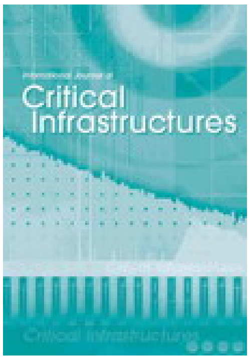


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# Major hazard industries disaster preparedness: an empirical study of liquefied petroleum gas storage facilities

Rasyimawati Mat Rashid, Radin Zaid Radin Umar, Nadiah Ahmad

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# Major hazard industries disaster preparedness: an empirical study of liquefied petroleum gas storage facilities

Rasyimawati Mat Rashid

Fakulti Kejuruteraan Pembuatan,
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia
and
Department of Occupational Safety and Health,
Level 5, Block D4, Complex D,
Federal Government Administrative Centre,
62530 Putrajaya, Malaysia
Email: rasyimawati@mohr.gov.my

Radin Zaid Radin Umar* and Nadiah Ahmad

Fakulti Kejuruteraan Pembuatan,
Centre of Smart System and Innovative Design,
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia
Email: radinzaid@utem.edu.my
Email: nadiah@utem.edu.my
*Corresponding author

**Abstract:** Liquefied petroleum gas (LPG) storage facilities storing more than 50 tonnes of LPG are classified as major hazard installations (MHIs). This industry involves highly flammable hydrocarbon chemicals that can cause destruction of property and endanger human lives. This study aims to investigate the level of disaster preparedness among 23 LPG storage facilities in Malaysia. The preparedness performance of the facilities was assessed through a five-point instrument measure in six preparedness domains. For overall preparedness, 60% of LPG facilities were rated poor or weak, and remaining 40% were rated as good or satisfactory. This indicates a serious gap in the overall current capacity of the majority of facilities to respond to major hazard disasters. Across all facilities, 'risk assessment' was the best performance domain, while the worst was 'emergency exercise'. The findings provide an overview of the level of preparedness that can guide areas of improvement among LPG facilities in Malaysia.

**Keywords**: liquefied petroleum gas; LPG storage; LPG stockist; emergency preparedness; major hazard installation; MHI; control industrial major accident hazards; CIMAH; emergency response plan; ERP; preparedness domain; industrial disaster; Malaysia.

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**Biographical notes:** Rasyimawati Mat Rashid is a Government Officer in the Department of Occupational Safety and Health, Malaysia. She has more than 20 years of experience in enforcement and prosecution activities related to occupational safety and health (OSH) laws in Malaysia. In addition, she provided multiple advisory services to the industry on engineering design for pressured equipment, OSH training centre certifications, and OSH compliances audit. She attended University Sains Malaysia, where she received her Bachelor's in Chemical Engineering. She obtained her Master's in Occupational Health for Safety Professionals from Loughborough University, UK. She is currently a PhD candidate at the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka. Her main research interest is disaster management in major hazard industries.

Radin Zaid Radin Umar is a Senior Lecturer at Universiti Teknikal Malaysia Melaka where he specialises in the area of occupational ergonomics and human factors engineering. His interests are in the area of human-system interactions, human operational performances, and human preparedness. He has more than 12 years of diversified experiences in providing industrial services and contract researches to various multinational companies from different industries and work environments in his area of interests. He obtained his Bachelor's in Mechanical Engineering from University of Wisconsin-Madison, USA, before pursuing hid Master's and PhD Programs in Industrial and Systems Engineering from the Ohio State University, USA.

Nadiah Ahmad is a Senior Lecturer in Manufacturing Engineering Faculty at Universiti Teknikal Malaysia Melaka. Her academic interest is in the integration of human factors and ergonomics into operation management and system optimisation. She has contributed to multiple industry-based projects to assess and optimize safety and work system efficiency. She obtained her Bachelor of Science in Industrial Engineering from University of Wisconsin-Madison, USA and later obtained her Master's and PhD in Industrial and System Engineering from the Ohio State University, USA.

## 1 Introduction

Any facility undertaking industrial activities involving hazardous substances that could potentially lead to a major or catastrophic incident is defined as a major hazard installation (MHI) (DOSH, 1996). In Malaysia, the workplace would be classified as an MHI if the number of hazardous materials stored in its facility exceeded the threshold values set by the Department of Occupational Safety and Health (DOSH), a regulatory body under the purview of the Ministry of Human Resources. The activities of MHI are governed by a set of rules and requirements set out in the Control of Industrial Major Accident Hazards (CIMAH) regulation, which was gazetted by the Malaysian Government in 1996. Examples of companies classified as MHIs include chemical processing plants, water treatment plants, petrochemical plants, insecticide manufacturing plants, and liquefied petroleum gas (LPG) cylinder storage facilities. As of 2016, DOSH identified and categorised a total of 315 workplaces as MHIs (DOSH, 2016).

Major hazard industries have a significant impact on economic contributions to Malaysia. One of the sectors classified as MHI is the oil and gas industry. Industrial activities in the oil and gas industry are synonymous with chemical substances that pose risks to major accident hazards. Main activities include the processing of petrochemical materials, the bottling and packaging of cylinders and gas, the transport of petrochemical products, and the storage of processed products such as LPG. The LPG industry has been established in Malaysia since 1980s (PETRONAS, 2013). The number of LPG cylinder storage facilities has increased significantly in recent years. Only eight LPG cylinder storage locations were identified as MHIs in 2001 (Shaluf and Ahamadun, 2003). However, this number increased to 36 MHIs in 2016, which saw a significant 350% increment in just 15 years (DOSH, 2016). In comparison, there was an approximately two-fold increase (98%) in total designated MHIs over the same span of years, between 2001 and 2016 as shown in Table 1. LPG industry is associated with risks that can cause destruction of property and environmental pollution as well as endanger human life (Jeon, 2014; The High Pressure Gas Safety Institute of Japan, 2016). The operations of the LPG industry involve highly flammable hydrocarbon chemicals. Incorrect handling, processing, and storage of materials in LPG stores can lead to catastrophic consequences. Leaking gas cylinders or tubes, damaged regulators, and improper storage methods of LPG cylinders may lead to major occupational disasters such as jet fire, flash fire, and even explosion (such as boiling liquid expanding vapour explosion – BLEVE) (Manap, 2017; Millo et al., 2008).

