors using Structural Equation Modeling (SEM)

In the context of studying the relationships of risk-causing factors, the Structural Equation Model (SEM) can help to uncover the underlying connections between observable variables and latent variables. Therefore, SEM was used to find the relationship between the identified 12 risk-causing factors. Subsequently, 13 hypotheses denoted as H1 to H13 were defined as follows.

Hypotheses 1: H1

A comprehensive model for Safety Risk Prediction of industrial liquefied petroleum gas is designed based on the effects of 12 latent dimensions identified at the literature survey and focus group interview stage. Therefore, latent dimensions, "Location of the cylinder manifold", "ILPG Cylinder Manifold Design", "Operations of the ILPG System", "Audit assessment and monitoring", "Cylinder Stacking Methods", "Cylinder Stack Sizes", "Ventilation for LPG supply system", "Vehicle movements", "Fire Protection", "Maintenance of ILPG Supply System", "Training & Emergency Procedures and Electrical/Pneumatic installation" predict the safety performance of the ILPG installations in hotel segment Sri Lanka.

Hypotheses 2: H2

The conformity of "Location of the cylinder manifold" has a positive direct effect on "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 3: H3

The conformity of "ILPG Cylinder Manifold Design" has a positive direct effect on "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 4: H4

The conformity of "Operations of the ILPG System" has a positive direct effect on "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 5: H5

The conformity of "Audit assessment and monitoring" has a positive direct effect on "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 6: H6

The conformity of "Cylinder Stacking Methods" has a positive direct effect on "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 7: H7

The conformity of "Cylinder Stack Sizes" has a positive direct effect on "safety performance of the ILPG installations in the hotel segment Sri Lanka"

Hypotheses 8: H8

The conformity of "Ventilation for LPG supply system" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 9: H9

The conformity of "Vehicle movements near the storage area" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 10: H10

The conformity of "Fire Protection" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 11: H11

The conformity of "Maintenance of ILPG Supply System" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 12: H12

The conformity of "Training & Emergency Procedures" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypotheses 13: H13

The conformity of "Electrical & Pneumatic installation" has a positive direct effect on the "safety performance of the ILPG installations in hotel segment Sri Lanka"

Hypothesis testing results showed that all of the above hypotheses were supported.

Step 3: Defining the relationship of risk-causing factors hotel segment using Conformity Factor Analysis (CFA)

Conformity Factor Analysis (CFA) was used to analyze the model developed for safety risk prediction of ILPG systems in the hotel segment in Sri Lanka. Assessment of uni dimensionality, convergent validity, reliability, and discriminant validity was carried out by CFA. The final results of the model confirmed strong support for all the mentioned factors, with high loading factors and satisfactory goodness of fit. After validating the model, measurements were taken to assess the correlation between observed and latent variables, as well as the relationship between latent variables.

Since there is a linear correlation between safety factors to overall safety performances of the LPG system, relative weight will be used as a multiplication factor in the developed formula.

Step 4: Develop a safety risk prediction Index

The mixed method was derived by using the methodologies of Thomas Ng et al. [47], Yoo and Donthu [48] and Avcılar

[49] to derive the Index. The input parameters for predicting the safety risk of LPG installations in hotels included the weight of latent and observable risk factors, their relative importance, and scores from the questionnaire survey findings. Second-order CFA to evaluate the effects of each different 12 latent safety factors was performed. In this research, the relative factor weight was derived by getting the individual path coefficient to the summation of the path coefficients ratio (Table 6). Table 6 further shows the relative weights of first-order factors.

Table 6. Standard path coefficients of risk-causing factors and Relative weights of first-order factors

