SAFETY RISK OF INDUSTRIAL LIQUEFIED PETROLEUM GAS INSTALLATIONS OF THE HOTEL SEGMENT IN SRI LANKA

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Abstract. The increasing use of Liquefied Petroleum Gas (LPG) in homes and businesses is attributed to its effectiveness, affordability, and eco-friendliness compared to other fuels, despite the potential fire and explosion hazards. When handling this highly flammable gas, it is crucial to implement specific control measures based on its application. Numerous incidents related to LPG are frequently reported in the industry due to issues associated with handling and technical aspects. The use of industrially liquefied petroleum gas (ILPG) in hotel kitchens has become a critical concern due to several safety incidents. This research established 88 risks causing factors under 12 main categories. Bibliometric analysis and focus group interviews were carried out to establish those factors. Further, a questionnaire survey was conducted to assess risk levels contributed by those risk factors to ILPG safety in the hotel segment in Sri Lanka. Findings show that exposed electrical parts, flammable gas contact with electrical circuits, capacity of cylinder stacking, hazardous electrical equipment's without installation, explosion-proof mechanical installations, provision of ventilation, faulty wiring, emergency procedures, compliance with the design code and availability of fire extinguishers are the most vulnerable risks related to ILPG installations in hotel segments. The findings of this research would allow safety practitioners and policymakers to provide preventive measures to enhance the safety of ILPG operations.

Keywords. Liquefied Petroleum Gas, Safety, Risk Causing Factors, Hotel Segment, Bibliometric Analysis

1. Introduction

Liquid Petroleum Gas (LPG) used as a fuel in Sri Lanka is a hydrocarbon gas that contains propane (C3H8) and butane (C4H10). In addition to these two primary chemical compounds, several other compounds are available for various purposes (Sarvestani et al., 2021). According to the revised Sri Lanka Standard, SLS 712:2022, the maximum allowable propane composition in LPG in Sri Lanka is 30% (SLS 712;2021). Bulk usage of LPG with cylinder manifolds for industrial applications refers to Industrial Liquid Petroleum Gas (ILPG) systems. In Sri Lanka, 37.5 kg commercial cylinders are utilized in various industrial applications, and bulk LPG storage systems are used due to high consumption needs (Basnayake & De Silva,2024).

The country's demand for LPG in 2024 was 480,000 MT, with ILPG consumption at approximately 120,000 MT (Central Bank Annual Report,2024). According to ILPG demand, the tile manufacturing sector is the highest consumer, followed by rubber manufacturing, glass manufacturing, hotels, and the textile industry (Rajmohan & Weerahewa,2010). In commercial applications, LPG is widely utilized for space and process heating, running industrial ovens, food production, operating kilns and furnaces, manufacturing processes, packaging materials, and powering forklift trucks in warehouse operations (Malviya & Rushaid, 2018).

This high demand is mainly due to its greater energy content, which provides a competitive edge over other alternative fuel sources (Amuzuvi & Ashilevi, 2016). In many industries, a higher flame temperature is a crucial necessity (Gupta, 2000). Since LPG has a high heating capacity, it allows for quicker temperature attainment, significantly reducing fuel expenses for industrial applications. Propane and Butane complete combustion give a higher heat value, leaving no residue or particulate matter, resulting in lower maintenance costs and a reduced carbon footprint (Gould & Urpelenean,2018). ILPG also contributes to reduced emissions compared to traditional fossil fuels, supporting cleaner and more sustainable industrial operations. As a result of the above factors, the adoption of ILPG has significantly risen in recent years among commercial enterprises (Amuzuvi & Ashilevi, 2016).

LPG is a highly flammable gas that easily catches fire. A leak or unanticipated gas release occurs when the system's primary containment fails. When ILPG leaks, it evaporates and creates a substantial gas cloud that tends to accumulate in low-lying areas, such as drains, LPG storage zones, or basements. Hence, there is a huge risk of fire if a flammable source is introduced (Chakraborty et al., 2015). An explosion, fire or cold burn has become an intrinsic risk associated with the use of LPG (Bruce et al., 2015). Under these circumstances, many incidents have been reported related to ILPG (Bariha et al., 2019). They were mainly due to users' lack of knowledge, failure in design, operation, and maintenance (Yadav et al., 2017; Paliwal et al., 2014).