**Table 1** The number of MHI based on the types of business operation in Malaysia

| *Types of business operation* | *2001* | *2016* | *Change (%)* |
|---|---|---|---|
| Chemical processing plant | 25 | 30 | +20 |
| Water treatment plant | 22 | 55 | +150 |
| Petrochemical plant | 19 | 28 | +47 |
| Bottling of gas GPC | 12 | 10 | –17 |
| *LPG cylinder storage* | *8* | *36* | *+350* |
| Bulk storage of petroleum products | 23 | 44 | +91 |
| Bulk storage of hazardous material | 11 | 31 | +182 |
| Air separation plant | 5 | 1 | –80 |
| Glove manufacturing | 5 | 20 | +300 |
| Bottling of ammonia gas | 3 | 2 | –34 |
| Insecticide manufacturing | 3 | 4 | +34 |
| Textile manufacturing | 3 | 0 | –100 |
| Others* | 20 | 54 | +170 |
| Total | 159 | 315 | +98 |

Notes: *Others: Warehouse, wood industries, paper industries, gold mining, and fertiliser industries.

*Source:* DOSH (2016) and Shaluf and Ahamadun (2003)

There have been several documented accidents involving LPG storage facilities. For example, Mihailidou et al. (2012) reported the first documented LPG-related explosion in 1979 in Linden, USA. The accident resulted in one fatality, with damage costing a total of USD 17.5 million. In the same publication, the authors reported that one of the worst LPG disasters occurred in 1984, in Mexico City, Mexico. The LPG explosion killed 650 people, with 6,400 more injured. In an analysis of the major accident reporting system in Europe, Nivolianitou et al. (2006) reported that accidents in LPG storage and distribution facilities accounted for about 20% of the total 106 major hazard accidents in the petrochemical industry between 1985 and 2002. In Malaysia, one of the worst major hazard accidents involving LPG storage facilities occurred in Johor State in April 2008 (DOSH, 2019). The accident resulted in three death tolls and significantly damaged the building structure and two distribution lorries located on the premises. In the following year, April 2009 in Klang, Selangor, a fire and explosion accident involving LPG facility occurred again, involving one fatality, one serious burn and four minor injuries (JKKP, 2016). The vibration impact could be felt by the surrounding area up to a radius of three kilometres. The accident caused significant damage to the buildings and distribution vehicles. These past accidents have demonstrated the susceptibility of the LPG storage facilities to major hazard disasters. Consequently, disaster preparedness related activities are crucial to ensuring that the facilities are in the state of readiness to face major hazard disaster, if and when they occur.

One of the disaster preparedness activities is the preparedness audit or evaluation, which examines the processes, strategies, and planning of the host (MHIs) implementation actions in the event of a disaster. It should be noted that the preparedness audit does not focus on the prevention stage, as the main emphasis is the ability of the MHIs to respond once the disaster started. Previous research has considered several aspects of disaster preparedness assessment in major hazard industries. For example, Larken et al. (2001) introduced the emergency management performance indicator risk evaluation framework, which includes seven preparedness evaluation domains:

1. emergency philosophy
2. emergency management structure
3. emergency organisation
4. emergency facilities
5. emergency plans
6. team preparedness
7. site incident potential.

Another study by Jones (2003) used experts to assess the level of preparedness based on eight components:

1. risk identification and analysis
2. human resource management
3. response management
4. organisational learning
5. response assurance
6. definition of requirement
7. training and development
8. research and innovation.

In Malaysia, DOSH has currently adopted a preparedness evaluation method based on six domains:

1 risk assessment
2 organisation
3 emergency equipment
4 preparedness planning
5 emergency exercise
6 training.

The primary purpose of this study is to investigate the level of disaster preparedness among LPG storage facilities in Malaysia. Limited studies have been conducted to summarise the level of preparedness performance of MHIs, particularly among LPG storage facilities. Overview of the overall level of preparedness enables a benchmarking of the preparedness status of LPG storage facilities in Malaysia to deal with potential disasters at the national level. In addition, the study also aims to investigate the level of preparedness of LPG Storage facilities according to specific preparedness domains. Specific preparedness domains can provide guidance and directions for a particular area of improvement from a disaster preparedness point of view.

## 2 Methodology

### *2.1 Overview*

In order to assess the status of disaster preparedness among LPG storage facilities, site audits were selected as the assessment method. A site audit is a part of the occupational safety management system, and considered to be a well-established method widely used in the field of occupational and process safety to determine the risk level of identified hazards (Kent, 2012). The scope of this preparedness audit is in line with Malaysia's CIMAH Regulations 1996, which aim to control the risk of technological disasters caused by hazardous materials. Specifically, the objective of the audit is to review the emergency response plan (ERP) prepared by the LPG Storage facilities, as well as the level of preparedness as described and detailed out in the ERP.

In total, there were 36 LPG storage facilities individually operated private companies in Malaysia. The audit, conducted in five consecutive years between 2011 and 2015 covers a total of 23 different LPG storage facilities, representing a sample size of 64% of the total LPG storage facility population in Malaysia. The LPG storage facilities audited in this study were located in a number of states such as Selangor, Johor, Kedah, Kelantan, Wilayah Persekutuan Kuala Lumpur, Melaka, Negeri Sembilan, Pahang, and Perak. No LPG storage facilities were audited in East Malaysia (Sabah, Sarawak, and Wilayah Persekutuan Labuan) within these five-year study period. The audited LPG storage facility stored all five major gas supplier brands in Malaysia.

The audits were conducted by experienced and trained DOSH officers. The team responsible for managing the audits comes from the major hazard unit of DOSH. Overall, a total of six experienced officers from the unit were involved in the audit process. Each audit team consists of two or three DOSH officers, depending on the size of the operation of the facility. Two officers may audit a small or medium-size operation, while an audit process with larger facility compounds may involve up to three officers. The audit team took approximately one day for each LPG storage facility to carry out an audit assessment. The overall audit process was organised into three phases:

1 pre-audit activities

2 auditing process on-site

3 post-audit activities.