Risk Causing Latent Factor	Standardized Path Coefficient	Relative Weights of First Order Risk Factors
Location of the cylinder manifold	X1	X1/ $(\sum_{i=1}^{12} Xi)$
ILPG Cylinder Manifold Design	X2	X2/ $(\sum_{i=1}^{12} Xi)$
Operations of the ILPG System	X3	X3/ $(\sum_{i=1}^{12} Xi)$
Audit assessment and monitoring	X4	X4/ $(\sum_{i=1}^{12} Xi)$
Cylinder Stacking Methods	X5	X5/ $(\sum_{i=1}^{12} Xi)$
Cylinder Stack Sizes	X6	X6/ $(\sum_{i=1}^{12} Xi)$
Ventilation for LPG supply system	X7	X7/ $(\sum_{i=1}^{12} Xi)$
Vehicle movements near the storage area	X8	X8/ $(\sum_{i=1}^{12} Xi)$
Fire Protection	X9	X9/ $(\sum_{i=1}^{12} Xi)$
Maintenance of ILPG Supply System	X10	X10/ $(\sum_{i=1}^{12} Xi)$
Training & emergency Procedures	X11	X11/ $(\sum_{i=1}^{12} Xi)$
Electrical & Pneumatic installation	X12	X12/ $(\sum_{i=1}^{12} Xi)$
Total		1.0000

As explained by Thomas Ng et al. [47], Yoo and Donthu [48] and Avcılar [49] the safety risk prediction index is a multiplication of relative weights of observable and latent safety risk causing factors and site score of different safety performances factors compared to standard requirement levels. This method has been applied for risk prediction applications in many industries such as construction, marketing business development etc.

Accordingly, calculations of the relative weights of the 12 different latent dimensions of the “Safety Risk Prediction Model” were performed based on the findings.

4. RESULTS AND DISCUSSION

This research aimed to assess the risk of using Industrial LPG (ILPG) for the hotel sector in Sri Lanka, using a safety risk prediction model applicable to ILPG usage. The research accomplished its objectives of examining the hazards in Industrial LPG (ILPG) supply systems in the hotel industry, identifying the factors that contribute to these risks, and establishing safety standards for the above risk-causing factors through the literature survey. Ten main risk-causing factors and relevant seventy-eight sub-risk factors were identified from the first round of the literature survey. Standard clauses applicable to these risk factors were also identified through the literature survey. Furthermore, the focus group interview revealed two additional primary risk factors and the secondary literature survey uncovered seven more relevant sub-risk factors. Finally, a total of 12 main risk-causing factors and 85 sub-risk factors were achieved as the results of the literature survey and focus group interview, and these 97 factors were used in the CFA model.

4.1 Results of the questionnaire survey

The research findings relied heavily on the quality of responses from the chosen participants, who were selected based on their expertise in the ILPG field, project capability, involvement in accident investigations and close-outs, contributions to the industry, and detailed knowledge of the field. The eligibility criteria aimed to ensure a comprehensive understanding of the questionnaire and instill confidence in the results. Detailed statistical analysis of the respondents is provided in the tables and charts below.

Tables 7 to 10 show demographic details of the respondents who participated in the questionnaire survey.

Table 7. Respondents working sector

	Respondents	Percentage (%)
Public Sector	57	28.8
Private Sector	87	43.9
Self Employed (Consultants)	41	20.7
Retired	13	6.6
Total	**198**	**100**

Table 8. Respondents positions in the organizations

	Respondents	Percentage (%)
Engineers	45	22.7
Consultants	35	17.7
Managers	41	20.7
Owners	5	2.5
Technicians/Supervisors	72	36.4

Table 9. Respondents level of education

Level of Education	Respondents	Percentage (%)
NVQ 3	117	59.1
Basic Degree	60	30.3
Masters	21	10.6

Table 10. Respondents experience in the LPG field

	Respondents	Percentage (%)
Less than 5 Years	27	13.6
5- 10 Years	27	13.6
10- 15 Years	23	11.6
15-20 Years	31	15.7
More than 20 Years	90	45.5