Numerous hotels worldwide have reported incidents involving fires, explosions, and cold burns in kitchens and storage areas (Roberts & Chan, 2000;Wu, 2007; Rasbash, 2010; Zheng & Chen,2011; Pradhan et al., 2017). On average, approximately six incidents related to LPG fires are reported each month within the industrial and commercial sectors of Sri Lanka (Incidents Reports LGLL,2024). In the year 2024, 18 incidents were reported from hotels (Incidents Reports LGLL,2024). The majority of incidents pertain to asset damage, with one case of severe injury documented in this segment. In terms of fire risk, hotels often contain hazardous industrial equipment, particularly in their kitchens, as 80% of their cooking depends on ILPG. Less area availability for ILPG installations, poor knowledge on safety procedures, high replacement frequency of LPG cylinders, design & installation failures, appliance failure, defective installation, and user carelessness are identified as common root causes of many incidents in hotels (Malviya & Rashid,2018; Basnayake & De Silva, 2024). In Korea, more than 54% of total accidents were attributed to unsafe user behaviour (Park et al., 2015; Jung et al., 2020). According to the Annual Report on Liquefied Petroleum Gas-Related Accidents (2018 version) of Japan, in 2017, 27% of accidents reported in hotel kitchens were due to issues in the ILPG distribution system. Therefore, it is evident that there are many lapses in the distribution of ILPG system safety and safety behaviours of ILPG stakeholders in the hotel sector. In Sri Lanka, there are a lot of installation-related deviations observed. Special considerations must be made to consider the function of a hotel kitchen as an industrial application in terms of safety within the hotel sector.

Many control measures have been introduced to enhance the safety of ILPG users. For instance, countries such as the USA, UK, Japan, and Korea have implemented a range of strategies, regulations, and technologies to reduce the risks of ILPG systems (WLPGA,2020). In Sri Lanka, the regulations for ILPG usage, including SLS 1196 and SLS 712, and several international standards, such as NFPA, BS, APA, and CODAP have been used. While installers may refer to these standards as necessary, there are no compulsory requirements or regulatory bodies to ensure their enforcement.

Despite the availability of numerous risk prediction methods in other industries, identifying a suitable approach for assessing risks in ILPG installations remains a significant challenge. A comprehensive system to compile all risks associated with ILPG installations and assess the significance of their deviations has not yet been addressed by researchers.

2. Literature Survey

This topic has become an important area for many researchers, as more than 500 LPG application-related articles have been published since the year 2000, according to VOS Scopus journal publication data (Table 1).

Table 1: ILPG highlighted in research publications (VOS Scopus Journal Analysis)

No.	Year	Number of Publications
1	2000 to 2005	67
2	2005 to 2010	96
3	2011 to 2015	115
4	2015 to 2020	104
5	2021 to 2024	144
	Total	526

Risks of using ILPG have been discussed by many researchers over the past decade (Rasbash, 2010; Zheng & Chen,2011; Bansal et al., 2012; Pradhan et al., 2017). The primary risk in an ILPG distribution system is the loss of primary containment (LOPC), which occurs when liquid spills from a pressurized container or pipeline. This can lead to rapid dispersion and evaporation of the substance (Rasbash, 2010). Fire, explosions and toxic release are considered major consequences of ILPG leaks (Kumar et al., 2024; Nyanana et al., 2024). ILPG liquid can cause cold burns upon contact with the skin or eyes, and further, inhaling LPG vapour at high concentrations may lead to fainting or death. Exposure to LPG vapour can also cause irritation of the nose and throat, headaches, nausea, vomiting, dizziness, and loss of consciousness (Nyanana et al., 2024). The primary cause of death following LPG exposure has typically been attributed to asphyxia due to hypoxia (Iacoponi et al., 2024). The fire risk of the ILPG distribution system can be divided into three segments including (1) ILPG tank that includes filling and safety systems, such as an automatic fill limiter, excess-flow valve, non-return valve, and pressure relief valve; (2) the procedure for preparing the fuel mixture (Zheng & Chen, 2011); and (3) the processes involved in fuel delivery, gas/air mixture formation, and injection control (Lam & Cruz, 2018;Zheng & Chen, 2011)