## *2.2 Stage 1: Pre-audit activities*

The process begins with the initial preparation of the audit team prior to the site visit. Potential LPG storage facilities to be audited were identified from DOSH's database, and their priority for selection for audit was based on several criteria:

1 the existing LPG storage facility had never been inspected before

2 the existing LPG storage facility had not been audited for more than three years

3 LPG storage facility that had recently been classified as a major hazard industry

4 the LPG storage facility had prior hazardous material incident case(s).

Selected LPG storage facilities were then contacted by the audit team to set the date of the audit. The selected LPG storage facilities were then instructed to prepare the relevant documents related to their ERP and to submit them to the audit team within 14 days for initial review. The information reviewed by the audit team includes:

1 possible emergency scenarios

2 the emergency response organisation and structure

3 the emergency procedures for each scenario

4 the emergency equipment and systems required for immediate response in the event of a disaster.

## *2.3 Stage 2: The auditing process on site*

The on-site auditing process began with an audit team meeting with key representatives of the LPG storage facility, such as the plant manager, the emergency coordinator, or the safety and health officer. The main representatives were briefed on the purpose, scope, and agenda of the audit. Subsequently, primary representatives were asked to describe their organisation structure and system prior to the start of the audit process. Through active engagements with the key representative, the audit was conducted through a series of inquiries, observation of the workplace, document review, discussion, and on-site verification of preparedness activities as described in the ERP. Throughout the auditing process, the audit team utilises the standard checklist as the main instrument for measures. The checklist included a total of six preparedness domains and twenty-two preparedness indicators, as shown in Table 2. Each preparedness indicator was audited by a standardised five-point rating of the audit team. The rating criteria used by the audit team to determine the score and level of preparedness are summarised in Table 3.

**Table 2** The preparedness domains and elements audited in this study

| *No.* | *Preparedness domain* | *No.* | *Preparedness indicator* |
|---|---|---|---|
| 1 | Risk assessment | 1 | Can the manufacturer identify the initiating events and scenarios that can lead to a major accident? |
| | | 2 | Can the manufacturer estimate the probability, consequence, and risk of a major accident? |
| | | 3 | Are all reasonable measures taken to prevent and mitigate major accident? |
| | | 4 | Can the manufacturer show that human factors have been taken into account in assessing the measures to prevent major accidents and to limit their consequences? |
| | | 5 | Has the manufacturer used adequate criteria to decide the requirement for the prevention, control, and mitigation measures? |
| | | 6 | Have appropriate measures been taken to prevent and effectively contain releases of dangerous substances? |
| 2 | Organisation | 7 | Can the manufacturer describe the Organisation of the emergency response in the event of a major accident and provide evidence that the necessary measures have been taken on-site |
| | | 8 | Have the roles and responsibilities of personnel involved in the management of major hazards been clearly defined, at all levels in the Organisation? |
| | | 9 | Can the manufacturer provide evidence that sufficient personnel (emergency team) can be made available within appropriate timescales to carry out the mitigatory actions required by the internal emergency plans; |
| | | 10 | Are sufficient resources (people, money, and facilities) available to implement the manufacturer's activities to prevent major accidents effectively? |
| 3 | Emergency equipment | 11 | Can the manufacturer show that an appropriate (preventive) maintenance scheme is established for all safety-critical installations and systems to prevent major accidents or limit their consequences, in particular for at least the safety-related control, alarm systems and domains and leak detection systems; |
| | | 12 | Can the manufacturer show that an appropriate (preventive) maintenance scheme is established for all safety-critical installations and systems to prevent major accidents or limit their consequences, in particular for at least the relief, vent systems, pressure systems, and other containment tanks for dangerous substances? |
| | | 13 | Can the manufacturer show that safety-critical plant and systems are examined and tested at appropriate intervals by a proper person with the necessary competence? |
| | | 14 | Are there established procedures that are required for maintenance being performed on emergency equipment, vessels, and piping containing hazardous materials? |
| | | 15 | Can the manufacturer demonstrate that, where relevant, suitable and sufficient provision has been made for monitoring wind speed and direction, and other environmental conditions, in the event of a major accident |
| | | 16 | Can the manufacturer provide evidence that suitable arrangements have been made for the maintenance, inspection, examination, and testing of the mobilisable resources and other emergency equipment to be used during the emergency response |

**Table 2** The preparedness domains and elements audited in this study (continued)

| *No.* | *Preparedness domain* | *No.* | *Preparedness indicator* |
|---|---|---|---|
| 4 | Preparedness planning | 17 | Can the manufacturer provide evidence that there is an emergency plan in writing to address all possible emergencies for all major accident scenarios |
| | | 18 | Can the manufacturer provide evidence that suitable and sufficient provisions have been made for coordination and communications during the emergency response; |
| | | 19 | Have the manufacturer-supplied information to outside services and Organisations to enable the external help and emergency plan to be activated and effectively implemented |
| 5 | Emergency exercise | 20 | Can the manufacturer provide evidence that procedures have been made and adopted to test and review emergency plans; |
| 6 | Training | 21 | Can the manufacturer show that training needs to prevent major accidents are identified and that such training is provided? |
| | | 22 | Can the manufacturer provide evidence that suitable arrangements have been made in the safety management system for the training of individuals on-site in the emergency response |

**Table 3** The criteria uses to determine score rating and level of preparedness for each preparedness indicator

| *Score rating* | *Level* | *Criteria for scoring* |
|---|---|---|
| 1 | Unsatisfactory | Nothing was done to date, or some attempt made but no effective implementation. |
| 2 | Poor | Only partially effective – there is room for improvement. |
| 3 | Fair | Implemented, but not wholly satisfactory. |
| 4 | Good | Satisfactory implemented and effective. Meet legal requirement. |
| 5 | Excellent | Fully implemented and effective and exceeds the legal requirement. |

The audit walkthrough concludes with a discussion on preliminary audit results between the audit team and key representatives of the LPG storage facility. Potential improvements within the scope of audits were provided, where applicable. Depending on the risk severity and current level of preparedness of each indicator, the audit team may issue a notice of improvement or even a notice of prohibition, if the level of preparedness is considered to be inadequate or insufficient. The level of preparedness audited by each indicator indirectly indicates the level of compliance with CIMAH Regulations 1996.