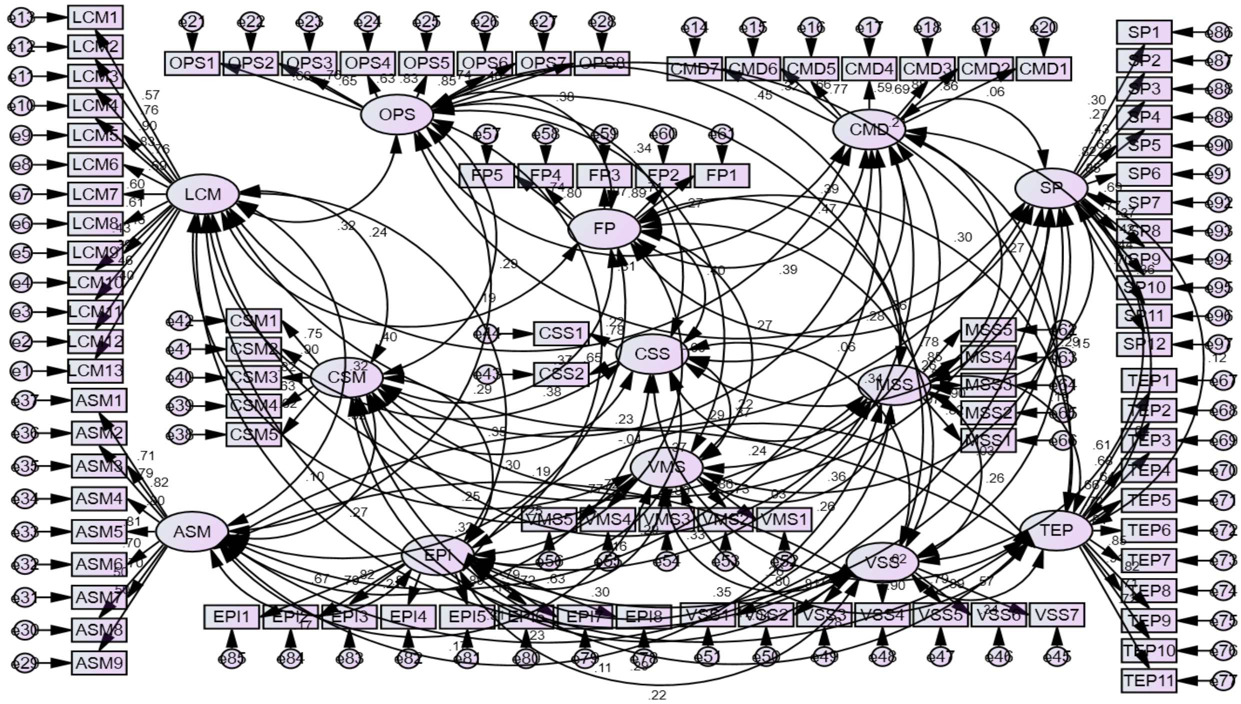

Figure 1. CFA model

Table 11. Abbreviations of CFA model

Location of the cylinder manifold (LCM)	LCM1, …, LCM13
ILPG Cylinder Manifold Design (CMD)	CMD1, …, CMD7
Operations of the ILPG System (OPS)	OPS1, …, OPS8
Audit assessment and monitoring (ASM)	ASM1, …, ASM9
Cylinder Stacking Methods (CSM)	CSM1, …, CSM5
Cylinder Stack Sizes (CSS)	CSS1, CSS2
Ventilation for LPG supply system (VSS)	VSS1, …., VSS7
Vehicle movements near the storage area (VMS)	VMS1, …, VMS5
Fire Protection (FP)	FP1, …, FP2
Maintenance of ILPG Supply System (MSS)	MSS1, …, MSS5
Training & Emergency Procedures (TEP)	TEP1, …, TEP11
Electrical & Pneumatic installation (EPI)	EPI1, …, EPI8
Safe Performance (SP)	SP1, …, SP12

4.2 Model development

In this study total of 97 factors were used to derive the CFA model as shown in Figure 1.

Abbreviations of the above CFA model are given in Table 11.

The fitness of the CFA model was tested using various indicated and findings are shown in Table 12.

Table 12. Acceptable fit indices of the model

Fit Indices	Recommended Value	Coefficient
χ^2 Value	Not significant/P<0.05	4203.9/ .000
CMIN/DF	<5 Preferable <3	1.491
CFI	>0.9	.875
TLI	>0.9	.867
RMSEA	<0.06	.051

The CMIN/DF value is 1.491. That value is less than 3. Hence, the fit index is acceptable. CIF and TLI were also approximately 0.9. Therefore, results are within the acceptable limits of the indexes. Finally, the RMSEA value is less than 0.06. Hence, this important index is also acceptable. After obtaining the best fit measurement model, proceeded to test the validity and reliability of the data.