An explosion results from the rapid release of energy, as energy release is generally sudden, which creates a localized accumulation of energy. This energy is then dissipated by a variety of mechanisms, including formation of a pressure wave, projectiles, thermal radiation and acoustic energy (Kumar et al., 2024). If an explosion occurs in LPG, the energy causes the gas to expand rapidly, forcing back the surrounding gas and generating a pressure wave that rapidly propagates outward from the blast source. Figure 1 can be used as a process mapping tool in the identification of risks of fire or explosions, such as Boiling Liquid Expanding Vapour Explosion (BLEVE), Vapour Cloud Explosion (VCE), etc. (Beheshti et al., 2018).

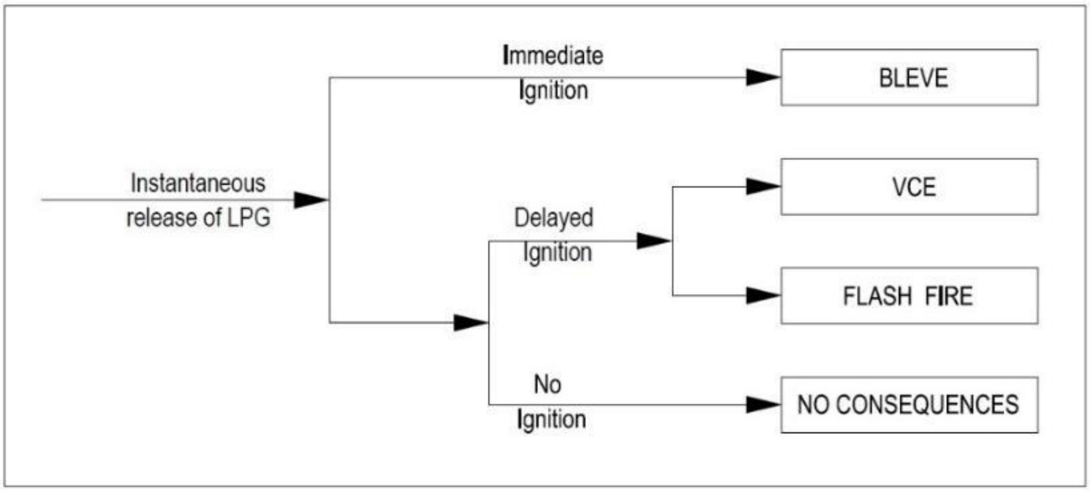

Figure 1: Consequences of LPG leaks

Source: Beheshti et al., 2018

These scenarios are generally recognized as the energy from an explosion poses a risk during the processes of energy dissipation and dispersion (Tauseef et al., 2010). Research by Roberts & Chan (2010) has revealed that 1744 major industrial accidents have occurred due to BLEVE. Indeed, some significant tragedies have been caused by these explosions, which often lead to fires and secondary incidents (Tauseef & Abbasi, 2013). While it is impossible to eliminate the risks associated with LPG installations, the level of safety largely depends on the reliability of safety devices (Kumar et al., 2024).

Lack of awareness among people regarding safety measures, fire escape plans, fire databases and increased defects of cylinders and accessories has led to a rise in ILPG related burns (Zheng & Chen,2011; Bansal et al., 2012; Pradhan et al., 2017). Usage of recommended standard pipes, good quality accessories and gas cylinders, increasing supply to meet the demands, standard operation procedures, proper design and distancing to keep cylinders, and personnel training are discussed in the literature to prevent ILPG related burns and accidents inside the kitchens (Tauseef & Abbasi, 2013).

