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- Publishes original research reports, topical article reviews, book reviews, case reports, short communications, invited editorial and letter to editor.
- Welcomes articles in occupational safety and health related fields.

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Contents

Introducing the Journal of Occupational Safety and Health

The National Institute of Occupational Safety and Health (NIOSH), Malaysia is delighted to announce the publication of Journal of Occupational Safety and Health (JOSH).

JOSH is devoted to enhancing the knowledge and practice of occupational safety and health by widely disseminating research articles and applied studies of highest quality.

JOSH provides a solid base to bridge the issues and concerns related to occupational safety and health. JOSH offers scholarly, peer-reviewed articles, including correspondence, regular papers, articles and short reports, announcements and etc.

It is intended that this journal should serve the OSH community, practitioners, students and public while providing vital information for the promotion of workplace health and safety.

Apart from that JOSH aims:

• To promote debate and discussion on practical and theoretical aspects of OSH

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• To inform OSH practitioners and students of current issues

JOSH is poised to become an essential resource in our efforts to promote and protect the safety and health of workers.

From the Chief Executive Editor

In this edition, a research article studied the Evaluation of Occupational Safety and Health (OSH) Compliance among Ice Industry Operating using Ammonia Ice Refrigeration System in Selangor. This study's primary focal point is to investigate the lack of awareness regarding the use of ammonia in the ice-manufacturing industry. Furthermore, it aims to assist statutory authorities and the ice manufacturing industry by recommending the best practices and approaches to OSH compliance.

The article highlights the need for more awareness alongside low OSH compliance when using ammonia in the ice manufacturing industry. This validates the act of proposing a novel audit checklist for assessing non-compliant ice manufacturing companies that are under the jurisdiction of the Control of Industrial Major Accident Hazard regulations. The study's findings conclude that the level of OSH compliance is indeed low and insufficient knowledge regarding risk assessment, ineffective OSH practices and approaches, and poor implementation of safe operating procedures contribute to low compliance

This research recommends considering relevant risk assessment tools based on hazard identification, risk assessment, and risk control processes in legislation or industrial codes of practice to mitigate further misconduct concerning the use of ammonia in the industry.

This paper supplied various insightful points regarding the lack of understanding of ammonia usage among workers despite the field of research being 55 respondents in 14 selected ice-manufacturing companies in Selangor, Malaysia. The study still makes a valid argument while providing sufficient evidence to support its claims.

I eagerly anticipate more similar research studies as a more diverse array of perspectives contributed by individuals at all levels across various industries will ultimately further enhance the improvement of OSH risk management practices and foster safer and compliant work environments. Therefore, we should all remain resolute in preserving the spirit of exploration, diligently monitoring changes in circumstances, and embracing adaptation for continuous improvement.

Haji Ayop Salleh
Chief Executive Editor

Original Article

Evaluation of Occupational Safety and Health (OSH) Compliance among Ice Industry Operating using Ammonia Ice Refrigeration System in Selangor

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ABSTRACT: *Most ice plants in the refrigeration industry use ammonia as a coolant in their refrigeration systems. Ammonia is hazardous and toxic. Ammonia release events have been alarming in the past few years and persist regardless of numerous inspections and audits. Therefore, by investigating the lack of awareness about ammonia use, this study aims to assist the relevant statutory authorities and the ice-manufacturing industry in recommending best practices in and approaches to occupational safety and health (OSH) compliance among ice plants, in accordance with the Occupational Safety and Health Act 1994. This study also proposes a novel audit checklist for assessing companies in the not-to-comply category under the Control of Industrial Major Accident Hazard regulations introduced in 1996. The survey involved distributing questionnaires to 55 respondents in 14 selected ice-manufacturing companies located in Selangor, Malaysia, and the results obtained were analysed using the Statistical Package for Social Sciences statistical software. The results indicated that the level of OSH compliance in ice plants is low. The results were attributed to inadequate OSH knowledge regarding risk assessment, ineffective OSH practices and approaches, and the poor implementation of safe operating procedures. Therefore, relevant risk assessment tools, specifically those based on the hazard identification, risk assessment and risk control process, should be considered in the legislation or regulation of the industrial code of practice or the non-major hazard installation (NMHI) audit checklist. New guidelines regarding ammonia use should be developed and implemented, and OSH training should be conducted based on an emergency response plan. As a recommendation, the Department of Occupational Safety and Health, Malaysia, should implement safe operating procedures throughout the ice-manufacturing industry by ensuring that ice plants are upgraded to the NMHI category through administrative orders.*

Keywords: *OSH Compliance, Risk Assessment, Safe Operating Procedures, Training.*

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1.0 INTRODUCTION

In Malaysia's ice-manufacturing industry, most ammonia leakage incidents occur in ice plants. Consequently, numerous inspections and audits have been conducted. According to the control of industrial major accident hazard (CIMAH) regulations introduced in 1996, every manufacturing company that uses chemical substances, including ice-manufacturing companies, must submit the notification of industrial activity form, as specified in Schedule 5 (JKKP 5), to determine whether such companies fall under major hazard installation (MHI), non-major hazard installation (NMHI), or not-to-comply (NTC) categories. Most ice-manufacturing companies fall under the NTC category because their threshold quantity of ammonia falls below the requirement (100 tons) for the MHI category and below 10% of the threshold quantity (10 tons) for the NMHI category.

Two main frameworks have been employed to evaluate the levels of occupational safety and health (OSH) compliance: workers' safety practices and human resource practices. The five aspects of discussion under workers' safety practices are as follows: (1) OSH compliance in the ice-manufacturing industry; ensuring comprehensive safety practices according to OSH compliance guidelines regarding the ice-manufacturing industry involves addressing industry-specific hazards related to ice production, storage, and transportation, while implementing broader occupational safety measures to protect workers from accidents and injuries, (2) OSH Awareness; the management should make use of the most suitable form of employee participation to facilitate cooperation between them and their employees, thereby enhancing OSH in the workplace (Surienty et al., 2011), (3) Attitude and Compliance; throughout their work activities, employers should ensure that occupational accidents and injuries in the workplace are avoided by complying with safety standards, procedures, and regulations (Reinhold et al., 2015), (4) Procedure and Process; according to the safety management perspective, occupational accidents primarily result from human error (Bottani et al., 2009), which can be reduced when employers set up proper safety systems (Gordon et al., 2005), (5) OSH Assessment and Evaluation; evaluation of performance may be defined as the process of quantifying the effectiveness of actions (Neely et al., 2005).

Regarding human resource practices, three pivotal elements are considered, as follows: (1) Supervisory Support; the cornerstone of achieving excellence in OSH compliance lies in robust supervisory support throughout the organisational hierarchy. The positive impact of effective supervisory support resonates with enhanced employee satisfaction and performance, as documented by Gottlieb et al. (2003) and Gagnon and Michael (2004), (2) Management Commitment; attaining OSH objectives necessitates active involvement and commitment from the management, as emphasised by Cooper (2006). Management commitment is instrumental in steering an organisation towards a culture of safety and health, (3) Safety Training; safety training is imperative in any workplace. The absence of proper safety training has frequently been identified as the primary cause of workplace accidents, as highlighted by Jaselskis et al. (2005) and Buchanan et al. (2005). Hence, investing in comprehensive safety training programs is essential for fostering a secure and accident-free work environment.

As reported by the public and in newspapers, in three years, the Department of Occupational Safety and Health (DOSH) recorded and documented over five incidents of ammonia-related accidents within companies in the ice-manufacturing industry. Specific cases of accidents involving ammonia leakage in Malaysian ice-manufacturing companies over three years are listed in Table 1.

Table 1 Accident Cases Related to Ammonia Leakage among Ice Plants in Malaysia (2016–2018)

No	Accident case	Date	Accident details
1	Ammonia leakage at Everest ice factory, Shah Alam	13 Aug 2018	2 fatalities, 24 workers injured
2	Ammonia leakage at an ice factory in Taman Sri Maju, Kuala Kangsar	25 Apr 2017	3 workers injured
3	Ammonia leakage at an ice factory in Penampang, Sabah	10 Oct 2017	1 worker injured
4	Ammonia leakage at an ice factory in Perlis	14 Aug 2018	2 workers injured
5	Ammonia leakage at Nekmat Ice Tube Factory, Semambu, Pahang	26 Jan 2016	3 workers at a nearby pump station injured

(Sources: DOSH Malaysia and Newspapers 2016–2018)

This safety issue emphasises the high number of occupational accidents resulting from a lack of safety culture and noncompliance with the requirements outlined in the Occupational Safety and Health Act (OSHA) of 1994 (Ali et al., 2017). These cases included various incidents with varying causes, such as human error and negligence, instrumentation failure, and poor maintenance. Moreover, according to the results of an OSH audit conducted by the DOSH, 79.9% (115 out of 144 companies) of ice-manufacturing companies throughout Malaysia comply with C, D, E, and Not Available (unregistered) grading, as shown in Figure 1.

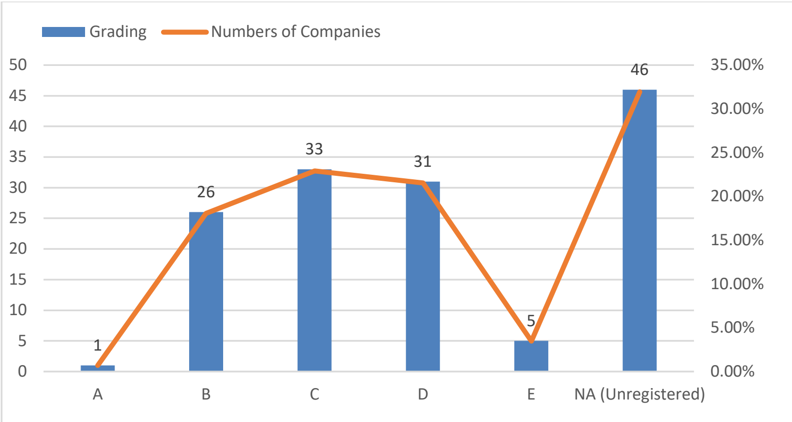

Figure 1: Results of an OSH Audit of Malaysian Ice-manufacturing Companies Conducted by the DOSH (2010–2018)

To address ammonia release events, this study aimed to enhance OSH practices within the ice-manufacturing industry in Malaysia. Despite the ice-manufacturing industry's exemption as that in the NTC category under the CIMAH regulations of 1996, this study prioritised OSH compliance, specifically under the OSHA, 1994. Through an assessment of OSH awareness among employers and the factors influencing compliance, this study sought to guide the improvement of safety measures and the implementation of OSHA regulations in the ice-manufacturing industry. Additionally, this study aimed to contribute to increased OSH awareness across the ice-manufacturing sector in Malaysia.

2.0 METHODS

Both primary and secondary sources were used for data collection. Immediate information was acquired by observing the locations and conducting a survey of staff and employers at ice-manufacturing companies. Secondary data were collected from the DOSH and the Ministry of Health, Malaysia. This study involved 15 ice-manufacturing companies in Selangor that operate using ammonia refrigeration systems. The study's sample size was determined by estimating 20% of a total population of 288 participants. Both parties involved employees and workers, making up 58 correspondents. According to a previous study, generally, in a sample, the number of respondents acceptable for descriptive research should be 10% of the target population for the study. However, if the target population is small, 20% is required to ensure in-depth analyses and accurate results (Cohen, 1988; Gay & Diehl, 1992). A questionnaire survey was conducted among ice-manufacturing companies in Selangor, Malaysia. The questionnaire was divided into five sections, as shown in Table 2.

The collected data were analysed using the Statistical Package for Social Sciences statistical software, and reliability was assessed using Cronbach's alpha, followed by two normality tests evaluating the normality of the collected data, as follows: (1) a histogram bell curve and (2) skewness and kurtosis for the Z-value. Regarding the evaluation of the demographic information and the identification of hazards, two types of analysis were conducted: descriptive analysis and frequency analysis. Factors associated with awareness of hazards and other variables were identified using dependentvariable models formulated and evaluated through multiple linear regression analysis. Finally, the findings were interpreted into the structural model of the standardised coefficient determining the β- and p-values.