4.3 Validity and reliability

The standardized loading of all indicator variables ranged from 0.528 to 0.937 and all variable loadings exceeded 0.5 (Table 13).

In all latent variables, Cronbach's alpha values exceed 0.7. CR values were higher than 0.7 and AVE also exceeded 0.5. Therefore, these results established reliability and convergent validity. Similarly, Table 14 represents the discriminant validity results of the study.

Based on the results can be seen the square root of AVE value of all construct variables is larger than their correlation coefficient. Therefore, all factors have adequate discriminant validity. After checking the goodness of fit, reliability and validity results, it is confirmed the model is fitting well. The final derivative measurement model is depicted in the Figure 2.

Based on the above tests, all sub-loading factors and related variables are shown in Table 15.

Table 13. Results of reliability and convergent validity

Factor	Cronbach's Alpha	Composite Reliability (CR)	AVE
Location of the cylinder manifold (LCM)	.896	.895	.524
ILPG Cylinder Manifold Design (CMD)	.883	.866	.530
Operations of the ILPG System (OPS)	.871	.884	.528
Audit assessment and monitoring (ASM)	.871	.870	.530
Cylinder Stacking Methods (CSM)	.861	.864	.617
Cylinder Stack Sizes (CSS)	.70	.70	.515
Ventilation for LPG supply system (VSS)	.929	.923	.666
Vehicle movements near the storage area (VMS)	.882	.874	.583
Fire Protection (FP)	.898	.897	.638
Maintenance of ILPG Supply System (MSS)	.920	.912	.935
Training & Emergency Procedures (TEP)	.923	.912	.515
Electrical & Pneumatic installation (EPI)	.923	.917	.941
Safety Performance	.887	.883	.921