Literature showed hotels kitchen are more prone to accidents due to presence of cooking oil and that makes an ideal combination for fire hazards (Kumar et al., 2024; Nyanana et al., 2024). Further, low- and high-voltage electrical systems, gas installations, boilers, and even tanks containing liquid petroleum products are other sources for fire risks (Bansal et al., 2012; Pradhan et al., 2017). Additionally, the presence of larger and more complex units in crowded hotel kitchens can increase the potential for significant damage (Malviya & Rushaid, 2018). Further, large-scale pool fires have high risk consequences related to hotel segment accidents (Rasbash, 2010).

Therefore, to assess the potential fire and explosion hazards associated with the ILPG systems in hotels, it is essential to consider specific risk-causing factors. They can be mainly segmented as process related and system related risks (Bribián et al., 2009). While the process related risk is mainly due to deviations in operations procedures, maintenance issues, design issues, competency issues, process safeguarding & installation issues (Bansal et al., 2012), System-related risks are mainly due to issues in the distribution system or primarily LOPC (Bruce et al., 2015). Literature highlighted many factors, and they are summarized in Table 2.

Table 2: Most highlighted risk causing factors

Risk factor	**Literature source**
1. Location of the Cylinder Manifold	Selvan, 2016; Setiyo, 2016; Tauseef, 2017; Park, 2015; Qian, 2021; Sarker, 2022; Hadzihafizovic, 2024; SLS 1196; BS 6891; NFPA 54; COP1
2. Cylinder Manifold Design	Sridhar et al., 2016; Moorthy & Srinivas, 2018; Kiran & Sruthi, 2018; Shevtsov, 2018; Majerczyk,2011; Mohsen et al., 2023; BS 6891; SLS 1196; NFPA 54; COP1
3. Cylinder Manifold Operations	Jafarzadeh et al., 2016; Menon, 2019; Shevtsov, 2018; Rissman et al., 2020; Diab et al., 2024; BS 6891; SLS 1196; NFPA 54; COP1
4. Audit, Assessment and Monitoring	Rissman et al., 2020; Hasan & Ahammed, 2021; Nyabuto et al., 2020; Dewantari et al., 2023; Thürer et al., 2023; BS 6891; SLS 1196; NFPA 54; COP1
5. Cylinder Stacking Requirement (if the area is not enough)	Rissman et al., 2020; Chatelier, 2021; Drgoňa et al., 2020; Kim et al., 2018; Kora, 2023; Lin, 2018; BS 6891; SLS 1196; NFPA 54; COP1
6. Cylinder Stack Sizes	Derhami et al., 2016; Yener & Yazgan, 2019; Molina et al., 2018; Sawicki & Sawicka, 2023; Silalahi et al., 2022; BS 6891; SLS 1196; NFPA 54; COP1
7. Ventilation to the Cylinder Manifolds	Brzezinska, 2016; Lin, 2018; Kim et al., 2018; Drgoňa et al., 2020; BS 6891; SLS 1196; NFPA 54; COP1
8. Vehicle Movements near the LPG Supply System	Chakraborty & Saha, 2024; Chawla & Chawla, 2023; Martin et al., 2023; Papadopoulos et al., 2018; Ulutaş et al., 2023; Viskup et al., 2019; BS 6891
9. Fire Protection	Jiao,2023; Brzezinska, 2016; Shevtsov et al., 2018b; Yener & Yazgan, 2019; Kim et al., 2018; BS 6891; SLS 1196; NFPA 54; COP1
10. Maintenance of ILPG Supply System	Sridhar et al., 2016; Moorthy & Srinivas, 2018; Kiran & Sruthi, 2018; Shevtsov, 2018; Majerczyk,2011; BS 6891; SLS 1196; NFPA 54; COP1
11. Training & Emergency Procedures	Shevtsov et al., 2018b; Malviya & Rashid, 2017; Park, 2017; BS 6891; SLS 1196; NFPA 54; COP1
12. Electrical & Pneumatic Installation	Kiran & Sruthi, 2018; Shevtsov, 2018; Majerczyk,2011; Mohsen et al., 2023; BS 6891; SLS 1196; NFPA 54; COP1