## *2.4 Stage 3: The post-audit activities*

The audit team conducted post-audit analyses on the basis of data collected during the site visit. Two types of analyses performed were based on:

1 the overall grade of LPG storage facility preparedness

2 the grade of specific preparedness domains.

Both analyses were obtained from the processing of the 22 preparedness indicators obtained during the site visit.

In order to obtain the overall level of preparedness of the individual LPG storage facility, each score was counted from a single preparedness indicator, divided by a total denominator of indicators (22 indicators × 5 score points = 110 total points), and multiplied by 100 to get an overall percentage. The overall preparedness percentage of the score formula is:

$$\text{LPG cylinder storage overall preparednesspercentage score} = \frac{\sum \text{indicator score rating}_i \times 100\%}{n_i} \tag{1}$$

where

*i* the score rating for each preparedness indicator

*n* the total preparedness indicators dominator (110).

where *i* is the score rating for each preparedness indicator and $n_i$ is the total preparedness indicator dominator (110). The study classifies the overall disaster preparedness grading performance into five levels, as shown in Table 4.

**Table 4** The LPG cylinder storage overall grading performance

| *Performance grade* | *A* | *B* | *C* | *D* | *E* |
|---|---|---|---|---|---|
| Score | 90%–100% | 80%–89% | 70%–79% | 60%–69% | 0%–59% |
| Performance level description | Excellent | Good | Satisfactory | Weak | Poor |

In addition to LPG storage facility overall preparedness grading, data were also organised based on the six specific preparedness domains. Each domain was linked to several preparedness indicators (except emergency exercise, which only have one indicator). As such, each score rating from the individual preparedness indicator were counted and averaged within the cluster of each domain. The average performance score of each indicator is a preparedness rating based on specific domain categories. Performance average scores can be interpreted using the same level and criteria as described in Table 3.

## 3 Result

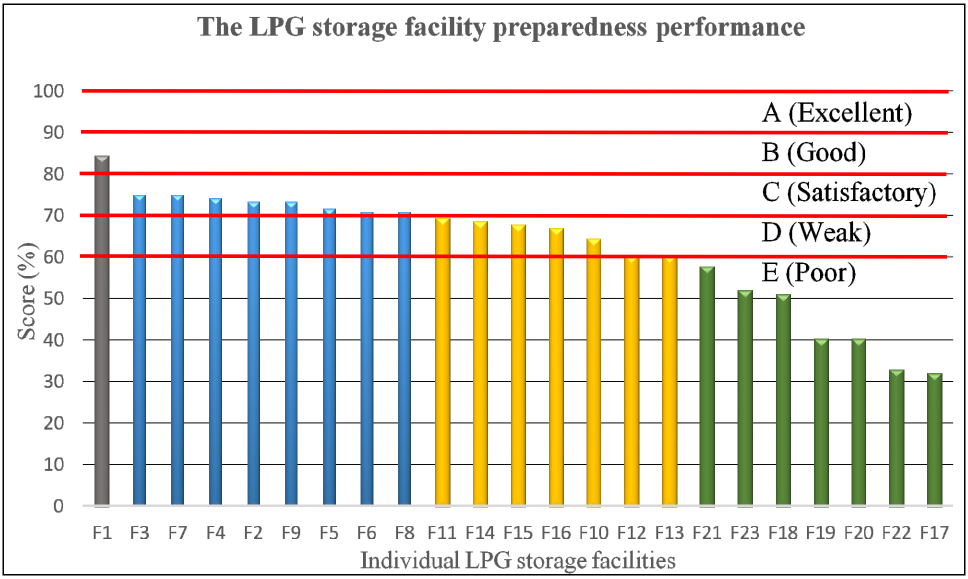
The LPG demographic data for 23 LPG storage facilities are shown in Table 5. The sampling location of the organisation applies only to the peninsular of Malaysia. The state of Selangor has the highest sample (44% of the sample population), followed by Perak (18%) and Johor (14%). It was found that the LPG storage facility consisted of a minimum of five personnel. The majority of the LPG storage facility (n = 14) has employees ranging from 11 to 30 people. In addition, the majority of LPG storage facilities (82%) have been in operation for more than 10 years, with two installations operating for more than 30 years. Most of the facilities (74%) are privately run by family businesses.

**Table 5** Profile of organisations

| *Demographic variables* | *Category* | *Frequency (n = 23)* | *Percentage (%)* |
|---|---|---|---|
| State location | Selangor | 10 | 44 |
| | Perak | 4 | 18 |
| | Johor | 3 | 14 |
| | Kedah | 1 | 4 |
| | WP Kuala Lumpur | 1 | 4 |
| | Negeri Sembilan | 1 | 4 |
| | Melaka | 1 | 4 |
| | Pahang | 1 | 4 |
| | Kelantan | 1 | 4 |
| No. of employees | 1–10 | 4 | 17 |
| | 11–20 | 7 | 30 |
| | 21–30 | 7 | 30 |
| | 31–40 | 5 | 22 |
| Years in business | 1–10 | 8 | 35 |
| | 11–20 | 9 | 39 |
| | 21–30 | 4 | 17 |
| | more than 31 | 2 | 9 |
| Ownership | Family business | 17 | 74 |
| | Non-family business | 6 | 26 |

The data analysed in the auditing process reveals the distributed overall rating performance among the 23 LPG storage facilities. It was found that none of the LPG storage facilities received grade A (excellent), and only one storage facility (5%) received grade B (good). Eight LPG storage facilities (35%) were rated as C grade (satisfactory) in terms of their level of preparedness, while seven storage facilities (30%) were rated as weak (D grade) in terms of their level of disaster preparedness. Unfortunately, the remaining seven LPG storage facilities (30%) were rated as E (poor). Overall, the majority of the LPG storage facilities (60%) audited were considered either poor or weak in terms of their disaster level of disaster preparedness, indicating a serious gap in the current capability and capacity of LPG storage facilities to respond to disasters, if and when they occur. The overall grades of preparedness performance for individual LPG storage facilities are summarised in Figure 1.