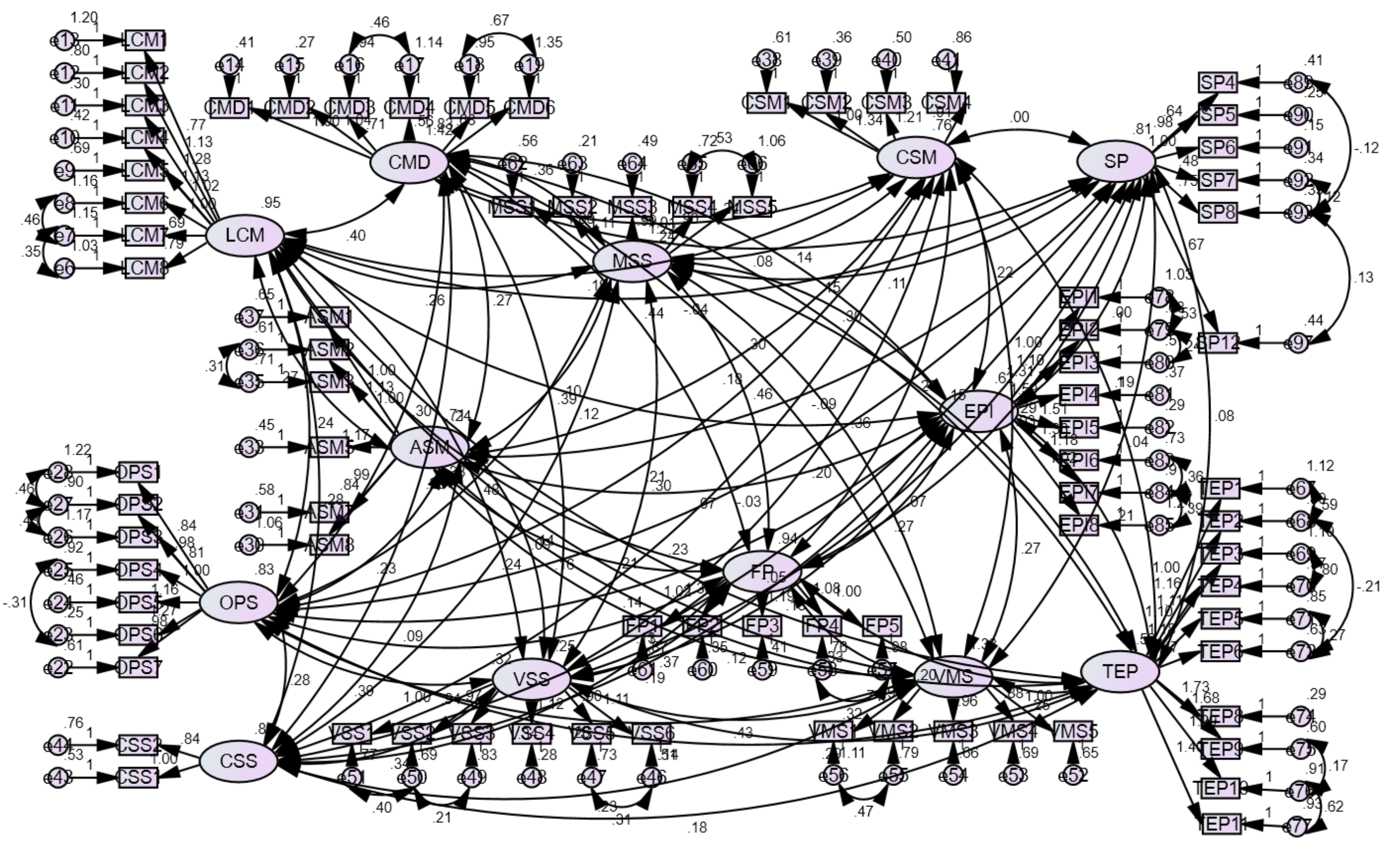

Figure 2. Final CFA model

Table 14. Discriminant validity results

	TEP	LCM	CMD	OPS	ASM	CSM	CSS	VSS	VMS	FP	MSS	EPI	SP
TEP	*0.718*												
LCM	0.302	*0.724*											
CMD	0.354	0.345	*0.728*										
OPS	0.220	0.267	0.273	*0.727*									
ASM	0.199	0.329	0.264	0.297	*0.728*								
CSM	0.298	0.221	0.235	0.268	0.243	*0.785*							
CSS	0.279	0.324	0.272	0.348	0.118	0.291	*0.718*						
VSS	0.359	0.216	0.295	0.386	0.151	0.201	0.336	*0.816*					
VMS	0.299	0.079	0.220	0.245	0.137	0.286	0.219	0.332	*0.764*				
FP	0.293	0.353	0.385	0.364	0.190	0.340	0.396	0.340	0.295	*0.799*			
MSS	0.191	0.238	0.277	0.480	0.111	0.146	0.239	0.244	0.280	0.429	*0.823*		
EPI	0.364	0.152	0.365	0.199	0.110	0.321	0.269	0.203	0.299	0.354	0.170	*0.764*	
SP	0.124	0.050	0.071	0.034	0.113	0.005	0.066	0.074	0.038	0.037	0.115	0.003	*0.750*

Table 15. Final variables of risk-causing factors after SEM analysis

Risk Causing Latent Factor	Number of Observable Variables Verified by SEM Model
1. Location of the cylinder manifold	8
2. ILPG Cylinder Manifold Design	6
3. Operations of the ILPG System	7
4. Audit assessment and monitoring	6
5. Cylinder Stacking Methods	4
6. Cylinder Stack Sizes	2
7. Ventilation for LPG supply system	6
8. Vehicle movements near the storage area	5
9. Fire Protection	5
10. Maintenance of ILPG Supply System	5
11. Training & Emergency Procedures	11
12. Electrical & Pneumatic installation	8