3. Research Methodology

3.1 ESTABLISHING ILPG RISK DOMAIN

With the rapid increase in the number of academic journals, congresses, and other publications in recent years, scientific knowledge has drastically increased (Kraus et al., 2020). Therefore, it is difficult to follow the state, new developments, and evolution and to categorize the body of knowledge in a given field using traditional literature review methods (Öztürk et al., 2024). Therefore, many researchers have used bibliometric analysis, which enables the review of literature relevant to a particular research field systematically. Therefore, bibliometric analysis was carried out to search for risk causing factors related to ILPG from the impactful publications from 2000 to 2024. VOSviewer software tool was used to analyze the identified literature sources. The following steps are followed to establish the ILPG risk domain.

- Step 1

Literature review was conducted using Scopus and WLPGA articles. The title search was conducted using the search string of "LPG Safety" or "LPG Risk." The selected publications were further filtered using;

(a)Papers published between 2010 and 2024,

(b) Papers available in online databases,

(c) Papers written in English.

Based on the above filtering process, a total of 526 research papers were identified.

- Step 2

Abstracts of the identified 526 papers were reviewed manually, and those identified as relevant to the risks of LPG installation were selected to be retrieved and reviewed in full. Thus, abstracts focus on hotels, restaurants, catering facilities, event & conference facilities, where LPG cylinder manifolds are used for cooking, have been selected to identify ILPG risk causing factors in the hotel segment. However, papers focus on the use of LPG cylinder manifolds for construction, manufacturing, such as tile, rubber, etc., confectionery, chemical processing, textiles, auto gas stations, and apartment complexes have not been utilized for this research. Based on the above search results, a total of 82 papers were selected for detailed analysis.

- Step 3

Qualitative content analysis was conducted using the NVivo software tool to identify patterns and similarities of factors. This method involves a detailed and systematic examination of a body of material to uncover themes, trends, or biases (Zou et al., 2011). It is recognized as a systematic and replicable technique for condensing large volumes of text into meaningful content categories based on clear coding rules (Stemler, 2001). Eighty-two research papers were categorized based on several key aspects, including their type, data collection methods, analytical techniques, research objectives, key findings, contributions, limitations, year of publication, and country of origin. Using NVivo, 10 main factors and 78 sub-variables were identified.

- Step 4

The identified 10 main risk factors and 78 sub-factors were presented with the aid of a questionnaire to 20 experts for confirmation to validate the literature findings.

These 20 experts were divided into two groups. The most senior-level experts with more than twenty years of experience in the LPG industry available in the field of LPG safety, based on the "LPG suppliers' consultant registration list", were selected as group one. A total of ten members were included in this group. The second group comprised operational-level field experts in the LPG industry. A total of ten members were invited to the discussion. Table 3 shows their profiles.

Table 3: Profile of experts

Expert Group and Name	Description	No. of years of experience in the field of LPG
FG1_E1	Working as a Consultant	10 years - local and 10 years - foreign
FG1_E2	Working as a Consultant	30 years - local
FG1_E3	Working as a Consultant	27 years - local
FG1_E4	Retired Consultant	35 years - local
FG1_E5	Working as a Consultant	30 years - local
FG1_E6	Working as a Consultant	31 years - local
FG1_E7	Working as a Consultant	20 years - local
FG1_E8	Working as a Consultant	10 years - local
FG1_E9	Retired Consultant	35 years - local
FG1_E10	Working as a Consultant	30 years - local
FG2_E11	Working as an Engineer	11 years - local
FG2_E12	Working as a Safety Manager	8 years - local
FG2_E13	Working as a Project Engineer	18 years - local
FG2_E14	Working as an HSE Manager	22 years - local
FG2_E15	Working as a Safety Engineer	30 years - local
FG2_E16	Working as a Process Engineer	24 years - local
FG2_E17	Working as a Consultant	13 years - local

FG2_E18	Working as a Project Manager	10 years - local
FG2_E19	Working as a Technical Manager	10 years - local
FG2_E20	Working as an Engineer	20 years - local

During this task, two new factors were added to the list of main risk-causing factors, increasing the initial 10 factors to 12. Therefore, to identify the sub factors for the newly added two main risk causing factors, another round of literature survey was conducted by referring to the keywords of the factors. A total of 5 new sub factors were identified under each new factor, based on 8 journal papers published after 2010. These were validated through the same experts in the focus group.