Table 2 Sections in the Questionnaire

Section	Consists of:
1. **Section A:** General/demographic information	Company and general information (age, gender, education level, and workforce)
2. **Section B:** Health and safety awareness and attitude survey	Management commitment, supervisory support, and employees' compliance to rules
3. **Section C:** Safety and health program evaluation	OSH training program, managers' roles, supervisors' roles, employees' obedience, safety, and health committee and safety and health inspection
4. **Section D:** Safety and health issues/legislation	Identification of work activities, procedures and processes, and accident reporting
5. **Section E:** Knowledge regarding and understanding of safe practices	Management of change in work task or process, OSH communication and effectiveness, active and effective organisation/OSH committee, response in investigation issues, priority in conducting risk assessment (HIRARC or JSA) and safe operating procedures, and implementation of risk assessment and control of risks

3.0 RESULTS

As shown in Figure 2, the identified types of hazards (chemical and explosion hazards) were 32.73%; the number of physical hazards was 12 (21.82%), that of fire hazards was 5 (9.09%), and that of hot surface hazards was 2 (3.64%). Although the percentages of chemical and explosion hazards are the same, the percentage of the explosion hazards mentioned above results from chemical hazards in the event of an accident in an ice plant, whereby the leakage of ammonia results in the failure of the ice refrigeration system, thereby causing an explosion.

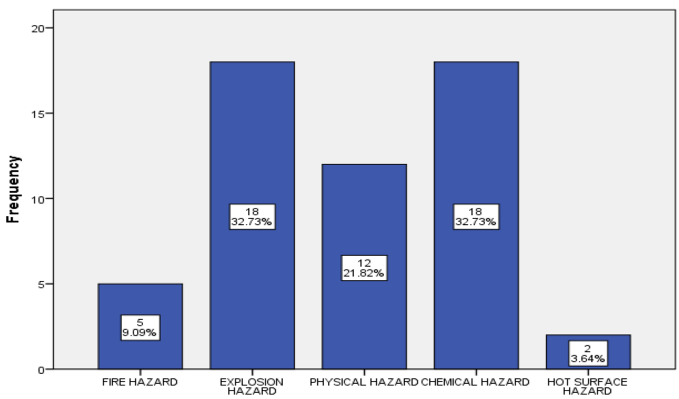

Figure 2: Types of Hazards in the Ice-manufacturing Industry

The results of the data analysis, as presented in Figure 3, demonstrate that best practices in and approaches to OSH compliance among ice-manufacturing companies with the highest to those with the lowest mean values above 3.50 points are as follows: 1) the hazard identification, risk assessment and risk control (HIRARC) process should be implemented in all organisations (mean value = 4.055), 2) Job safety analysis (JSA) should be conducted in all organisations (mean value = 3.927). Both the HIRARC process and JSA are considered the best practices that should be implemented across all organisations to ensure safety and health, in compliance with the law, 3) Notifying the management of hazards shows that early response could save lives, property, and the environment in cases of potentially unwanted and unsafe conditions, 4) Safe operating procedures (SOPs) are essential in preventing existing workplace risks. A high understanding of the risks and safety practices among workers and employers significantly enhances the implementation of the HIRARC process and JSA.

Ensuring OSH compliance by conducting training and implementing SOPs for every activity throughout the ice-manufacturing process in every factory would enable compliance with OSH laws and regulations in Malaysia.

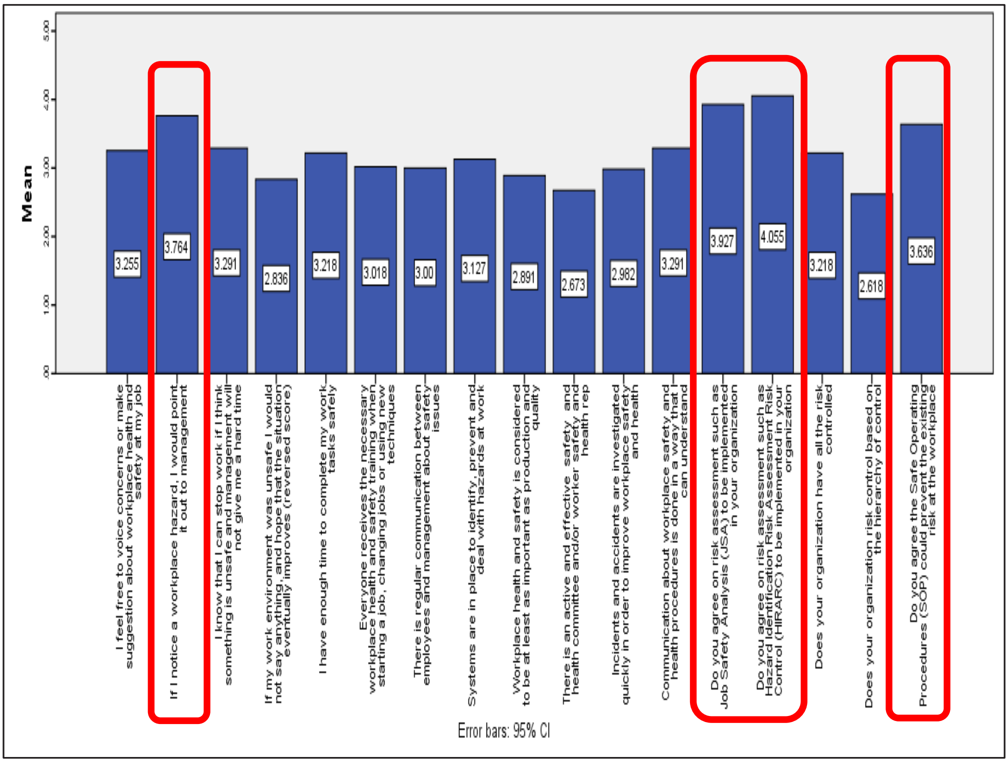

Figure 3: Questionnaire Results on Knowledge and Understanding regarding Safe Practices

Table 3 shows that the overall OSH compliance levels across all organisations in the ice-manufacturing industry are low. This study shows that the current state of OSH compliance throughout the ice-manufacturing industry in Selangor is shocking. Therefore, in the future, drastic measures must be taken by all agencies and authorities engaged in raising awareness and passing legislation regarding OSH compliance in Malaysia's ice-manufacturing industry.

Table 3 Descriptive Statistics of OSH Compliance Levels

Elements	Mean	OSH compliance levels
I carry out a risk assessment before conducting a work activity	1.6727	Low
Dangerous occurrences (e.g., failure of lifting equipment, fire in the workplace) must be reported	1.8909	Low
Occupational diseases reported	1.1091	Low
Work-related injuries/accidents reported	1.4364	Low
First aid services (e.g., first aider, first aid box, first aid room) are present at the workplace	1.9455	Low
Periodic maintenance and inspection of first aid facilities is done at the workplace	1.3636	Low
Training and re-training of workers/supervisors for emergency responses (e.g., fire, chemical spills) are conducted at the workplace	1.8182	Low
Training/orientation programmes of workers on safe and healthy work practices	1.6545	Low
Management of hazardous chemicals	1.4364	Low
Ergonomics assessment was conducted	1.0364	Low
A written policy for safety and health is available at work	1.5636	Low
Are there OSH objectives stated in the safety and health policy in your organisation?	1.4364	Low
Does the organisation conduct hazard identification at the workplace?	1.5091	Low
Does the organisation conduct risk assessment at the workplace?	1.4000	Low
Are the identification, evaluation, and measures to eliminate, prevent, or reduce exposure to workplace hazards conducted?	1.2727	Low
Is the training on and assessment of personal protective equipment usage, including fit testing and monitoring on correct use, conducted?	1.5455	Low
Is hygiene monitoring (e.g., noise and chemical health risk assessment) conducted?	1.2909	Low
Is the information on workplace hazards and risks communicated to the managers/supervisors responsible for implementing prevention and control measures?	1.5273	Low
Is information regarding the possible workplace hazards and risks communicated to the employees?	1.4000	Low
Is the information on physical and psychological health communicated to the employees?	1.1636	Low
Valid N (list wise)		
Average	1.390	Low

4.0 DISCUSSION

Based on the data analysis presented above, many OSH elements must be included in the OSH audit checklist. Although the OSH-WA checklist is used in enforcement activities, it does not cover all critical OSH elements for ice-manufacturing companies in the NTC category. Therefore, the existing NMHI checklist could be used to ensure OSH compliance throughout the ice-manufacturing industry, and we recommend including the HIRARC process to this checklist in future studies.

Additionally, to ensure OSH compliance among all organisations in the ice-manufacturing industry throughout Malaysia, all the government agencies mandated with ensuring OSH compliance must ensure that all ice-manufacturing companies adhere to the following:

i. All companies in the ice-manufacturing industry must conduct practical OSH compliance training on-site to ensure that all the employees and employers in such organisations achieve enhanced awareness about OSH compliance and to improve the attitude of the employees and employers towards emergency action plans and SOPs.

ii. All employees working in ice-manufacturing companies must be trained in OSH compliance in accordance with the regulations set out in the OSHA, 1994.

iii. All organisations in the ice-manufacturing industry should establish and implement the HIRARC process and implement JSA. Risk assessment tools based on the HIRARC process, as well as the NMHI Checklist, should be considered when formulating legislation or regulations associated with such companies.

iv. All ice-manufacturing companies that use ammonia as a coolant in their refrigeration systems should be upgraded to the NMHI category, which is a higher category under the CIMAH regulations introduced in 1996. This is because, based on the descriptive-data statistical analysis of the questionnaire employed in this study, the overall OSH compliance levels among ice-manufacturing companies in Malaysia are low.

v. The DOSH should develop and enact new rules regarding ammonia use throughout the ice-manufacturing industry in Malaysia.

5.0 CONCLUSION

This study's results can be attributed to inadequate knowledge and insufficient awareness about the implementation of OSH practices within companies in the ice-manufacturing industry, thereby resulting in noncompliance with the OSHA of 1994 (OSHA, 1994). The primary sources of the issues addressed in this study include a lack of understanding regarding safety and health, improper management of information during emergencies, and failure to recognise exposure to unique hazards in the workplace. Improving knowledge about the risks and best practices among workers and employers is crucial for enhancing OSH compliance. This can be achieved through comprehensive OSH training, implementing SOPs in alignment with OSH legislation, and strict adherence to regulations in Malaysia.

Based on this study's findings and the limitations reported, we propose the following recommendations to enhance future research on this subject:

i. Further studies on ice-manufacturing or refrigeration companies focusing on cold rooms should be conducted. This is because the amount of ammonia used in cold room operations is higher than that in the scope of this study. Many of them are categorised as NMHI under the CIMAH regulations of 1996 or as SME chemical companies under the NTC category.

ii. Regarding the ice-manufacturing industry in Malaysia, no studies have been conducted to assess major hazardous incidents involving ammonia dispersion in the workplace and the surrounding communities, thereby highlighting a critical gap in research. Relevant authorities should address this issue in future studies.

iii. Related government authorities must effectively enforce and evaluate the effectiveness of existing emergency response plans in workplaces that use ammonia.

iv. Conducting an in-depth examination of the repercussions of the threshold quantity of ammonia and its potential contribution to major hazardous incidents presents a valuable opportunity for enhancement, thereby prompting the need for the DOSH in Malaysia to formulate and develop pertinent laws and regulations.

In conclusion, there is a prospect for the future assessment and implementation of the recommendations outlined in this study to enhance and ensure adherence to OSH compliance standards within ice-manufacturing companies.