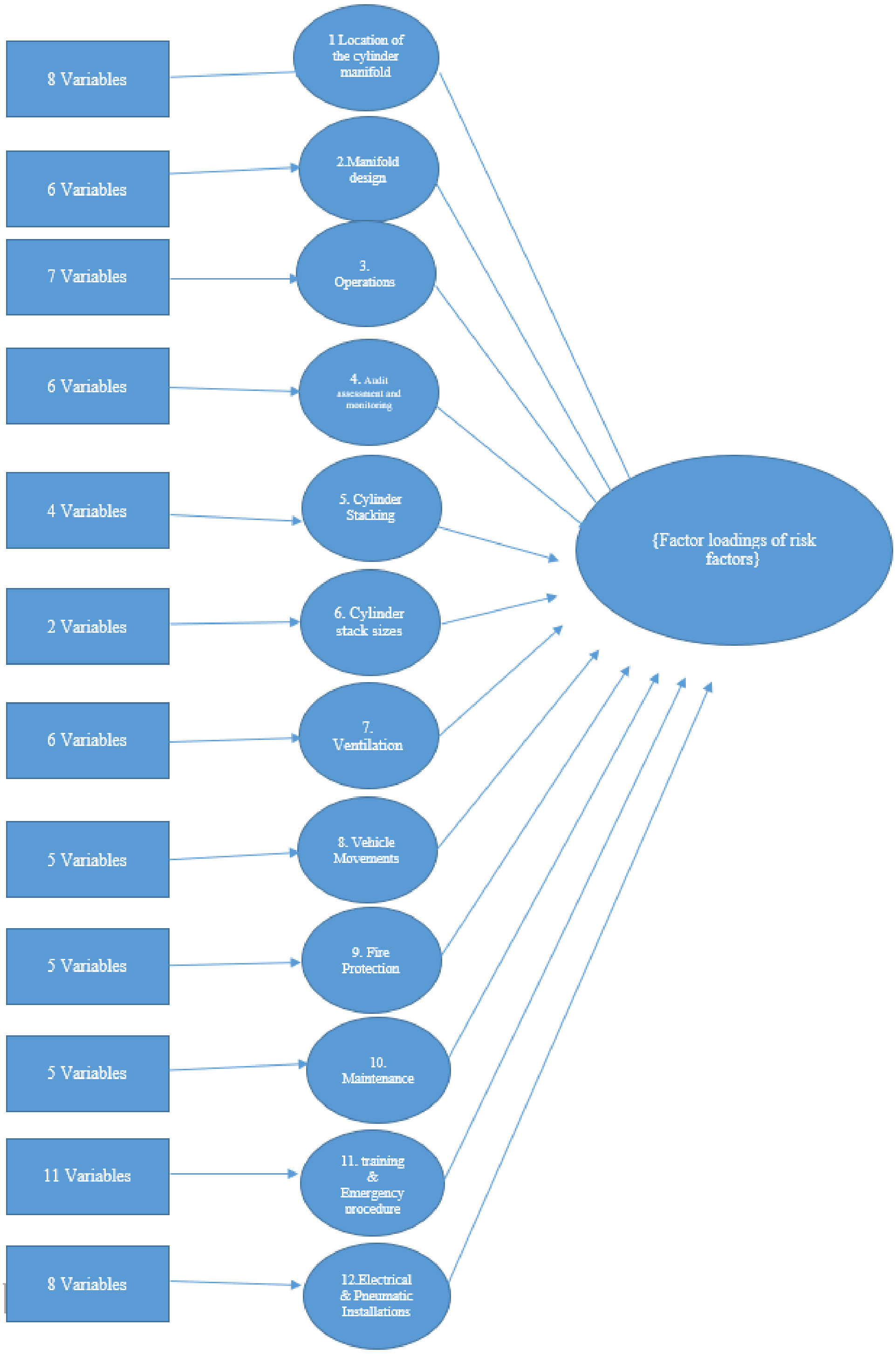

Figure 3. Safety risk prediction model

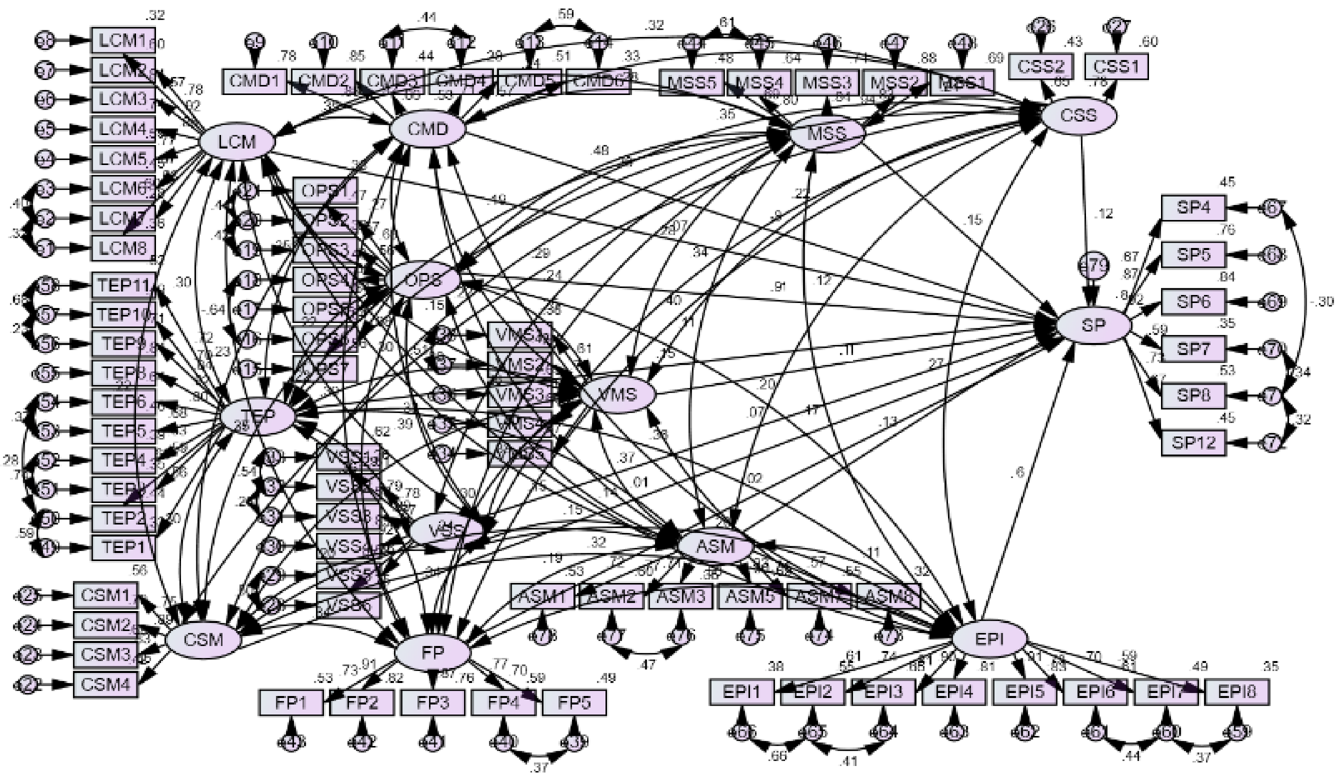

Figure 4. The structural model

Based on the above factors proposed the Safety Risk Prediction model can be illustrated as shown in Figure 3.

The Structural Model for the sample is depict in Figure 4.

Table 16 shows the path coefficient for the proposed hypothesis in the structural model.

Table 16. Results of hypothesis

Hypothesis	Proposed Relationship	Path Coefficient	Results
H_2	LCM → SP	.276**	Supported
H_3	CMD → SP	.794***	Supported
H_4	OPS → SP	.910***	Supported
H_5	ASM → SP	.128**	Supported
H_6	CSM → SP	.142**	Supported
H_7	CSS → SP	.124**	Supported
H_8	VSS → SP	.371**	Supported
H_9	VMS → SP	.114*	Supported
H_{10}	FP → SP	.534***	Supported
H_{11}	MSS → SP	.150**	Supported
H_{12}	TEP → SP	.155**	Supported
H_{13}	EPI → SP	.560***	Supported

Note ***Significant at 0.01 level, **Significant at 0.05 level, *Significant at 0.1 level

4.4 The results of the squared multiple correlation (R^2)

The results of the squared multiple correlations, which provide information about the structural model explained in the statistically significant variance of each construct variable are confirmed as 79. The overall model was explained by 80% (R^2=0.79) of the variance in the outcome variables. That means 12 latent constructs of risk factors (Location of the cylinder manifold, ILPG Cylinder Manifold Design, Operations of the ILPG System, Audit assessment and monitoring, Cylinder Stacking Methods, Cylinder Stack Sizes, Ventilation for LPG supply system, Vehicle movements near the storage area, Fire Protection, Maintenance of ILPG Supply System, Training & Emergency Procedures, and Electrical & Pneumatic installation) confirmed accounting for 80% of the variance of Safety Performance. So, Hypothesis testing results showed that all of the research hypotheses were supported.