3.2 ASSESS THE RISKS

3.2.1 Data Collection

A questionnaire survey was conducted to obtain data to assess the impact and probability of those established risk factors on ILPG safety in the hotel segment in Sri Lanka. Data were collected from the industry practitioners with the aid of qualitative terms as "Low, Medium, High". Accordingly, respondents were asked to rank the 88 risk factors according to the above scale provided.

Consultants, Site Managers, Engineers, Safety Professionals, LPG accessory suppliers and ILPG installation contractors were selected based on the database maintained by LPG suppliers. A total of 400 questionnaires were emailed, of which 198 respondents fully completed the whole survey. Another 100 emails were sent to LPG suppliers, where their staff also contributed to completing the questionnaire survey. A total of 198 were received, with a 49% response rate.

3.2.2. Risk Quantification

Risk ratings obtained for (impact) and (2) probability using qualitative terms of "low", "moderate and "high" were converted to quantitative terms using fuzzylogy. The conversion process is discussed in the following steps.

- Step 1

In order to derive the potential risk levels using those two variables (i.e. impact and probability), the Mandani-style if-and-then fuzzy rules used by Han (2005) and Dikmen et al. (2007) were applied. Since these rules are more intuitive and easier to understand, they are well-suited to expert system applications where the rules are created from human expert knowledge, which is more acceptable and widespread (Kaur and Kaur,2012; Hishammuddin 2008), and hence used for this study.

- Step 2

Trapezoidal fuzzy membership function is used to diffuzified linguistic values into quantitative numbers (i.e. crisp values) as applied by Chen (1997) and further by Yener in 2007. Figure 2 illustrates a typical trapezoidal fuzzy membership function.

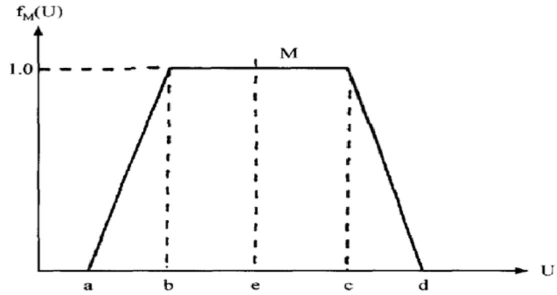

Figure 2: A typical trapezoidal fuzzy membership function

4. Results and Discussion

4.1 ILPG RISK DOMAIN FOR HOTEL SEGMENT

ILPG risks identified through literature and focus group interviews were used to establish the ILPG risk domain for the hotel segment in Sri Lanka, which consists of 12 main risk causing factors and 85 sub risk causing factors (Table 4).