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Review Article

Post-COVID-19 Workplace Health: Addressing Musculoskeletal Concerns

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ABSTRACT: *This review aimed to delve into the intricate interplay between coronavirus disease 2019 (COVID-19) and the musculoskeletal system within the workplace context. It highlights the critical role of the musculoskeletal system in manual tasks, energy production, and physiological adaptations. The effects of COVID-19 on musculoskeletal health, particularly its prevalence and persistence, are thoroughly examined. Potential mechanisms underlying muscle damage are discussed, encompassing inflammation, vitamin D deficiency, hospitalisation effects, and treatment effects. This comprehensive analysis highlights the importance of addressing musculoskeletal concerns in the post-COVID-19 work environment, ensuring that the well-being and productivity of the workforce are prioritised.*

Keywords: *COVID-19, Ergonomics, Long COVID, Manual Handling, Musculoskeletal System, Occupational Health*

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1.0 INTRODUCTION

Coronavirus disease 2019 (COVID-19) is a viral infection caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in the respiratory tract. SARS-CoV-2 can cause significant inflammatory and oxidative stress, damaging the pulmonary alveoli and leading to severe acute respiratory distress syndrome (ARDS), bilateral viral pneumonia, and respiratory failure (Xu et al., 2020; Zhou et al., 2020).

The skeletal muscle, the body's most significant tissue responsible for glucose metabolism, is one of the tissues damaged by SARS-CoV-2 (Nasiri et al., 2020; Zhu et al., 2020). Muscle soreness is one of the most common symptoms in hospitalised individuals after contracting SARS-CoV-2 infection during the first 3 days of infection (Nidadavolu & Walston, 2021; Paliwal, Garg, Gupta, & Tejan, 2020; Vacchiano et al., 2020). Meta-analytic investigations have demonstrated that myalgia (muscular tiredness) is the third most prevalent symptom in patients with SARS-CoV-2 symptoms (after persistent fever and cough). The duration of myalgia mainly depends on the severity of the condition (Akbarialiabad et al., 2021; Zhu et al., 2020). However, the exact mechanism and effects on the musculoskeletal system are poorly understood, especially among workers, and current data show that almost 10% of post-COVID-19 patients experience long COVID (Sivan & Taylor, 2020). Long COVID is defined as any illness in individuals who have either recovered from COVID-19 but with lasting effects or have had the usual symptoms for far longer than expected (Mahase, 2020). According to the Occupational Safety and Health Act (OSHA, 1994), employers are generally responsible for ensuring the safety, health, and welfare of workers, including workers with a history of COVID-19 (Kementerian Sumber Manusia, 1994). This review aimed to examine (i) musculoskeletal involvement at work, (ii) the effects of COVID-19 on the musculoskeletal system, and (iii) the possible mechanism of musculoskeletal damage among workers with a history of COVID-19.

2.0 MUSCULOSKELETAL DEMAND AT WORKPLACE

In the workplace, manual handling activities require employees to engage in various physical tasks. These tasks encompass actions, such as lifting, carrying, moving, and maintaining specific body postures. To accomplish these tasks effectively, the human body relies on the musculoskeletal system, which comprises bones, muscles, and connective tissues.

Within this complex system, each skeletal muscle has a highly organised structure consisting of numerous elongated muscle fibres. These muscles work in concert through the intricate interplay between actin and myosin, which occurs primarily within the sarcomere. The sarcomere is the fundamental unit responsible for muscle contraction and relaxation. It is crucial to understand the importance of the coordinated efforts of actin and myosin in the range of activities involved in manual handling, including eccentric contractions (muscle lengthening), concentric contractions (muscle shortening), and isometric contractions (muscle tension without length change) (Marieb & Keller, 2018). Fig. 1 shows the interaction between actin and myosin; both can slide against each other during the contraction process as actin filaments can curl around and slide along the stationary myosin rods (Grandjean & Kroemer, 1997).

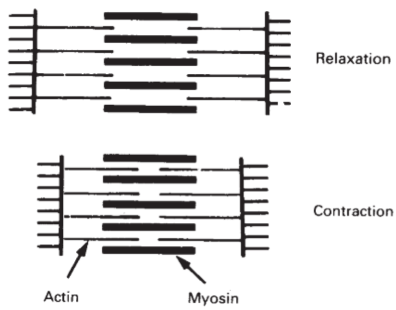

Figure 1: Model of Muscle Contraction Adapted From Kroemer & Grandjean (2009)

Every muscle movement requires energy from the food intake. Foods comprise macronutrients and micronutrients that work synergistically to meet the body's physiological demands. Carbohydrates, proteins, and fats are converted into energy through various pathways.

Manual handling involves muscle activity required to break down adenosine triphosphate (ATP) to contract or relax. In our muscle cells, mitochondria are energy-producing factories that ensure that our body has a continuous supply of ATP to work (Marieb & Keller, 2018). There are three primary sources of ATP in the muscles: creatine phosphate, oxidative phosphorylation (aerobic metabolism), and anaerobic glycolysis (anaerobic metabolism) (Ministry of Health Malaysia, 2017). Thus, the body can automatically adapt to the physiological demands during physical movements at work. A commonly observed manifestation of COVID-19 is diminished appetite and gustatory impairment (Hossain et al., 2021). This symptom can lead to a decrease in dietary intake, consequently perturbing the equilibrium of macronutrients indispensable for the generation of ATP, a pivotal energy currency that enables muscular contractions during occupational activities. Macronutrients include carbohydrates, proteins, and fats, all of which play integral roles in facilitating the body's capacity to produce ATP.

At the beginning of work activity, most of the energy provided to the musculoskeletal system comes from the creatine phosphate system and anaerobic metabolism when muscles have insufficient oxygen for aerobic metabolism. Our metabolic system requires approximately 1–3 min of adaptation before any changes occur (Wickens, Lee, Liu, & Gordon-Becker, 2014). Prolonged usage of anaerobic metabolism produces lactic acid, an accumulation of lactic acid-induced muscle fatigue and soreness. Excessive lactic acid accumulation interferes with pH, calcium release, troponin C sensitivity, and cross-bridge cycling, thereby reducing the ability of the muscle to generate force (Tidball, 2011). The ability to generate muscle force can reduce worker productivity, particularly during strenuous manual handling activities. However, during low-to-moderate manual handling tasks, energy may originate from aerobic metabolism. Subsequently, the body adapts to metabolic demands, and several physiological changes occur. For example, the respiratory system can increase the breathing frequency. By increasing the breathing frequency, lung capacity can be increased along with oxygen uptake ('Your lungs and exercise', 2016). Simultaneously, the circulatory system adapts by increasing the heart rate to increase the cardiac output. Increased cardiac output means that more blood is pumped out from the heart, and more oxygen with essential nutrients reaches the muscles for force generation activity (Marieb & Keller, 2018). With oxygen available, our cells use glucose to produce energy, carbon monoxide, and water as by-products. Both by-products can be disposed of through breathing, sweating, and urination.

Aerobic metabolism is energy efficient for the musculoskeletal system because the fuel sources for this reaction are glucose, pyruvic acid, free fatty acids, and amino acids (Hargreaves & Spriet, 2020). In addition, the aerobic metabolism produces more energy than the other two energy-generating systems. Failure of the system to adapt and supply critical nutrients during multiple tasks at work may cause physiological changes, such as musculoskeletal disorders, and reduce cognitive ability. The efficiency of the body in replenishing essential nutrients for muscle activity also depends on the training level of the worker, age, sex, medical history, nutritional status, and work environment (Abdelhamid & Everett, 2000).

The muscle adapts to changes in its mechanical environment by modifying gene expression and protein stability, thereby affecting its physiological functions and mass. Skeletal muscle constantly adapts to changes in its mechanical environment. However, mechanical stress frequently exceeds the parameters that cause adaptation, resulting in acute injury rather than adaptation. A healthy individual's adaptation process through injury–repair regeneration is based on several theories as explained by Tidball (2011). These include (i) activation of proteases and hydrolases that contribute to muscle damage, (ii) activation of enzymes that drive the production of mitogens for muscle and immune cells involved in injury and repair, and (iii) enabling protein–protein interactions that promote membrane repair. However, COVID-19 may impair injury repair and regeneration in workers.

3.0 EFFECTS OF CORONAVIRUS DISEASE 2019 (COVID-19) ON THE MUSCULOSKELETAL SYSTEM

The relationship between SARS-CoV-2, the virus responsible for COVID-19, and its predecessor, SARS-CoV-1, which causes severe acute respiratory syndrome (SARS), is of significant interest. Both the viruses primarily target the respiratory system; however, their effects extend to multiple organ systems, including the musculoskeletal system. Drawing from epidemiological findings during the 2002–2004 SARS pandemic, it became evident that patients with moderate and severe SARS often experienced a range of musculoskeletal issues. These include myalgia, muscle dysfunction, and conditions, such as osteoporosis (OP) and osteonecrosis. Although the two viruses are not identical, computational biology and in vitro experimental studies have highlighted a substantial similarity in their pathological responses to SARS-CoV-1 and SARS-CoV-2 infections (Disser et al., 2020).

Musculoskeletal issues have become a prevalent concern in individuals affected by COVID-19, with back pain being the most reported problem (Jacob et al., 2022). This observation emphasises the strong association between COVID-19 and musculoskeletal symptoms, particularly the noteworthy presence of back pain. Interestingly, this study also revealed a significant association between musculoskeletal symptoms and underlying health conditions, including hypertension, diabetes, and obesity.

Another study by Jeyaraman, Selvaraj, Jeyaraman, Gollahalli Shivashankar, & Muthu (2022) among 2334 participants found a higher occurrence of musculoskeletal symptoms in individuals who were not vaccinated against COVID-19 than in those who were vaccinated. The study also found that musculoskeletal scores were significantly higher in males, those with lower educational attainment, individuals with comorbidities, and those who had not received the COVID-19 vaccination than their counterparts. The same study revealed a range of musculoskeletal symptoms associated with COVID-19, including joint pain, muscle soreness, new-onset back pain, fatigue, inflammatory joint conditions (symmetrical or polyarticular), reactive joint problems, OP, femoral head osteonecrosis, nerve-related disorders, myositis, and muscle diseases.

There were significant differences in physical assessment post COVID-19 infection. Individuals affected by COVID-19 experience persistent alterations in their range of motion, such as an increase in sitting-to-standing time, reduction in walking speed, and notable changes in gait patterns, even after the completion of an 8-week recovery period (Kowal et al., 2023). This was supported by another study by Karasu, Karataş, Yıldız, & Günendi (2023), who demonstrated that the use of a comprehensive set of outcome measures, such as the hand grip strength, five-times sit and stand test, modified Borg scale, Barthel index, and visual analogue scale, for myalgia improved the physical assessment over time but did not return to typical standards.

4.0 POSSIBLE MECHANISM UNDERLYING MUSCULOSKELETAL SYSTEM DAMAGE OF COVID-19

Known to be associated with substantial systemic inflammation, COVID-19 can cause severe cytokine responses in some individuals, particularly those with a previous infection history (Welch, Greig, Masud, Wilson, & Jackson, 2020). However, the underlying mechanisms that cause muscle wasting in patients with COVID-19 are unknown (Ali & Kunugi, 2021). Hence, some researchers have theorised that the development of muscle sarcopenia in patients with COVID-19 may be associated with various factors. These factors include inflammation, vitamin D levels, body weight fluctuations, duration of hospitalisation, dietary intake alterations, prolonged periods of bed rest, diminished physical activity, COVID-19 treatment regimens, and subsequent recovery processes (Nidadavolu & Walston, 2021; Perez et al., 2023; Pescaru et al., 2022; Welch et al., 2020).

4.1 Inflammation

Patients with COVID-19 who require critical care usually have high serum inflammatory cytokine levels (Huang et al., 2020). High concentrations of serum cytokines decrease messenger ribonucleic acid translational efficiency because of eukaryotic translation initiation factor 4E alterations (Lang, Frost, Nairn, MacLean, & Vary, 2002). High cytokine concentrations negatively affect muscle protein synthesis and anabolic resistance. To overcome anabolic resistance, patients are required to consume more protein. Aging is associated with increased cellular deterioration. Although aging cells have slowed their growth, they also secrete several inflammatory cytokines that may be exaggerated among ill and aged individuals (Coppé, Desprez, Krtolica, & Campisi, 2010; Foletta, White, Larsen, Léger, & Russell, 2011; Trinity et al., 2021).