**Figure 1** Overall grades of preparedness performance for individual LPG storage facilities (see online version for colours)

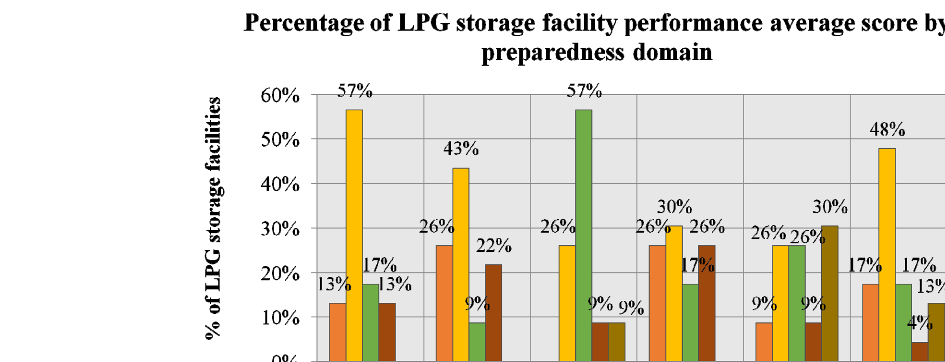



Further analysis of the data for categorising the level of preparedness of LPG storage facilities by six specific domains also shows the distribution of results across 23 audited LPG storage facilities. Each of the preparedness domains was given an average score ranging from 1 (unsatisfactory) to 5 (excellent) to indicate the level of preparedness of the LPG storage facilities in that domain. The total LPG storage facilities preparedness performance score, sorted by preparedness domains, is summarised in Figure 2.

The first domain of preparedness is ‘risk assessment,’ where it was found that LPG storage facilities generally did well, as 70% of storage facilities were rated either good or excellent, and none of the LPG storage facilities was rated to be unsatisfactory. This indicates that, in general, LPG storage facilities have carried out an appropriate level of risk assessment activities to identify and assess risks of potential hazards that could lead to disasters within the storage facility. Similarly, it was found that the ‘organisation’ preparedness domain was also highly rated, with 69% of LPG storage facilities rated either good or excellent levels. However, 22% of the LPG storage facilities were classified as ‘poor,’ indicating that the organisational structures, roles, and responsibilities of personnel, and resources were not well prepared. In the domain of ‘emergency equipment’, the majority of LPG storage facilities (57%) were rated as fair in terms of their level of preparedness. LPG storage facilities rated to be at a good level consisted of 27% of the sample population, while 18% were rated either poor or unsatisfactory. One of the most striking findings is that more than 50% of LPG storage facilities have been found to have inadequate emergency equipment or tools to monitor the wind directions, although their work compounds are susceptible to the risk of fire and toxic release. The next preparedness domain is ‘planning’, in which 56% were audited to be either good or excellent, while the rest (46%) were rated at fair or poor levels. The ‘exercise’ domain has shown that the highest population of LPG storage facilities (30%)

to be graded is not satisfactory. The audit team found that these LPG storage facilities were unable to provide evidence that their ERPs had been simulated or implemented. On the other hand, 35% of the storage facilities were considered to be either excellent or good. The last domain is ‘training,’ in which 65% of the LPG storage facilities were rated as either good or excellent, while the rest were considered to be either fair, poor, or unsatisfactory in terms of their performance audit score.

**Figure 2** Performance of average score of LPG storage facilities, sorted by specific preparedness domain (see online version for colours)




| Performance ave. score for LPG storage facility | Risk assessment | Organization | Equipment | Planning | Exercise | Training |
|---|---|---|---|---|---|---|
| Between 4 to 5 (excellent) | 13% | 26% | 0% | 26% | 9% | 17% |
| Between 3 to 4 (good) | 57% | 43% | 26% | 30% | 26% | 48% |
| Between 2 to 3 (fair) | 17% | 9% | 57% | 17% | 26% | 17% |
| Between 1 to 2 (poor) | 13% | 22% | 9% | 26% | 9% | 4% |
| Between 0 to 1 (unsatisfactory) | 0% | 0% | 9% | 0% | 30% | 13% |

## 4 Discussion

The most prominent finding to emerge from this study is that the majority of the LPG storage facility (60%) audited were graded either in D or E levels, indicating either weak or poor overall preparedness performances. This is an alarming finding as it indicates that the majority of these LPG related MHIs are not considered ready if and when a major hazard disaster occurs. One of the possible explanations for the overall low level of preparedness is that LPG related emergencies rarely occur, and these audited MHIs do not have any first-hand experience of a major hazard disaster at their facility. The preparedness audit process was conducted through the evaluation of six domains which are:

1 risk assessment

2 organisation

3 emergency equipment

4 preparedness planning

5 emergency exercise

6 training.

As such, the following contents of the discussion will be organised on the basis of these domains.

### *4.1 Risk assessment domain*

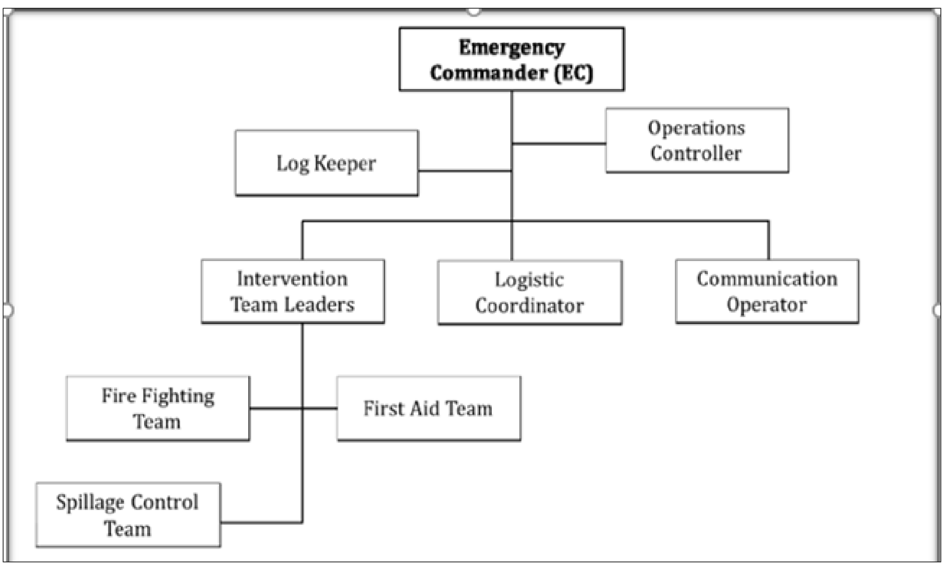
Risk assessment has been identified as one of the indicators in the frameworks for preparedness evaluation (Larken et al., 2001; NFPA, 2013; Simpson, 2008). The risk assessment process can identify potential hazards, as well as the likely outcome of a catastrophic event. Risk assessment and analysis should be the basis for decision making covering planning, budgeting, training, exercises, and other components related to general safety (Vidali et al., 2011). In addition, the risk assessment allows the authoritative bodies to determine the acceptable or tolerable risk level of a program being assessed (OECD, 2003).