Table 4: ILPG Risk Domain

Main Risk Causing Factors	Sub Risk Causing Factors
1. Location of the cylinder manifold	1.1 Base/floor conditions, 1.2 LPG storage area, 1.3 Escape and access routes, 1.4 LPG cylinder storage separation distance, 1.5 The zone boundaries, 1.6 Construction of robust fences, 1.7 Escape doors, 1.8Separation distance to boundary, 1.9 Fire extinguishers placements, 1.10 Access Controls, 1.11 Adjuscent drains pits, 1.12 Weather Protection, 1.13 LPG storage area identification
2. Cylinder manifold design	2.1 Equipment Selection, 2.2 Design Code,2.3 Basement Dimensions, 2.4 Safety Distances, 2.5 Cylinder markings, 2.6 Safety Devices Installations, 2.7 Number of cylinders in the manifold
3. Cylinder manifold operations	3.1 Availability of operation procedures at site, 3.2 Emergency procedures/ Call list display, 3.3 Warning signs and emergency action plan, 3.4 The failure to adhere to internal policies, 3.5 Risks arising from catastrophic events, 3.6 Health and safety guidelines, 3.7 ESD Functionality, Skill Operators
4. Audit assessment and monitoring	4.1 Conducting Health & Safety internal audits, 4.2 Conducting Health & Safety external audits, 4.3 Conducting specific risk related audits, 4.4 Equipment testing and inspection audits, 4.5 Workplace exposure monitoring, 4.6 Fire and LPG leak detection systems, 4.7 Legal compliance audit, 4.8 Management review audits, 4.9 Risk assessments

5. Cylinder stacking requirement (if the area is not enough)	5.1 Cylinder stacking storage, 5.2 Segregation of liquid and vapor withdrawal cylinders, 5.3 Filled and empty cylinder separation
6. Cylinder stack sizes	6.1 Capacity of Stacking, 6.2 Gangways between non- palletized stacks
7. Ventilation to the cylinder manifolds	7.1 Availability of ventilation, 7.2 Placement of ventilation openings, 7.3 Entrance, exit doors and windows gates and fences, 7.4 Ventilation openings availability from at least one side of the wall, 7.5 Storage ventilation protection, 7.6 Full cylinder stand-by storage ventilation, 7.7 Empty cylinder storage ventilation
8. Vehicle movements near the LPG supply system	8.1 Accessibility of delivery vehicles to site, 8.2 Maintenance of vehicles related to LPG supply system, 8.3 Internal traffic control, 8.4 Vehicle drivers
9. Fire protection	9.1 Fire approvals, 9.2 Fire extinguishers, 9.3 Fire brigade access to site, 9.4 Fire hydrants, 9.5 Other available fire extinguishing mechanisms, 9.6 Fire risk assessment, 9.7 Fire drills
10. Maintenance of ILPG supply system	10.1 Written schemes of examinations, 10.2 Maintenance scope, 10.3 Maintenance scheduling e.g. Rosters, 10.4 Maintenance records, 10.5 Cylinder testing, 10.6 Proactive Maintenance Plan
11. Training & Emergency Procedures	11.1 Operational trainings, 11.2 Conduct emergency training practical, 11.3 Conduct emergency drills, Conducting first aid trainings, 11.4 Staff members are aware of how to report emergencies, 11.5 Emergency procedures, 11.6 Gas leak detection system, 11.7 Use of necessary PPE, 11.8 Fire exits are clearly shown with directions, 11.9 Assembly point in case of emergency, 11.10 Emergency response plan, 11.11 Potential incident reporting
12. Electrical & Pneumatic installation	12.1 Hazardous electrical equipment with improper installation, 12.2 Electrical equipment's contact with metal surfaces, 12.3 Fires due to faulty wiring, 12.4 Ignition of fires or explosions due to electrical contact with potentially flammable, 12.5 Exposed electrical parts, 12.6 Inadequate wiring, Explosion proof mechanical installations, Pneumatic Installation inspection and maintenance

4.2 RISK ASSESSMENT USING FUZZYLOGIC

As per the Mandani-style if-and-then fuzzy rules, the potential levels for each risk causing factor were assessed (Table 5).

Table 5: Potential Risk Levels of Risk Risk-Causing Factors

Rule	If then Rule for Risk Situations	Potential Risk
1	If expected probability for an incident is **low** and the expected impact of the incident is also **low**	VERY LOW

2	If expected probability for an incident is **low** and the expected impact of the incident is **medium**	LOW
3	If expected probability for an incident is **low** and the expected impact of the incident is **high**	MEDIUM
4	If expected probability for an incident is **medium** and the expected impact of the incident is **low**	LOW
5	If expected probability for an incident is **medium** and the expected impact of the incident is **medium**	MEDIUM
6	If expected probability for an incident is **medium** and the expected impact of the incident is **high**	HIGH
7	If expected probability for an incident is **high** and the expected impact of the incident is **low**	MEDIUM
8	If expected probability for an incident is **high** and the expected impact of the incident is **medium**	HIGH
9	If expected probability for an incident is **high** and the expected impact of the incident is **high**	VERY HIGH

Trapezoidal fuzzy membership function was applied to difuzzified "very low", "low", "medium", "high", and "very high" to crisp values. The corresponding crisp values are shown in Table 6.