4.2 Vitamin D Deficiency

Vitamin D deficiency should be significantly considered when examining the multifaceted factors contributing to muscle atrophy, particularly in type II muscle fibres (Ceglia, 2009). Moreover, there has been speculations regarding the role of vitamin D deficiency in influencing the immune system response to respiratory infections, with growing recognition that the deficiency itself may be a consequence of inflammation rather than its cause (Ceglia, 2009; Hansdottir & Monick, 2011). In this context, vitamin D deficiency is increasingly being considered a biomarker of heightened inflammation. Although some studies have drawn the association between low vitamin D levels and the development of COVID-19, establishing a direct causal association remains elusive as multiple confounding factors need to be considered (D'avolio et al., 2020; Hastie et al., 2020).

OP is characterised by a decline in bone mass accompanied by alterations in bone tissue microarchitecture, resulting in increased bone fragility and a heightened risk of fractures. In the assessment of OP, the significance of nutritional elements, such as calcium and vitamin D, cannot be understated. Notably, the risk of fractures attributable to OP a decade after its onset is substantial, reaching 40% (Moga et al., 2022).

4.3 Body Weight

Obesity plays a significant role in COVID-19 outcomes, as evidenced by a higher risk of hospitalisation, critical care admission, and fatality (Public Health England, 2020). This increased risk may be attributed to the association between obesity and elevated systemic inflammation, which may exacerbate the effect of acute illness on muscle metabolism. Moreover, the concept of sarcopenic obesity, characterised by reduced muscle mass and increased fat mass (Zamboni, Mazzali, Fantin, Rossi, & Di Francesco, 2008), adds complexity. Sarcopenic obesity is associated with ectopic fat and intramyocellular lipid deposition, both of which have the potential to detrimentally affect muscle structure (Batsis & Villareal, 2018). These factors may collectively contribute to a significant decline in muscle function and quantity among individuals with obesity and catabolic diseases (Welch et al., 2020). This interplay among obesity, inflammation, muscle metabolism, and body composition underscores the multifaceted nature of the effect of COVID-19 on individuals and provides valuable insights for further studies and clinical considerations (Vimercati et al., 2021).

4.4 Hospitalisation Period

The most significant changes in muscle function are observed among hospitalised patients who require extensive critical care (Disser et al., 2020). These changes are caused by systemic inflammation, prolonged bed rest, muscle relaxants to aid prone positioning, and the risk of viral spread (Luo et al., 2020). Acute sarcopenia has been documented in previously fit and active individuals but has shown significant decreases in muscular function during hospitalisation. This also results in a state of induced fragility, which makes them more vulnerable to stressful events in the future (Clegg, Young, Iliffe, Rikkert, & Rockwood, 2013; Mira et al., 2017). In addition, frailty weakens the immune system, rendering patients more vulnerable during recovery (Mira et al., 2017).

4.5 Dietary Intake

According to previously mentioned studies, inflammation is associated with catabolic states and anabolic resistance in patients with COVID-19, increasing nutritional demand, particularly for proteins. Despite this, several patients with COVID-19 cannot fulfil their most basic needs, such as food. Loss of taste and smell is a well-known sign of COVID-19, which can occur in up to two-thirds of all viral infections (Meng, Deng, Dai, & Meng, 2020) and results in reduced appetite. Furthermore, the elevation of proinflammatory cytokine levels, such as those observed in COVID-19, is related to leptin production and anorexia (Grunfeld et al., 1996). When the symptoms of anorexia in old age are combined, older individuals become more vulnerable to the effects of these conditions. Sarcopenia is also associated with the weakening of masticatory muscles, which may aggravate diminished food intake (Cox et al., 2020; Yoshida & Tsuga, 2020).

4.6 Bed Rest and Reduction of Physical Activity

Several individuals admitted to hospitals with COVID-19 are forced to stay in bed for extended periods and have limited physical activity levels. This may have been exacerbated by the isolation policies that restrict the movement of patients with COVID-19. Among those who do not require hospitalisation, patients with COVID-19 experience extreme fatigue (Huang et al., 2020; Zhu et al., 2020), which may limit their physical activity levels (Greenhalgh, Knight, A'Court, Buxton, & Husain, 2020). Restrictions placed on daily activities during the COVID-19 pandemic also contribute to reduced physical activity levels among patients (Kirwan et al., 2020). Furthermore, bed rest has been related to reducing muscle mass, strength, and aerobic performance even among healthy participants (Kortebein, Ferrando, Lombeida, Wolfe, & Evans, 2007; Kortebein et al., 2008).

4.7 Treatment of COVID-19 and Recovery Process

The use of dexamethasone may increase the rate of survival among patients with COVID-19 (The Recovery Collaborative Group, 2021). When combined with bed rest, medically induced hypocortisolemia causes more muscle loss than bed rest alone (Bodine et al., 2001; Paddon-Jones et al., 2006). Therefore, dexamethasone may increase the likelihood of acute sarcopenia in patients who are already at risk. In a previous study, a loss in lean muscle mass was observed in patients with ARDS during the year following their discharge from critical care (Chan et al., 2018). This indicates a long-lasting effect that prevents the formation of new muscles following severe acute illness. Sepsis-induced muscle regeneration in mice is severely limited, with increased fibrosis and decreased number of functioning satellite cells. As a result of sepsis or COVID-19, it is hypothesised that the body's ability to synthesise muscle is impaired, resulting in prolonged side effects of acute muscle wasting (Chan et al., 2018).

5.0 CONCLUSION

The intricate association between COVID-19 and the musculoskeletal system presents a multifaceted challenge, particularly in the workplace. The effects of this viral infection on skeletal muscle, coupled with the dynamics of manual handling activities, underscore a critical association that demands further attention and action. The effects of COVID-19 on musculoskeletal health extend beyond myalgia and acute symptoms. The long COVID phenomenon has emerged as a relatively uncharted territory, affecting a substantial portion of the workforce. Employers, as per OSHA (1994), bear the responsibility of safeguarding the health and welfare of their employees, including those with a history of COVID-19.

Understanding the complex mechanisms by which COVID-19 damages the musculoskeletal system is crucial. Inflammation, vitamin D deficiency, body weight fluctuations, hospitalisation duration, dietary intake alterations, and reduced physical activity levels contribute to the multifaceted challenge of musculoskeletal damage after post-COVID-19. These factors intersect and increase the risk of acute sarcopenia and other types of musculoskeletal damage.

Addressing this issue requires a holistic approach that encompasses adequate nutritional support, rehabilitation programmes, and close monitoring of post-COVID-19 workers. Collaborative efforts among healthcare providers, employers, and policymakers are essential to mitigate the long-term musculoskeletal consequences of COVID-19 and ensure the continued well-being and productivity of the workforce in the post-pandemic era. This study underscores the urgency of recognising the musculoskeletal dimensions in the fight against the long-term effects of COVID-19.

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Original Article

Uncertainty Estimation and its Effect to Respirable Crystalline Silica Exposure Between Direct and Indirect Method

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ABSTRACT : *Due to its carcinogenic nature, many countries establish occupational exposure limits for respirable crystalline silica (RCS) at very low levels, typically ranging between 0.025 and 0.1 mg m^{-3}. Consequently, industrial hygienists encounter substantial challenges in selecting suitable sampling methods to adhere to these stringent exposure limits. Factors to consider include selecting between direct or indirect methods and the uncertainties associated with each method. This study aimed to determine the correlation between RCS exposure using direct and indirect analysis methods, validate the application of both methods to underpin compliance status, and evaluate the effects of sampling and analytical uncertainty on exposure levels. Sampling was performed among 31 crusher operators at six quarries, with each worker equipped with a pair of integrated sampling devices to facilitate parallel comparisons between direct and indirect methods. Exposure data from direct and indirect methods showed substantial correlation ($p<0.05$, $r^2 = 0.82$) with no significant differences ($p > 0.05$). For the direct method, 35.9% of crusher operators exceeded the RCS exposure limit compared to 30.9% for the indirect method. The total coefficient variance (CV_T) was 0.10 and 0.09 for the direct and indirect methods, respectively. For both methods, CV_T was influenced more by the coefficient of variance for analytical procedures (CV_A) than by the coefficient of variance for sampling procedures (CV_P). Integration of CV_T values into the upper confidence limit (UCL) calculations revealed an increased number of non-compliance exposures for both methods. The indirect method demonstrated lower uncertainty and better quality assurance compared to the direct method. However, no significant differences ($p>0.05$) were found among the field samples. Industrial hygienists may choose either method that meet their criteria concerning quality, timing, or cost.*

Keywords : *Direct Method, Indirect Method, MDHS 101, NMAM 7500, Respirable Crystalline Silica*

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1.0 INTRODUCTION

Exposure to silica has been linked to various respiratory conditions, including silicosis and lung cancer (ALS, 2016; Dong et al., 1995; Kane, 1997; WHSQ, 2011). Recent research suggests that silica exposure may also lead to autoimmune diseases (Rocha-Parise et al., 2014). The International Agency for Research on Cancer (IARC) classified crystalline silica in the form of quartz or cristobalite as a Group 1 carcinogen in 1997 (IARC, 1997; Lin et al., 2012). The carcinogenic properties of silica and the need to limit its exposure to workers have led to the establishment of low occupational limits ranging from 0.025 mg m^{-3} to 0.1 mg m^{-3}. For instance, The American Conference of Governmental Industrial Hygiene (ACGIH) established a threshold limit value (TLV) of 0.025 mg m^{-3} for respirable crystalline silica (RCS) (ACGIH, 2015). Many countries, such as the United Kingdom (HSE 2011), Australia, Belgium, Canada, France, Ireland, Denmark, Singapore, Malaysia (DOSH 2000), Spain, and Sweden, maintain an occupational limit for respirable quartz at 0.1 mg m^{-3}. The limit value for Austria, Hungary, and Switzerland is 0.15 mg m^{-3}, while Finland, South Korea, and Argentina adhere to a limit of 0.05 mg m^{-3} (IFA, 2015; Maciejewska, 2008). Monitoring substances with low occupational thresholds presents challenges for field and laboratory personnel. Industry stakeholders have expressed concerns about the efficacy of current methods in ensuring compliance monitoring and detecting violations at very low levels (Cox Jr et al., 2015).

Selecting the most appropriate sampling and analytical techniques is crucial for achieving minimal exposure limits. The primary concerns are the sampling and analytical errors inherent to each method. Errors at such low occupational limits may introduce uncertainty into the compliance status of exposure results. Uncertainty, in this context, is a parameter associated with the result of a measurement that characterises the dispersion of a value that can reasonably be attributed to the measurement. Uncertainty relates to the concept of doubt (Ellison et al., 2000). There is a lack of information regarding the errors occurring in measurements performed under real conditions (Garcia et al., 2013). Furthermore, the selection of an RSC sampling method necessitates experienced and critical judgement. Consequently, there is ongoing debate between selecting direct (HSE, 2005) or indirect methods (NIOSH, 2003a, b) and choosing between X-ray diffraction (XRD)(NIOSH, 2003b) or infrared (NIOSH, 2003a) methods.

XRD and infrared are commonly utilised analytical techniques for quantifying RCS (Key-Schwartz et al., 2003; Madsen et al., 1995; Miller, 2014; Page, 2006; Verpaele and Jouret, 2013). However, XRD is a more accurate and precise technique compared to the infrared technique (Kuo et al., 2010). Analysis of crystalline silica is considered a selective method as it relies on the individual crystalline properties of the substance (HSE, 2005; Markku et al., 2012). Frequently employed methods include the National Institute of Occupational Safety and Health (NIOSH) Manual Analytical Method No.7500 (NMAM 7500) for silica, crystalline, XRD via filter deposition (NIOSH, 2003b), and Methods for the Determination of Hazardous Substance Guidance No.101 (MDHS 101) for RCS in Airborne Dust (HSE, 2005). NMAM 7500 is fully validated and the only method with any legal significance (Smith, 1992).