The CIMAH Regulations specifically require MHIs to conduct risk assessments as part of their industrial activities reporting to the authority. As such, the efforts to comply with the CIMAH Regulations could explain a good overall score of the 'risk assessment' preparedness domain among LPG storage facilities, where 70% of LPG storage facilities were rated to be either good or excellent level. This indicates that most LPG storage facilities are aware of and have acknowledged the need to conduct a risk assessment at their facilities. However, the remaining 30% of LPG storage facilities were rated either fair or poor in terms of their preparedness from a risk assessment point of view. Although these storage facilities have met the minimum requirement to carry out a risk assessment, their assessments have not been ranked to be satisfactory, particularly as regards to the mitigation measure component to control identified risks. For example, although some storage facilities identified gas leakage as a risk, the auditors found that some had not installed adequate gas detectors in their facilities. Another example is a lack of clear protection processes or procedures to be separated between fully working cylinders and those with cap damage in a tight space area. Information on mitigation measures to control identified risks is part of the comprehensiveness of the risk assessment. Risk mitigation measures include, but are not limited to controlling the storage quantity of hazardous materials, isolating high-risk hazardous areas, labelling of hazardous material, and communicating risk management strategies to communities around the facility (Lewis and Payant, 2003).

### *4.2 Organisation domain*

Mitigation actions require organisations to develop comprehensive planning and strategies for controlling the potentials of major hazards at the workplace. 'Organisation' preparedness is one of the domains evaluated to measure the level of emergency preparedness (Larken et al., 2001; Shaluf and Ahamadun, 2006). In particular, this domain examines the commitment of management team to provide the necessary resources to ensure that the facility is ready to respond to major hazard disasters. This organisation's preparedness includes the adequacy of the human resources, facilities, and budgets needed to maintain the level of readiness. One of the main objectives of the organisation's domain is to examine the organisational structure of the emergency team, as well as the role and scope of each member to enable effective emergency response actions to take place. The emergency response team is an important component in responding to a disaster, as it is the first line of defence prior to and during a major hazard incident. The emergency response team should be made up of members trained in specific tasks such as search and rescue, emergency aid, and logistics management. However, the composition of the emergency team varies depending on the types of industry, types of hazards, and the total available workforce. The basic structure of the organisation for emergency response suggested by DOSH (2016) is shown in Figure 3.

**Figure 3** Recommended composition and structure of emergency response team




*Source:* DOSH (2016)

Similar to the 'risk assessment' preparedness domain, the majority of the LPG storage facilities audited generally did well, as approximately 70% of them were rated good or excellent in the 'organisation' preparedness domain. It was interesting to discover that all storage facilities ranked fair or poor in this domain (approximately 30% of the study population) were found to be a family-based business model. Among these business entities, it was found that the employees were made up of family members. There have been duplicates of names that cover different functions and scopes of emergency response tasks. The auditors were concerned that the names duplicates would not allow the effective execution of emergency response tasks during the occurrence of a major accident. Furthermore, low-grade storage facilities in the organisation preparedness domain have been found to have a poor documentation system of their past training, exercise, and internal audit data related to major hazard emergency response activities.

## *4.3 Emergency equipment domain*

Emergency equipment is essential to enable the emergency response team to respond effectively in the event of an emergency. Adequate and reliable emergency equipment that is ready to be used at any given time significantly contributes to the level of preparedness of MHI. The domain of emergency equipment was adopted as one of the evaluation criteria in the preparedness model by Sutton and Tierney (2006).

Several major hazard disaster case studies have been conducted which may be linked to the preparedness of emergency equipment. For example, the Deepwater Horizon offshore explosion in 2010 in the Gulf of Mexico which resulted in the fatalities of 11 employees provides a case study indicating few failures on emergency equipment when responding to the disaster. Post-accident investigations found that equipment issues related to heat insulations, emergency lighting, and rescue boats could be linked to the lack of periodic inspection and testing (Norazahar et al., 2014). In another case study, investigators also reported similar issues related to emergency equipment when investigating the 'Choon Hong III' chemical tanker explosion at Port Klang, Malaysia, in 1992. The accident resulted in 13 casualties and 400 tons of Xylene were discharged. Emergency respondents found that the firefighting equipment was not sufficient, in addition to not functioning properly (Said and Ahmadun, 2017). Another case study associated with equipment preparedness was the chlorine gas release accident in 2002's DPC enterprise plant near Festus, Missouri, USA. An investigation into the accident revealed that the location and accessibility of emergency equipment were one of the factors contributing to the ineffective control of the situation as soon as the disaster began (Majid et al., 2016). The ineffective response to the accident resulted in the release of 48,000 pounds of chlorine, which resulted in 3 workers and 63 residents seeking medical treatment.

In an emergency preparedness handbook, Lewis and Payant (2003) have comprehensively categorised different types of emergency equipment based on their functions in an emergency occurrence. The first category is detector equipment that detects hazardous material in the atmosphere such as gas detectors and smoke detectors. The second category is safety control equipment such as high-pressure alarm sensors, high-temperature alarm sensors, or non-explosive light. The facility also needs firefighting equipment to control fire hazards such as fire extinguishers or fire hydrants. In addition, search and rescue equipment, such as a fire entry suit, is also critical in enabling the response team to enter the danger zone for search and rescue tasks. Another category of equipment is medical assistance to be used by first-aid workers to perform initial treatment for injured survivors, while on-site professional medical assistance is provided. Examples of equipment a stretcher and first aid box. The handbook also mentions the need for communication equipment and tools to facilitate effective communications between the emergency response team and other stakeholders, such as walkie-talkie or speaker. Finally, each facility is required to provide appropriate personal protective equipment to provide some protection against hazard exposure while workers are evacuating to safe zones. Examples of personal protective equipment are fire retardants clothing and respirators.