The standard path coefficient of first-order variable safety risk-causing factors and second-order latent factors were seen as direct and significant. The standard path coefficient of all 12 latent dimensions calculated by AMOS, results are shown in Table 17 indicates 12 latent factors and their relevant standard path coefficients.

Developing a safety risk prediction model for the operational stage of ILPG supply systems in hotels was achieved as a result of the analysis. From the results, it is clear that the main risk-causing factors are representable as a combination of sub-risk-causing factors. The weight of latent and observable risk factors, their relative importance, and site-specific measurable scale were considered as the input parameters to calculate the predicted safety risk of ILPG installations in hotels. Second-order CFA to evaluate the effects of each different 12 latent safety factors was performed. In this research, the relative factor weight will be derived by getting the individual path coefficient to the summation of the path coefficient ratio. Few case studies were conducted to validate the formulae.

Despite the advantages of the ILPG, hotels experience high instances of LPG leaks, posing an elevated risk of explosions or fires. This highlights numerous safety oversights in the ILPG systems, operations, and safety practices of ILPG stakeholders within the hotel industry. To address key concerns, the existing frameworks or models used by other countries have limitations such as the lack of industry-specific safety prediction models, and an inability to provide a comprehensive approach for site-specific safety risk prediction. Some safety methods prioritize daily safety measures over safety management principles. Additionally, safety prediction is only presented qualitatively, and site-wise comparison is limited by the scarcity of qualitative measures.

The model takes a proactive approach by considering risk-causing factors and their sub-factors to fill the gaps in existing models. It assigns relative weights to identified risks and formulates relationships to create the final safety risk prediction index the model primarily focuses on the specific site and can be directly linked to the site's overall safety prediction based on site-specific scores. These findings serve as a reference for comparing site safety and can then be used to provide safety recommendations by identifying the level of safety compliance.

Table 17. Standard path coefficients and the relative weights of risk-causing factors

Risk Causing Latent Factor	Standardized Path Coefficient	Relative Weights of First-Order Risk Factors
1. Location of the cylinder manifold	.524	0.07
2. ILPG Cylinder Manifold Design	.530	0.07
3. Operations of the ILPG System	.528	0.07
4. Audit assessment and monitoring	.530	0.07
5. Cylinder Stacking Methods	.617	0.08
6. Cylinder Stack Sizes	.515	0.07
7. Ventilation for LPG supply system	.666	0.09
8. Vehicle movements near the storage area	.583	0.08
9. Fire Protection	.638	0.08
10. Maintenance of ILPG Supply System	.935	0.12
11. Training & Emergency Procedures	.515	0.07
12. Electrical & Pneumatic installation	.941	0.13
Total		1.00

5. CONCLUSION

There are numerous shortcomings in the safety of ILPG systems, operations, and safety practices of ILPG stakeholders in the hotel industry. To tackle some of the main issues, the existing frameworks and models used in other countries have their limitations. Most of these models rely on past accident data for predicting safety outcomes. The paper focuses on initially exploring the risks in Industrial LPG (ILPG) supply systems in the hotel segment, then establishing the risk factors and standards applicable to ILPG supply systems. It also aims to develop risk assessment criteria for identified ILPG risks, create a safety risk prediction model for the operational stage of ILPG supply systems in hotels, and assess the existing risk levels of ILPG systems in hotels using case studies. This model provides a solution for assessing safety risks in LPG installations, offering practical applications for industry safety benchmarking and comparing sites for LPG suppliers and industry evaluators. The results of safety risk predictions can be used to rank sites and recommend preventive measures to improve safety compliance. This model can be further developed into a computer software program and designed as a mobile app, providing a user-friendly tool for safety professionals to input site-specific data. The mobile app's results and recommendations can be easily transferred to email or paper for reference in safety improvements. This will be a potential area for future researchers.

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