In the direct method, field samples are analysed directly without any pretreatment, while the indirect method involves a series of pretreatments such as digestion, filtration, and/or ashing of field samples. Although the sampling techniques of the direct and indirect methods are similar, the analytical procedures differ (Amran et al., 2016). Direct analytical methods minimise sample handling; however, standards must be prepared under conditions similar to those of the samples (Kaufer et al., 2005). An example of a direct method is MDHS 101, where standard filters can be produced in an exposure chamber to simulate conditions similar to those of sampling (HSE, 2005). Indirect methods involve pretreatment of filter membranes, with NMAM 7500 being an example that employs XRD. Another indirect method, NMAM 7602, utilizes Fourier-transform infrared (FTIR) spectroscopy for analysis (NIOSH, 2003a). Kaufer et al. (2005) conducted a study evaluating direct and indirect methods using infrared technology, and a direct method using X-rays. In that study, results obtained through the indirect method using infrared techniques were approximately 13% lower on average compared to the mean results of two direct methods using infrared and XRD.

This study aimed to assess the correlation between direct and indirect methods for measuring RCS exposure, validate the application of both methods for compliance assessment, and examine the impact of sampling and analytical uncertainty on the resulting exposure data.

2.0 METHODOLOGY

The study protocol was approved by the NIOSH Malaysia Ethics Committee. Sampling was conducted at six quarries in Kuala Lumpur and Selangor, located in the central region of Peninsular Malaysia. All quarries used jaw crushers at primary crusher plants and Hydrocone® crushers at secondary and tertiary crusher plants. Each crusher was equipped with water sprinklers as a dust suppression system.

Sampling involved 31 crusher workers. The minimum number of samples in a similar exposure group (SEG) was determined based on the NIOSH USA Occupational Exposure Sampling Strategy Manual, 1977 (NIOSH 1977). For a sample size representing the top 10% with a confidence level of 0.95 ($\alpha = 0.05$) and an estimated population of over 200 crusher operators, the minimum sample size of 29 workers was required. This sample size exceeded the Department of Occupational Safety and Health (DOSH) guidelines for Monitoring of Hazardous Substances, which recommends 18 samples representing the top 10% with a confidence level of 0.9 (DOSH 2002). Crusher operators were selected owing to their excessive exposure to quarry dust. This group was classified as a similar exposure group (SEG) considering the exposure pattern and duration. SEG is defined as a group of workers with the same general exposure profile to an agent because of the similarity in the frequency of tasks performed, materials used, and processes (Bullock & Ignacio 2006). Sampling was conducted throughout the 8-hour work shift. Crusher plant activities were monitored and controlled from an enclosed air-conditioned room where operators spent most of their time. Occasionally, operators performed troubleshooting or maintenance outside the control room, exposing them to dust and crystalline silica produced during crushing, grinding, screening, loading, and unloading processes.

The sampling and analysis for the direct method strictly followed the Methods for the Determination of Hazardous Substance Guidance No.101 (MDHS 101) (HSE, 2005), while the indirect method followed the NIOSH Manual Analytical Method No.7500 (NMAM 7500) which uses crystalline silica by X-ray diffraction via filter deposition (NIOSH, 2003b). Both methods utilised XRD for analysis. Table 1 presents the comparison criteria between the direct and indirect methods.

Table 1 Comparison Between Direct and Indirect Methods

	Direct Method	Indirect Method
Reference method	MDHS 101	NMAM 7500
Method Published by	HSL, HSE, UK	NIOSH USA
Sampling pump	Standard flow	Standard Flow
Filter type	25 mm polyvinyl chloride (PVC) filter	37 mm polyvinyl chloride (PVC) filter
Cyclone type	SKC GS3 cyclone	SKC GS3 cyclone
Standard preparation by	By exposure chamber	By funnel filtration system
Sample preparation by	Direct filter method	Digestion with acid and ashing
Analytical instrument	XRD	XRD

Each worker was provided with two integrated sampling sets. All samples were collected in pairs to create parallel sets for comparison between the direct and indirect methods (Fig. 1). Each set consisted of a standard flow SKC sampler (AirChek XR5000, 2013, Dorset, USA), attached to an SKC GS3 cyclone and a 3-piece cassette loaded with a 5.0 µm polyvinyl chloride (PVC) filter. We used an SKC GS3 cyclone flow rate of 2.75 L min^{-1} as the separating device for the respirable fraction. The specification patterns matched the definitions of the respirable conventions (SKC, 2014). Volume calculations were based on the average pre- and post-calibration flow rates (SKC, 2014) and sampling duration. Air velocity and humidity were measured to determine environmental factors on the monitoring day, using an electronic integrated hot-wired anemometer and hygrometer (TSI, 8386-M-GB, 2014, Shoreview, USA). All equipment was in good condition, calibrated, and traceable to international standards. The final results were corrected for normal temperature (25 ̊C or 298 K) and pressure (760 mmHg).

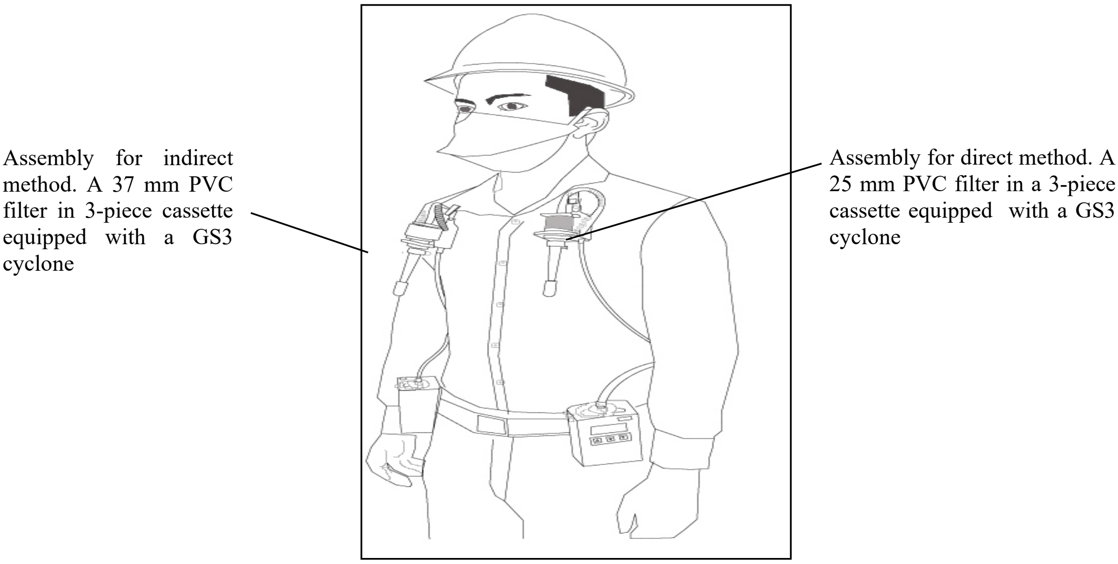

Figure 1: Assembly of Sampling Pump on Workers

Quartz measurements were performed using an XRD (Rigaku, Multiflek, Tokyo, Japan) equipped with six holder autosamplers and a sample spinner. An X-ray generator was used to obtain a maximum output of 2000 watts (tube voltage 40 kV; tube current 50 mA). The scanning range of the primary quartz peak was 26.0°–27.14°. Results were obtained from the integral signal intensities.

In total, 31 pairs of personal samples were collected, with each pair representing both the direct and indirect methods. The main difference between the direct and indirect methods related to sample preparation. In the direct method, the filters were analysed using XRD without any pretreatment procedures. Analyses using the indirect method involved acid treatment, ashing, and filtration processes to transfer dust from the 37 mm sampling filter onto the 25 mm XRD filter holder. The recovery rates for the direct and indirect methods were 95.6% and 90.7%, respectively. The total combined standard uncertainty was 19.54% for the direct method and 17.14% for the indirect method. Replication for airborne samples were not performed as it is nearly impossible to duplicate the same conditions owing to the variability of worker movement, machine operation, and environmental factors such as temperature, humidity, and wind direction. However, laboratory investigations, such as recovery and reproducibility, were based on the replication of seven to ten samples. Table 2 lists the performance characteristics of the direct and indirect methods.

Table 2 Performance Characteristics Between Direct and Indirect Methods

Performance Characteristic	Unit	Direct method	Indirect method
Calibration range	µg	17.33-570	10-500
Calibration slope (r^2)	-	0.8	0.7
Calibration regression	-	0.996	0.999
Limit of detection (LOD)	µg	13.04	4.11
Limit of Quantification (LOQ)	µg	43.46	13.70
Recovery	%	90.4	88.6
Precision	%	5.48	3.64
Trueness	%	5.97	6.77
Accuracy	%	±15	±13
Combined uncertainty component, U	%	8.10	7.69
Expanded Uncertainty, *U (k* value =2*)*	%	16.20	15.37

Uncertainty from recovery was obtained using the following equation:

$$u(\bar{R}_m) = \bar{R}_m \times \sqrt{\left(\frac{s_{obs}{}^2}{n \times \bar{C}_{obs}{}^2}\right) + \left(\frac{u\,(C_{spike})}{C_{spike}}\right)^2}$$

where:

$C_{obs}{}^2$ = mean of the replicate analyses of the spiked sample
C_{spike} = concentration of the spiked sample
S_{obs} = standard deviation of the results from replicate analyses of the spiked sample
$u(C_{spike})$ = standard uncertainty in the concentration of the spiked sample.
n = number of replicates

Combined uncertainty, $u(y)'$ was obtained using the following equation:

$$u(y)' = \sqrt{u\,(p)^2 + u\,(q)^2 + u\,(r)^2 + \ldots}$$

Where $u(p)$, $u(q)$, $u(r)$ represents the uncertainty for each factor

3.0 RESULTS AND DISCUSSION

3.1 Comparison of Exposure Pattern Between Direct and Indirect Methods

Fig. 2 shows the exposure patterns of personal samples using direct and indirect methods. The highest personal respirable dust exposure for the direct method was 0.41 mg m^{-3} while for the indirect method, it was 0.26 mg m^{-3}. The lowest exposure was 0.02 mg m^{-3} for the direct method and 0.17 mg m^{-3} for the indirect method. Overall, the exposure patterns fluctuated without any distinct trends. Although exposure among similar groups is expected to be similar, slight changes in environmental conditions and worker movements may cause irregularities. This variability was supported by Garcia et al. (2013), who attributed the findings to in situ errors, such as worker movement, machine influences, technology used, and irregular environmental factors, such as wind velocity, temperature, and humidity (Garcıa et al., 2013).

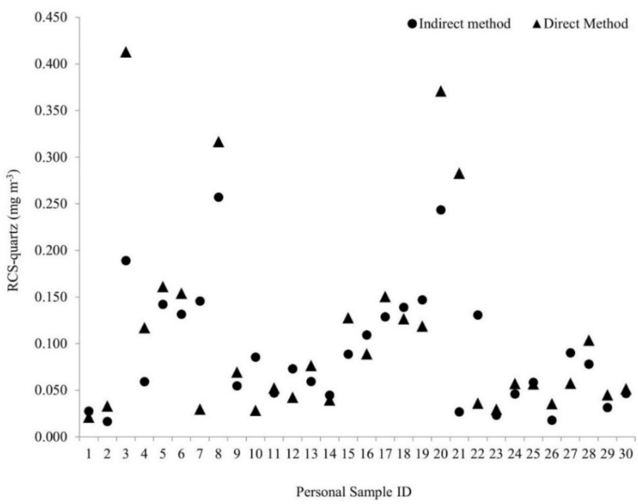

Figure 2: A Plot of Personal RCS-Quartz Exposure Based on Direct and Indirect Methods

3.2 Correlation and Regression Between Direct and Indirect Methods

The Wilcoxon signed-rank test revealed no significant differences (p>0.05) between the exposure data from both direct and indirect methods. Furthermore, the Spearman rank-order showed a positive correlation (p<0.05) between the two datasets. Regression analysis of personal exposure to RCS-quartz based on the two methods (Fig. 3) indicated a high correlation between the datasets (r^2 = 0.8172).