Table 6: Diffuzified Values

Linguistic Terms	**Crisp Values**
Very low (VL)	0.075
Low (L)	0.275
Medium (M)	0.5
High (H)	0.725
Very high (VH)	0.925

- Step 3

Based on the questionnaire results, ILPG risks are assessed using derived crisp values, risk rating matrix (Figure 3) was developed with five risk categories (Table 6). Results shows Exposed electrical parts, flammable gas contact with electrical circuits, capacity of cylinder stacking, hazardous electrical equipment's without installation, explosion-proof mechanical installations, provision of ventilation, faulty wiring, emergency procedures, compliance with the design code and availability of fire extinguishers identified as critical risk causing factors ILPG risk in hotels in Sri Lanka and relate to the "Very High" category. Figure 3 shows the respective risk category of each risk causing factor. As a summary, out of 88 risk factors, 9 factors have very low vulnerability, 23 factors have low vulnerability, 34 factors have medium vulnerability, 13 factors have high vulnerability, and 9 factors are very highly vulnerable.

Expected probability	**HIGH**	**MEDIUM** 1.8,11.11,11.12,11.13,3.1 3.2,3.4,3.5,3.6,4.1,4.4,9.3	HIGH 1.10,2.1,2.5,2.6, 3.8,4.6	**VERY HIGH** 12.1,12.3,12.4,12.5,12.6,11.5,6.1,2.2,9.2
	MEDIUM	**LOW** 1.1,1.2,1.3,1.4,1.5,1.6 1.9,2.3,2.4,2.7,3.3,4.2	**MEDIUM** 4.9,5.3,5.5,6.2,7.2, 7.4,7.5,7.6,9.1,9.2	HIGH 5.1, 5.2, 7.1, 9.5, 11.6, 11.7, 11.8
	LOW	**VERY LOW** 6.2,8.3,6.1,4.5,1.13 8.1,3.6,4.7,11.3	**LOW** 4.3,4.5,4.7,4.8,7.3, 8.3,8.4,8.5,10.4	**MEDIUM** 9.4,10.1,10.2,10.3,10.5, 11.1,11.3,11.4,11.5,11.9
		LOW	**MEDIUM**	**HIGH**
		Expected impact		

Figure 3: Risk rating matrix

5. Conclusion

A thorough investigation into the safety of industrial liquefied petroleum gas (ILPG) was carried out. Following a literature review and focus group discussions, a risk domain for ILPG was established, comprising 12 primary risk factors and 88 sub factors. The risks associated with these factors were quantified using fuzzy logic. A questionnaire survey with a sample of industry LPG practitioners was conducted to obtain data. The results indicated that critical risk factors for LPG installations in the hotels segment of Sri Lanka include exposed electrical components, flammable gas interaction with electrical circuits, cylinder stacking capacity, improperly installed hazardous electrical equipment, explosion-proof mechanical systems, adequate ventilation, faulty wiring, emergency procedures, adherence to design codes, and the availability of fire extinguishers are the most vulnerable risks, while Gangways between non- palletized stacks, Internal traffic control, Capacity of stacking, Work place exposure monitoring, LPG storage area identification, Accessibility of delivery vehicles to site, Health and safety guidelines, Legal compliance audit and Conducting first aid trainings are least vulnerable risks.

This research addresses the complexities associated with ILPG installations by pinpointing prevalent risks. The findings of this research could be effectively used for taking proactive measures to minimize ILPG accidents in the hotel segment of Sri Lanka.

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