The current study found that the majority of the LPG storage facilities in this study (75%) were either rated as fair, poor, or unsatisfactory in the domain of preparedness for their equipment. The auditors identified several issues related to the preparedness of emergency equipment. The first issue is the availability of detector equipment, which must be inspected periodically. An example of this is the alarm sound, which must be verified periodically to be at the specified frequency, audio level, and coverage areas in order to alert employees when activated. The second issue concerns proper calibration and maintenance of safety control equipment, such as pressure gauges and safety relief valves. Another common issue identified by the auditors involves the proper installation of the windsock. A windsock is a flag-like object installed at the highest point on-site for ease of visibility. It allows emergency responders to monitor wind speed and direction during firefighting and to set up an assembly point as safe zones. It was concerning that 43% of LPG storage facilities either did not have windsock installed or had their windsock in a poor condition (damaged due to wear and tear or poor maintenance). The fourth issue recorded by the auditors is the inadequacy of search and rescue as well as personal protective equipment such as breathing apparatus. Adequate numbers of sets must be readily available, depending on the size of the facility and staff. Other general preparedness issues are:

1 availability of records on emergency equipment being tested to ensure its acceptable working condition

2 evidences on the level of competence of the response team.

Maintaining the level of competence has been identified as a particular issue for facilities with a high turnover rate for workers. Workers who have achieved certain competency to operate specific emergency equipment may have resigned, and there might been a challenge to find competent replacement. As a result, certain emergency equipment becomes a 'white elephant' that is readily available but lacks workers who are competent to operate it in the event of a disaster. All of these issues provide an interesting insight into the complexities of preparedness for emergency equipment, as there are multiple factors to be considered by different stakeholders. A review of pieces of the literature revealed a gap in the consensus gold standard instrument for collecting and evaluating the preparedness of emergency equipment in major hazard sectors.

### *4.4 Preparedness planning domain*

Emergency practitioners and researchers use different technical terms for emergency preparedness such as pre-incident planning (FEMA, 2006; Nwabueze, 2016), crisis planning (Quarantelli, 2005), pre-emergency planning (O'Brien, 2008), ERP (Shaluf and Ahamadun, 2003; Shi et al., 2012; Tang and Shen, 2015) and emergency operational planning (FEMA, 1996). All these terms denote a similar concept of pre-event planning activities, whether anticipated or unforeseen. Preparedness planning intends to anticipate action during a disastrous event by optimising resources through a rigorous procedure (Gustin, 2003; Thomas and Larry, 2001).

Typically, ERP can be conducted once the information about the hazard is known. ERP prerequisites include comprehensive risk analysis with a risk contour, designated personnel involvement, and predetermined steps or emergency procedures based on projected disaster scenarios. The content of emergency planning has attracted many researchers to come up with the content of emergency planning evaluation tools (Quarantelli, 1997; Shamim et al., 2019). These tools examine specific indicators for ERP activities such as the activation and operation of the emergency response team, communication, information management, coordination of resources, and response task activity (DEMA, 2009). Another study by Shamim et al. (2019) found that the components of ERP include the availability of procedures, evaluation of procedural compliance, training, readiness of preventive measures, and emergency management system.

In Malaysia, the requirement for an ERP for designated MHI facilities has been documented in the 1996's CIMAH regulations. The ERP is a formal document summarising the facility's action plan in preparation for major hazard occurrences. The contents of the document include:

1 detailed procedures for the response activities

2 the names of the persons involved in the emergency team

3 the name of the management representative who can decide on response activities.

Due to a specific requirement to have an ERP under the CIMAH Regulations, all the facilities audited in this study provided an ERP document to the auditors during the audit process. In comparison, previous study by Shaluf and Ahamadun (2006) reported that 20% of their population study of Malaysian MHIs (n = 177) could not provide records of the ERP. This can be seen as a general improvement in the country's preparedness level.

More than half (56%) of LPG storage facilities were rated as either good or excellent in terms of their ERP preparedness domain. The remaining 43% of LPG storage facilities classified as fair or poor were found to have few similar issues in terms of generating different disaster scenarios, providing adequate coordination or communication plans, and showing evidence of engagement plan with external stakeholders such as local communities and external emergency authorities. Other issues related to this domain include a lack of periodic review of ERP, which resulted in an outdated document. Assigned personnel in the ERP document may have left employment in the ERP document, or the procedures for new emergency equipment procured may not be included in the ERP document that was audited.

Moreover, it was found that the ERP was well communicated to the emergency response team, but not to all employees within the facility's compound. This resulted in a concern about how the ERP looks good only on paper. The issue of how to disseminate the ERP to all relevant stakeholders that will be affected in the event of a disaster needs to be addressed. In addition, there is also complexities involved in the synchronisation of external response teams that may not be privy to specific strategies developed in the ERP. These implementation challenges provide actual gaps to be corrected post audit session.

According to CIMAH Regulations 1996, the ERP must be developed by a DOSH-approved competent person at high risk. Competent persons are usually third-party consultants assigned by MHIs to in-house specialists. There is currently limited information on the registration trends and overseeing the status of these practitioners. Since the ERP has to be developed by DOSH-approved competent persons, further studies and investigations focusing on learning lessons, challenges, and barriers may provide a deeper insight into how this domain of preparedness planning can be further improved in the future.

## *4.5 Emergency exercise domain*

Although ERP is a key component of MHI's preparedness effort, the preparation components remain to be theoretical on paper. In order to further evaluate the level of preparedness of MHI, the ERP needs to be implemented through preparedness exercise. [McEntire, (2015), p.478] defines emergency exercise as "a simulation of a crisis or disaster or emergency that has the goal of improving response and recovery operations in an actual event". Emergency exercise is therefore designed to test the response and capabilities of the emergency response team to follow through the ERP by simulating the critical response activities required in the occurrence of a disaster (DEMA, 2009). The emergency exercise is intended, among others, to evaluate the understanding and competence of the emergency response team on the response tasks, procedures, communication, and proper use of emergency equipment (Jones, 2003). An empirical study shows that effective emergency exercise can reduce the response time by 10%–20%, and therefore increase the survival rate to 1%–2.5% (Rodriruez et al., 2007). If carried out properly, emergency exercise can boost the confidence level of the emergency response team and increase their overall level of preparedness to deal with major hazards at the workplace (Skryabina et al., 2017).