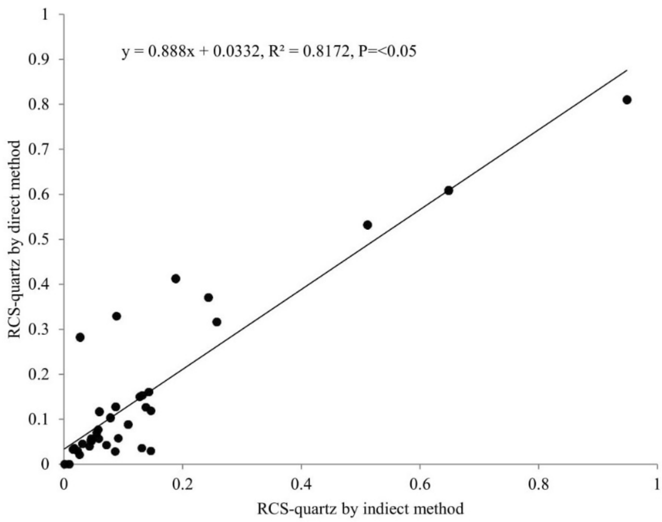

Figure 3: A Regression Plot of Personal RCS-Quartz Exposure Based on Two Methods

3.3 Compliance Status of RCS-Quartz Between Direct and Indirect Methods

Table 3 provides descriptive and inferential statistics for the time-weighted average (TWA) personal exposure to personal respirable dust based on the direct and indirect methods. The datasets displayed different arithmetic means (AM) and geometric means (GM). The AM for RCS-quartz exposure using the direct method was 0.106 mg m^{-3}, exceeding Malaysia's PEL. However, the AM for RCS-quartz exposure using the indirect method was 0.092 mg m^{-3}, which is lower than the PEL of 0.1 mg m^{-3} according to Malaysian requirements under the Occupational Safety and Health (Use and Standard of Exposure of Chemical Hazardous to Health) Regulations 2000 (USECHH Regulations 2000) (DOSH, 2000). The overall exposure range was between 0.010 and 0.413 mg m^{-3}. The highest AM for personal RCS-quartz exposure using the direct method was 0.189 mg m^{-3} in Quarry A, followed by 0.170 mg m^{-3} in Quarry E. The lowest AM was 0.058 mg m^{-3} recorded at Quarry F, followed by 0.071 mg m^{-3} in Quarry C. For the indirect method, the highest AM for RCS-quartz exposure was 0.163 mg m^{-3} in Quarry D, followed by 0.125 mg m^{-3} in Quarry B. The lowest AM was 0.055 mg m^{-3} in Quarry F, followed by 0.058 mg m^{-3} in Quarry E.

Table 3 Summary of Personal Exposure to RCS-Quartz Using Direct and Indirect Methods

Quarry	Method	N	AM (mg m^{-3})	GM (mg m^{-3})	GSD	Range (mg m^{-3})		% ≥ PEL
						Min	Max	
A	Direct	3	0.136	0.066	4.98	0.021	0.413	39.8
	Indirect	3	0.071	0.043	3.69	0.016	0.188	25.9
B	Direct	7	0.138	0.092	2.46	0.028	0.316	46.2
	Indirect	7	0.125	0.110	1.73	0.055	0.257	57.1
C	Direct	6	0.071	0.065	1.58	0.040	0.128	17.6
	Indirect	6	0.069	0.065	1.44	0.043	0.108	11.8
D	Direct	4	0.189	0.170	1.70	0.119	0.371	84.3
	Indirect	4	0.163	0.158	1.34	0.128	0.243	94.3
E	Direct	3	0.170	0.067	3.48	0.030	0.283	37.5
	Indirect	3	0.058	0.044	2.59	0.024	0.131	19.3
F	Direct	6	0.058	0.055	1.43	0.036	0.104	4.8
	Indirect	6	0.055	0.047	1.82	0.018	0.091	10.7
Overall	Direct	31	0.106	0.073	2.42	0.010	0.413	35.9
	Indirect	31	0.092	0.067	2.26	0.010	0.258	30.9

RCS-quartz, Respirable Crystalline Silica–quartz; AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; PEL, permissible exposure limit [a]; 8-hour TWA based PEL by Malaysian USECHH 2000 at 0.1 mg m^{-3}

Figs. 4-7 compare RCS-quartz exposure between direct and indirect methods using log probability plots, least-squares best-fit lines, and log-normal distributions. The GM for RCS-quartz exposure using the direct method of analysis was 0.073 mg m^{-3} and 0.067 mg m^{-3} for the indirect method. The geometric standard deviation (GSD) for RCS-quartz for the direct method and indirect method was 2.42 mg m^{-3} and 2.26 mg m^{-3}, respectively. The GSDs showed that the data represent similar exposure groups; however, the direct method had greater variance compared to the indirect method. These findings are reliable and may be used for inferential purposes. The variability of results may be due to environmental fluctuations and errors during sampling and analysis. Using the direct method, 35.9% of crusher operators were exposed to RCS-quartz levels exceeding the occupational limit (Figs. 4 and 6). However, when using the indirect method, 30.9% of crusher operators were exposed to RCS-quartz levels above the PEL (Figs. 5 and 7), based on Malaysian USECHH 2000 standards.

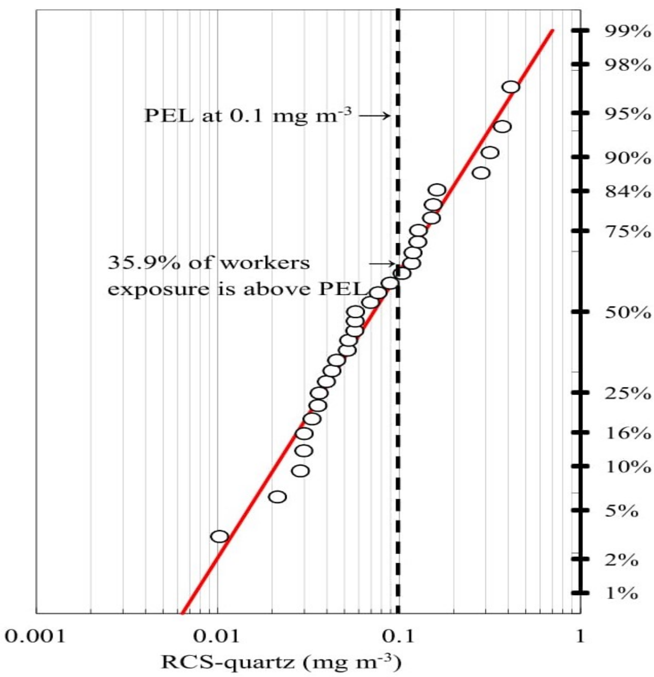

Figure 4: Log Probability Plot and Least-Squares Best-Fit Line for RCS-Quartz Exposure Using the Direct Method. PEL by Malaysian USECHH Regulations 2000 is at 0.1 mg m^{-3}

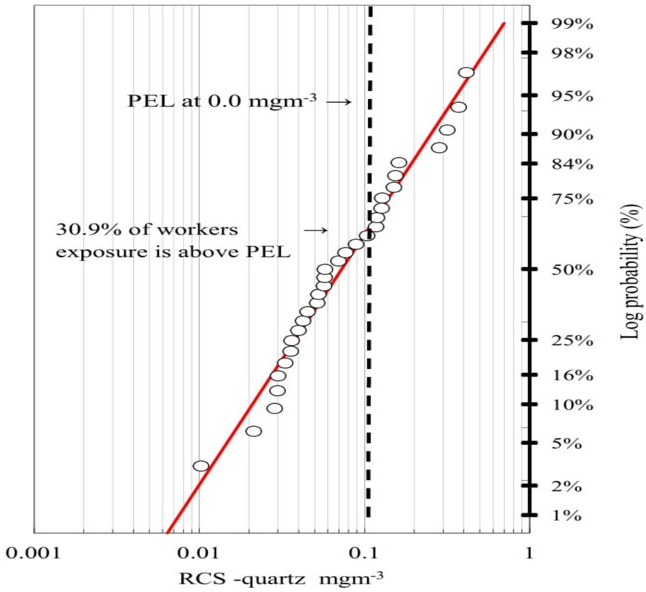

Figure 5: Log Probability Plot and Least-Squares Best-Fit Line for RCS-Quartz Exposure Using the Indirect Method. PEL by Malaysian USECHH Regulations 2000 is at 0.1 mg m^{-3}

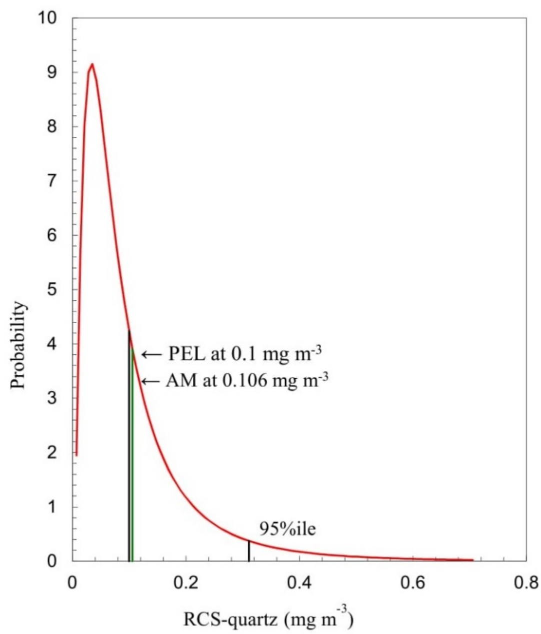

Figure 6: Log-Normal Distribution for RCS-Quartz Exposure using the Direct Method. AM, Arithmetic Mean

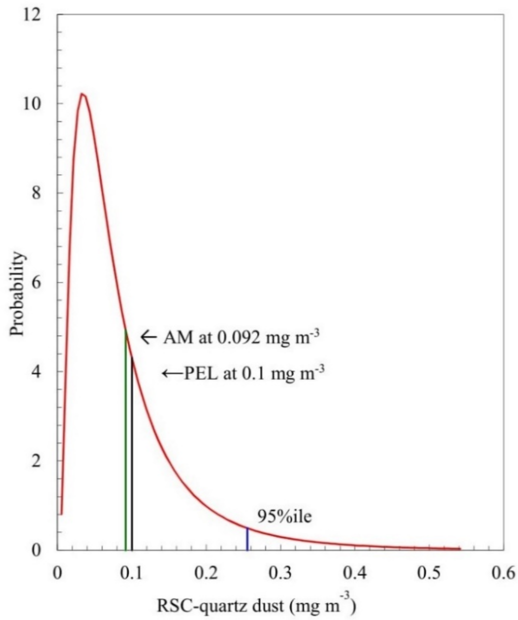

Figure 7: Log-Normal Distribution for RCS-Quartz Exposure using the Indirect Method. AM, Arithmetic Mean

3.4 Uncertainty Associated with Sampling and Analysis for Direct and Indirect Methods

Exposure-based 8-hour TWA was used to determine compliance with regulated or referred occupational limits. Statistical decision-making involves the concept of confidence intervals. When the average concentration is calculated, the exposure is unlikely to be the same as the true average concentration. The discrepancy between the calculated and true concentrations was due to sampling and analysis errors, thereby contributing to uncertainty in the final result. Based on the NIOSH sampling strategy, the accuracy of airborne concentration measurements considers four main causes of airborne concentration measurement errors: 1) random variations in the sampling device, 2) random variations in the analytical procedure, 3) systematic errors in the sampling method, and 4) systematic errors in the analytical procedure (NIOSH, 1977).

Based on this error, we calculated the uncertainty factor in the form of the coefficient of variance (CV) of the final exposure result. CV can be divided into the coefficient of variance for sampling (CV_P) and the coefficient of variance for analysis (CV_A). The CV_P arises from random variations in sampling devices and systematic errors in the sampling method (NIOSH 1977), whileCV_A originates from random and systematic analytical procedures errors (NIOSH, 1977). The total coefficient of variance (CV_T) is derived from the values of CV_A and CV_P using the following formula:

$CV_T = [(CV_P)^2 + (CV_A{}^2)]^{½}$

Where:
CV_P: coefficient of variance for sampling
CV_A: coefficient of variance for analytical
CV_T: total coefficient of variance

Table 4 lists the values of each uncertainty factor used in this study. The uncertainty calculations were based on the standard deviation (SD) of each factor. To standardise the unit of calculation, the SDs of each factor were converted to relative standard deviation (RSD) as percentage values. A lower RSD indicates less uncertainty or variability in the data.