Despite the importance of an emergency exercise, this study found that 30% (n = 7) of LPG storage facilities were unable to provide evidence of emergency exercise conducted at their facility. One of the possible explanations for this is that there are no specific provision for emergency exercise under the CIMAH Regulations 1996, unlike other emergency preparedness activities such as risk assessment or ERP. Another underlying rationale discovered by the audit team was that the implementation of a large scale emergency exercise would likely to interfere with business activities, and will directly affect the bottom-line of their organisation. The LPG storage facilities which have not carried out an emergency exercise, also report challenges of setting a schedule for conducting an emergency exercise with the full involvement of external emergency authorities such as local firefighting, police, and healthcare organisations. Finally, emergency exercise involves an additional budget to be implemented, which was been identified as a major challenge, especially for small and medium-sized industries such as LPG storage facilities.

One of the interesting trends in this audit is that although 100% of MHIs have an ERP, 70% of the sample size has conducted some level of emergency exercise. In contrast, a study by Matheny (2012) on local community preparedness in Ohio, USA found that emergency exercise was the 'most compliance' domain, although 23.2% of the sample study population did not have ERP. This indicates that emergency exercises can be conducted even without ERP (DEMA, 2009). Another interesting trend identified by the auditors is the lack of emergency scenarios used in the exercise activities of the LPG storage facilities. Emergency exercises that simulate multiple scenarios are seen to be advantageous because they provide each person with exposure to the response tasks (Skryabina et al., 2017). Lastly, another common trend found was that most MHIs conducted post-mortem analysis of their exercises. However, the auditors found that the contents of the post-mortem discovery had not been included among many MHIs in the next emergency exercise rounds. This is a significant trend, as it indicates a lack of continuity between exercises, as lessons learned have not been captured and integrated as a continuous improvement approach to preparedness activities.

## *4.6 Emergency training domain*

Another important component of major disaster preparedness concerns the awareness and competence of employees to act accordingly in the event of a disaster. Emergency training has been identified as one of the leading domains for disaster preparedness by several researchers (Pelfrey, 2005; Renschler et al., 2016). It is an activity that provides information, enhances knowledge, and builds the skills of people who may be harmed by hazardous materials in the workplace (EPA et al., 1987; Hardy and Roberts, 2003). Emergency training provides a linkage between planning and response action.

Emergency training is the door of information to survival, where all emergency know-how would be delivered to all employees. The employees involved in emergency training can be categorised into different groups, such as first responders responsible for disaster response activities, the decision-maker management group, and employees in need of safety zone guidance. Pinkowski et al. (2008) in their handbook on disaster management emphasised that emergency training needs to be tailored to the specific target group. Thus, the type of emergency training may therefore differ on the basis of the specific roles and responsibilities of the workers.

Quantity and quality of emergency training can directly affect the effectiveness of response activities. In a disaster and recovery guide for facility managers, Gustin (2007) recommends that emergency training are to be conducted on an annual basis or if there are any new changes made to the preparedness plan, equipment, and procedures. The contents of training should include information such as:

1 individual roles and responsibilities
2 information about threats, hazards, and protective actions
3 notification, warning, and communications procedures
4 responsibility of family members in emergencies
5 disaster/emergency response procedures
6 evacuation, shelter and accountability procedures
7 location and use of common emergency equipment
8 disaster/emergency shutdown procedures.

Emergency training may also point out new concerns that can be integrated and updated into the organisation's ERP.

Nevertheless, 21% of the LPG storage facilities were poorly rated in emergency training domain during the audit process. The auditors found that the common issue revolves around the management of emergency training. For example, some LPG storage facilities claimed that they had sent their employees to attend emergency training, but there were no records or evidences available during the audit process. Another issue in these poorly rated facilities is that their trained employees have been assigned specific emergency training roles and scopes, but have not been appointed to carry out responsibilities relevant to the training they attended at their workplace. Similar to emergency exercise, there was no specific provision under CIMAH Regulations 1996 that specifically requires MHIs to conduct emergency training, which may explain why 13% of LPG storage facilities did not conduct training in their facilities. The lack of budget, awareness, and commitment from the top management was also among the other reasons given among those LPG facilities with poor rating in this domain.

## 5 Conclusions

This study provides an overview of the level of preparedness performance among Malaysian LPG storage facilities at the national level. LPG business is considered to be one of the fastest-growing sectors under major hazard industries, which is governed by CIMAH Regulations 1996. Overall, the majority of the LPG storage facilities (60%) audited were rated to be either poor or weak in terms of their overall disaster preparedness level. The remaining 40% were rated as good or satisfactory, while none of the storage facilities was rated as excellent overall across all preparedness domains. The findings indicate a serious gap in terms of the overall current capability and capacity of LPG storage facilities to respond to major hazard disasters in their facilities. LPG storage facilities have generally done well in the areas of 'risk assessment', 'organisation', 'training', and emergency planning. The data shows that 70%, 69%, 65% and 56% of the population of storage facilities rated either good or excellent levels in these respective domains. On the other hand, only 35% and 26% of LPG's stockholders were found to be good or excellent in the 'emergency exercise' and 'equipment' domains. The audit also shows that the emergency exercise domain was the worst, as 39% of LPG storage facilities were rated to be poor or unsatisfactory. This is followed by planning and organisation domains, where 26% and 22% of LPG storage facilities were rated as poor or unsatisfactory. The results can be considered as one of the first documented benchmarks on the overall readiness of LPG storage facilities in Malaysia to face potential major hazard disaster. The overall disaster preparedness grades, as well as specific preparedness domains ratings provide a glimpse of the LPG facilities preparedness performance level as well as guidance and direction for specific areas of improvement from a disaster preparedness point of view.

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