Table 4 Uncertainty Values for CV_P, CV_A, and CV_T of the Final Results

	Uncertainty Factor	Unit	RSD for Direct Method (%)	RSD for Indirect Method (%)
Sampling Variation	Flow rate	>C	2.11	0.95
	CV for Sampling (CV_P)		0.02	0.01
Analytical Variation	Reproducibility	%	5.44	3.92
	Recovery	%	8.16	7.62
	Combined uncertainty	%	9.81	8.57
	CV for analytical (CV_A)		0.10	0.09
	Total CV(CV_T)		0.10	0.09

CV_P, coefficient of variance for sampling; CV_A, coefficient of variance for analysis; CV_T, total coefficient of variance

The CV_P for the direct method is 0.02 and 0.01 for the indirect method. The RSD of the sampling flow rate was slightly lower for the indirect method than that for the direct method because of the application of a different set of pumps. The sampling pumps used for both methods were of the same specifications and were interchangeable, but the data showed that the set of pumps used for the indirect method had fewer fluctuations and better performance than those used for the direct method. However, this factor was directly incorporated into the final uncertainty estimation.

The CV_A is 0.10 for the direct method and 0.09 for the indirect method, showing less uncertainty for the direct method compared to the direct method. The RSD for reproducibility was 5.44% for the direct method and 3.92% for the indirect method. The RSD of recovery was 8.16% for the direct method and 7.69% for the indirect method.

Overall, the total coefficient of variance (CV_T) was 0.10 for the direct method and 0.09 for the indirect method. In both methods, the CV_T was more influenced by CV_A than CV_P. The CV_T values indicated that the indirect method had less variance and better quality assurance than the direct method. This final CV_T can be incorporated into each exposure value to assess compliance status.

3.5 Effect of Uncertainty Estimation on Final Compliance Determination.

Using the CV_T values, statistical methods were used for the calculation of interval limits for estimated TWA concentrations at a 95% confidence level. The range of the average concentrations was determined using this procedure. A numerically larger limit is defined as the upper confidence limit (UCL), and a numerically smaller limit is defined as the lower confidence limit (LCL). The LCL and UCL were calculated as follows:

$$LCL\ (95\%) = Y - 1.645\ (CV_T)$$
$$UCL\ (95\%) = Y + 1.645\ (CV_T)$$

where Y is the exposure or TWA concentration divided by the occupational limit (0.1 mg m^{-3}). This formula is based on a 95% confidence interval and full-period single-sample sampling technique.

Table 5 compares RCS-quartz personal exposure using direct and indirect methods before and after considering the variances. The LCL is only calculated if results are slightly higher and UCL if results are slightly lower than the PEL value. The CV_T values are generally small and not significant enough to be incorporated into the final result if the exposure is relatively low or high compared to the occupational limit. However, in this study, UCL was calculated for each personal exposure datum. However, LCL was not reported because in the prevention approach, prediction must be based on the worst-case scenario. Table 5 shows a comparison of RCS-quartz personal exposure using direct and indirect methods after considering uncertainty factors. Adding CV_T values to the UCL calculation increased the AM, GM, and percentages above the PEL. However, the GSD for each method was reduced, indicating that each dataset had less variance and was more reliable for inferential discussions.

Table 5 Summary of RCS-Quartz Personal Exposure Using the Direct and Indirect Methods Before and After Consideration of Total Coefficient of Variance (CV_T)

	N	Direct Method				Indirect Method			
		AM	GM	GSD	% above PEL	AM	GM	GSD	% above PEL
Exposure results based on 8h TWA (before consideration of CV_T)	31	0.106	0.073	2.42	35.9	0.092	0.0667	2.26	30.9
Exposure results based on UCL (after consideration of CV_T)	31	0.121	0.093	2.1	46.1	0.103	0.085	1.90	51.8

RCS-quartz, Respirable Crystalline Silica–quartz; AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; PEL, permissible exposure limit [a]; 8-hour TWA based PEL by Malaysian USECHH 2000 at 0.1 mg m^{-3}

When interpretating each personal exposure result independently, both methods showed an increase in non-compliance cases. The direct method exposure results, based on the UCL, showed 13 non-compliance results compared to only 12 previously. Meanwhile, the indirect method showed 14 non-compliance results based on the UCL, compared to only 11 previously. These changes from compliance to noncompliance indicate possible overexposure due to uncertainty or errors during sampling and analysis. In such cases, management may struggle to make final decisions, as UCL results are not conclusive, while the results based on 8-hour TWA are questionable due to uncertainty. Therefore, it is advisable for management to consider resampling to verify actual conditions.

3.6 Variability Due to Environmental Factors

Table 6 shows the RSD values for environmental factors during sampling. Wind velocity, with an RSD reaching up to 83.3%, was the main factor affecting the uncertainty value. In this study, sampling was performed around the crusher plants, and all crusher plants were erected in open areas where the wind direction and speed are unpredictable and easily influenced by weather conditions. However, if sampling is performed under indoor conditions, these factors are minimised. Because the quarries are located in an equatorial region, humidity also plays a role in uncertainty, with an RSD of 13.9%. Temperature had the least contribution (RSD = 0.93%). The temperature differences between sampling and calibration were corrected for each sample volume calculation.

Table 6 Relative Standard Deviation for Environmental Factors

Uncertainty Factor	Unit	RSD for Direct Method (%)	RSD for Indirect Method (%)
Temperature	°C	0.93	0.93
Humidity	L min^{-1}	13.9	13.9
Wind Velocity	M s^{-1}	83.3	83.3

RSD, relative standard deviation,

In this study, variability in environmental factors was not included in the uncertainty calculations. These factors are considered random errors and should not be included in the CV_P calculation. These environmental factors may be minimised through the use of good sampling strategies.

4.0 CONCLUSION

Despite differences in the field sampling results, both the direct and indirect methods showed substantial correlation (p<0.05, r^2 = 0.82) and no significant differences (p>0.5) between the two sets of field data. Arithmetic mean (AM) exposure levels for RCS-quartz were reported to be 0.106 m gm^{-3} and 0.092 m gm^{-3} for the direct and indirect methods, respectively. Log probability plots indicated that 35.9% of crusher operators were exposed to RCS-quartz levels exceeding the exposure limit using the direct method, compared to 30.9% of crusher operators using the indirect method.

The total coefficient of variance (CV_T) was 0.10 for the direct method and 0.09 for the indirect method, with CV_T being more influenced by CV_A than by CV_P in both methods. Overall, the CV_T values indicated that the indirect method had less uncertainty and better quality assurance compared to the direct method. This final CV_T can be incorporated into each exposure value to determine compliance status. Herein, integrating the CV_T value into the UCL calculation showed an increasing number of non-compliance results. The direct method exposure results based on the UCL showed 13 non-compliance results compared to only 12 previously. Meanwhile, the indirect method showed 14 non-compliance results based on the UCL compared to only 11 previously.

In addition to instrument accuracy during sampling and analysis, the variability may also be affected by environmental factors. Wind velocity was the main factor contributing to environmental uncertainty, with an RSD of up to 83.3%. Humidity was also a determinant of environmental variation, with an RSD of 13.9%, while temperature contributed the least, with an RSD of only 0.93%. This study showed that there were no significant differences between the direct and indirect methods, providing industrial hygienists and researchers with flexibility to utilize the direct method based on cost-effectiveness, efficiency, and ease of implementation.

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Short Communication

HIRARC Development from Industrial Case-Based Study for TVET Students Using Peeragogy Learning Method

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ABSTRACT: *Hazard Identification, Risk Assessment and Risk Control (HIRARC) is used as a risk analysis tool in many industries in Malaysia, such as manufacturing, construction, agriculture, public services, hotels, and restaurants. Therefore, Technology and Vocational Education and Training (TVET) students need to understand HIRARC in preparation for the real workplace. Proficiency in HIRARC requires students to understand key terms, such as hazard, standard operating procedure (SOP), risk analysis, likelihood and severity, and methods to control risk levels with appropriate and efficient countermeasures. For the diploma in process engineering (Petrochemical), HIRARC is introduced in the Occupational Safety and Health for Engineering subject. This study proposes peeragogy learning as a method to enable process engineering students to explore and develop HIRARC based on industrial case-based studies under the supervision of their lecturer. They can help students learn better while providing teachers with better ways to teach.*

Keywords*: Department of Occupational Safety and Health (DOSH), Hazard Identification, Risk Assessment and Risk Con trol (HIRARC), Peeragogy, Standard Operating Procedure (SOP), Technology and Vocational Education and Training (TVET)*

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1.0 INTRODUCTION

Hazard Identification, Risk Assessment and Risk Control (HIRARC) provides a structured and comprehensive approach for managing workplace risks. The implementation of HIRARC helps organisations comply with safety regulations, reduce risk levels, and promote a safe working environment. The development of HIRARC was based on the 2008 Guidelines for

HIRARC produced by the Department of Occupational Safety and Health (DOSH). The following reasons highlight the importance of implementing the HIRARC.

1. **Safety:** HIRARC is primarily used for safety management. It helps to identify potential hazards, assess associated risks, and implement control measures to prevent accidents, injuries, or fatalities. Prioritising safety is crucial for protecting employees, visitors, and public.

2. **Legal Compliance:** Many countries and industries have regulations and legal requirements related to risk management and safety. Conducting HIRARC helps organisations comply with these laws and regulations, thus reducing the risk of legal consequences and penalties.

3. **Cost Savings:** Effective risk management can lead to cost savings. By identifying and mitigating risks early, organisations can reduce expenses related to accidents, injuries, property damage, and insurance premiums. This can improve the financial health of organisations.

4. **Reputation Management:** Incidents involving safety breaches or accidents can damage an organisation's reputation. HIRARC helps prevent such incidents, which, in turn, maintains the reputation and credibility of the organisation.

5. **Employee Morale:** A safe working environment can enhance employee morale and job satisfaction. When employees feel safety is a priority, they are more likely to be engaged, productive, and loyal to the organisation.

6. **Efficiency and Productivity:** HIRARC can improve the efficiency of operations by proactively addressing risks. It helps organisations identify bottlenecks, inefficiencies, and potential disruptions and take the necessary steps to mitigate them.

7. **Continuous Improvement:** HIRARC is not a one-time process; it is an ongoing cycle. Regularly reviewing and updating risk assessments allows organisations to adapt to changing circumstances, technologies, and environments by fostering a culture of continuous improvement.

8. **Environmental Protection:** HIRARC is not limited to safety, as it also includes environmental risks. It helps organisations to identify and address risks that may harm the environment by allowing for more sustainable and responsible practices.

In summary, the HIRARC is important because it helps organisations identify, assess, and control risks in a systematic and structured manner. This would not only enhance safety but also have broader positive impacts on the financial stability, reputation, employee well-being, and overall efficiency of an organisation.

Peeragogy, or 'peer-directed pedagogy', is a collaborative and participatory approach to learning and education that emphasises the active involvement of learners in shaping the learning process. In peeragogy, the traditional roles of teachers and students are blurred and the focus shifts towards a community-driven learning experience. This method is inspired by the principles of peer-to-peer collaboration, open-source software development, and social learning. The principles of peeragogy include self-determined roles, coteaching, coworking, colearning, and self-determined questions. Teaching HIRARC using peeragogy may increase students' level of understanding by allowing them to explore every part of HIRARC through discussions, collaborations, and presentations, compared to sitting in class and listening to a lecturer. Peeragogy is a collaborative and peer-driven learning approach that can be beneficial in teaching HIRARC in several ways.

1. **Self-Directed Learning:** Peeragogy promotes self-directed learning in which participants take ownership of their learning journeys. In the HIRARC, individuals must take responsibility for identifying and addressing risks. Peeragogy helps students develop the initiative and self-discipline required to excel.

2. **Active Engagement:** Peeragogy promotes active participation and engagement. Students are not passive recipients of information but active contributors to the learning process. In the context of HIRARC, this can lead

to thorough risk assessments, as students can actively discuss, analyse, and question the information and scenarios presented to them.

3. **Collaborative Learning:** HIRARC often involves teamwork and collaboration in real-world situations. Peeragogy mirrors this involvement by fostering collaborative learning environments. Students work together, share knowledge, and solve problems that align with the collaborative nature of risk assessment and control in professional settings.

4. **Problem-Solving Skills:** Hazard identification and risk assessment require strong problem-solving skills. Peeragogy encourages participants to collaboratively solve problems and make decisions, thus honing their critical thinking and decision-making abilities, which are directly transferable to HIRARC.

5. **Feedback and Peer Review:** In peeragogy, participants often provide feedback to their peers. This feedback can be invaluable in the context of HIRARC as it mimics the real-world practice of reviewing risk assessments and control measures. Peer reviews help students refine their skills and identify potential blind spots or areas for improvement.

Incorporating peeragogy into the teaching of HIRARC can create a dynamic and effective learning environment that not only imparts knowledge but also fosters the skills, attitudes, and collaborative abilities needed to excel in risk assessment and management.

The main objective of this short study is to provide a sample of industrial case-based studies for TVET students to develop HIRARC using the peeragogy learning method (2.0) and teaching lesson plan (3.0) as guidance for a TVET lecturer to conduct the peeragogy classes.

2.0 INDUSTRIAL CASE-BASED STUDY

The health and safety of employees are key concerns for most businesses. Although numerous countermeasures have been implemented, workplace accidents, injuries, and deaths continue to occur at alarming rates. The total number of workplace accidents that occurred in 2022 was 6,719, a slight increase from the number of cases in 2021 (6,686 cases), based on data provided by the DOSH. Table 1 lists the number of cases reported in each state of Malaysia. The impact of workplace accidents can be significant, affecting the individuals involved and the organisation. Workplace accidents can have various consequences affecting both human well-being and business operations. The following are some key aspects of the impact of workplace accidents:

1. Healthcare Costs;
2. Loss of Productivity;
3. Legal and Regulatory Consequences;
4. Reputation Damage;
5. Operational Disruption; and
6. Increased Insurance Costs.

Table 1 Statistics of Occupational Accidents by State from January to November 2022 (Reported to DOSH Only)

STATE	NPD	PD	DEATH	TOTAL
JOHOR	1082	59	24	1165
KEDAH	396	3	7	406
KELANTAN	115	4	5	124
MELAKA	362	7	2	371
N SEMBILAN	382	13	6	401
PAHANG	366	9	19	394
PERAK	747	26	20	793
PERLIS	12	0	2	14
PULAU PINANG	695	15	13	723
SABAH	227	22	9	258
SARAWAK	290	26	20	336
SELANGOR	1301	38	29	1368
TERENGGANU	135	3	11	149
WPKL	188	1	19	208
WP LABUAN	8	1	0	9
TOTAL	6306	227	186	6719

LEGEND:
PD - PERMANENT DISABILITY
NPD- NON PERMANENT DISABILITY

ISO 45001:2018 (Occupational Health and Safety Management Systems) provides the minimum standard set of practices for employee protection. ISO 45001:2018 is important for several reasons.

1. Enhances worker safety and reduces workplace accidents;
2. Ensures legal compliance in occupational health and safety;
3. Boosts employee morale and job satisfaction;
4. Reduces costs related to accidents and illnesses;
5. Enhances the reputation and competitiveness of an organisation;
6. Improves operational efficiency and productivity;
7. Provides a framework for risk management and continuous improvement; and
8. Enables global recognition and access to international markets.

To qualify for ISO 45001:2018 accreditation, HIRARC is an important element that must be complied with. The HIRARC is a compound word representing three consecutive activities. These activities include Hazard Identification, Risk Assessment, and Risk Control. Hazard identification refers to the act of recognising objects that may cause injury or harm to a person. Risk assessment focuses on the possibility of injury or harm to a person if they are exposed to a hazard. Introduction of measures to eliminate or reduce the risk of a person being exposed to a hazard is known as risk control. Table 2 presents the HIRARC forms according to the 2008 HIRARC guidelines.

Table 2 Hazard Identification, Risk Assessment & Risk Control Table (HIRARC) Form

TITLE :
DEPARTMENT:
LOCATION / EQUIPMENT:

HIRARC NUMBER :
PREPARED BY :
DATE :

1. HAZARD IDENTIFICATION					**2. RISK ANALYSIS**				**3. RISK CONTROL**		
NO	R/NR	WORK ACTIVITY	HAZARD	EFFECT	EXISTING CONTROL	L	S	RISK	RECOMMENDED CONTROL MEASURES	PIC	DUE DATE/ STATUS

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard / event being realized	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometime in future	3
Remote	Has not been known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

SEVERITY (S)	EXAMPLE	RATING
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruises, cuts, first aid type injury	1

	Severity (S)				
Likelihood (L)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

High

Medium

Low

RISK	DESCRIPTION	ACTION
15 - 25	HIGH	A HIGH risk requires **immediate** action to control the hazard as detailed in the hierarchy of control. Actions taken must be documented on the risk assessment form including date for completion.
5 - 12	MEDIUM	A MEDIUM risk requires a planned approach to controlling the hazard and applies temporary measure if required. Actions taken must be documented on the risk assessment form including date for completion.
1 - 4	LOW	A risk identified as LOW may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

Figure 1: Indications of Likelihood, Severity and Risk Level

HIRARC is applied mostly in technical industries. As a diploma holder in Process Engineering, the ideal job is that of an Assistant Engineer in the production team of the process and manufacturing industry. Chemical mixing processes are typically employed in industrial engineering. In these processes, two or more chemicals are combined in specific proportions to create new chemical mixtures or solutions. These processes are widely used in various industries such as manufacturing, pharmaceuticals, agriculture, food production, and cosmetics. The goal of chemical mixing is to achieve desired chemical reactions, physical properties, or end products by carefully controlling the composition and conditions of the mixture. The following hazards are common during chemical mixing.

1. Work environment (fire or hot temperature);
2. Mechanical (being caught between machines); and
3. Chemicals (flammable, corrosive, or toxic).

This study presents the development of HIRARC as a chemical mixing process. The HIRARC that is developed must follow DOSH guidelines and include the following activities.

Activity 1: Group Formation

To solve this industrial problem, a team of four (4) people needs to be formed.

Activity 2: Group Role Selection

In every group, participants are assigned the following roles:

1. SOP Developer;
2. Hazard Assessor;
3. Risk Assessor; and
4. Control Measure Person in Charge (PIC).

Activity 3: Group Discussion

Based on the roles listed above, a specific task for each team member was identified.

1. SOP Developer: Develops a detailed working procedure.
2. Hazard Accessor: Identifies the hazard based on the working procedure: chemical, physical, biological, etc.
3. Risk Accessor: Calculates the risk based on likelihood versus severity and determines the risk level.
4. Control Measure PIC: Suggests the appropriate control measure to reduce the risk level.

Then, according to the collected information, a complete HIRARC based on the 2008 HIRARC guidelines should be prepared.

Activity 4: Group Presentation
Present the HIRARC based on the role of each individual.

3.0 PEERAGOGY LESSON PLAN FOR LECTURER

Table 3 HIRARC Lesson Plan (Peeragogy)

Teaching plan	Description	Principle
Induction	To qualify for ISO 45001:2018 accreditation, HIRARC is an important element to be complied with. ISO 45001:2018 ensures safety and legal compliance, improves the efficiency of processes, and enhances the reputation of the company. As a production team in the chemical mixing process, they need to develop HIRARC in the process area to increase work safety. The HIRARC that will be developed needs to follow the 2008 HIRARC guidelines. Teachers need to perform the following: 1. Explain what ISO 45001:2018 entails in detail. 2. What is an example of a chemical mixing process in industry? 3. Provide real-world examples or case studies of the mixing process, such as chemical contact that can cause irritation or corrosiveness. 4. What is the guideline for HIRARC development?	PEERAGOGY
Activity	Activity 1: Group Formation Form a team of four persons to develop HIRARC in the chemical mixing process department.	Self-determined roles
	Activity 2: Group Role Selection To develop HIRARC in the mixing process department, several roles have been created. Discuss and self-appoint your group members according to these roles: 1. SOP Developer; 2. Hazard Assessor; 3. Risk Assessor; and 4. Control Measure Person in Charge (PIC).	Self-determined roles
	Activity 3: Group Discussion Based on the given role, collaboratively discuss your findings to obtain complete information to develop an HIRARC. 1. SOP Developer: develop detailed working procedures. List and identify all working procedures for the activities involved in the process area. Explain these working procedures to all team members in the chemical mixing process area. 2. Hazard Assessor: According to the list of working procedures, identify all chemical, physical, and biological hazards. Explain all hazard findings to the team members in the process area. 3. Risk Assessor: Calculate the risk level based on the likelihood and severity level. Establish a list of risk levels for each activity during the mixing process. Explain all risks to the team members in the process area. 4. Control Measure PIC: According to all gathered information, suggest appropriate control measures to reduce the risk level of every activity during the mixing process. Prepare a complete HIRARC based on DOSH	Co-teaching Co-working Co-learning

	guidelines. Explain to the team members every proposed control measure to reduce accident risks in the process area.	
	Activity 4: Group Presentation Present the generated HIRARC form to the class. Other groups need to share their feedback on the presented HIRARC form.	Co-teaching Co-working Co-learning Self-determined questions
Reflection / Assessment	Reflection will be done based on Peer Evaluation of the following activities: Activity 1–3: Evaluation will be done by each team member within the group. May refer to any suitable rubric for evaluation. Activity 4: Evaluation will be done by the class members during the presentation session. May refer to any suitable rubric for evaluation.	Co-learning

4.0 CONCLUSION

Currently, numerous teaching methods are available to ensure that students achieve their learning objectives, such as andragogy, peeragogy, heutagogy, and cybergogy. These learning methods are compatible with the current tech-savvy world and meet the needs of fast-paced industries. Previously, teachers or lecturers stood in front of the class and provided information to students during the learning and teaching processes. With the emerging and latest technology trends, TVET students need to adapt to the industrial revolution and become more proactive in gaining knowledge. When we talk about the use of peeragogy to learn about HIRARC, we think of it as teamwork. This is when everyone in a team offers ideas for solving a puzzle. HIRARC is practical, hands-on, and works together using peeragogy is essential. In this short study, the industrial case-based sample (2.0) and teaching plan (3.0) for the development of HIRARC have been provided as alternatives for lecturers and TVET students to explore and develop HIRARC using the peeragogical learning method. The teaching methods provided in this study were similar to those of a two-in-one tool. They can help students learn better while providing teachers with better ways to teach.

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Guidelines for Hazard Identification, Risk Assessment and Risk Control (HIRARC), 2008.

Original Article

Application of the Cause and Consequence Diagram to MLA Active Safety Barrier System

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ABSTRACT: *Safety barriers to Liquefied Natural Gas (LNG) systems can be physical and engineered systems or human actions based on specific procedures or administrative controls. Studies have not sufficiently examined the integration of safety barriers, risk, reliability, and performance on the total safety of the LNG Marine Loading Arm (MLA) terminal system. Therefore, this study attempts to assess the underlying effects of the MLA safety barrier failure. To this end, a cause and consequence analysis was performed by integrating the dynamic fault tree analysis with the cause-and-consequence model of the emergency shut-down system of the MLA. The MLA unit's safety barrier consists of the emergency shut down (ESD), powered emergency release coupling (PERC), cargo control room, and fire and gas detectors. The ESD has the highest failure rate of approximately 1.56x10–6 hours, while the PERC has the lowest failure rate of 1.7x10–13 hours. The safety barrier system was found to be highly reliable, with a reliability of approximately 99%. Six scenarios were assessed for the loss of containment event. The worst-case scenario was simulated to be fire or the formation of a vapour cloud. For the safety barrier system, the probability of a worst-case scenario was estimated at 3.2x10–7/year and is improved by 62.5% when a redundant system is in place. This work shows that the integration of risk assessment and consequence modelling can provide a quantitative estimate for a system with a failed barrier. It also provides some justifications for determining the set-up of the safety barrier system for a specific unit.*

Keywords: *Cause-Consequence Diagram, Dynamic Fault Tree Analysis, Marine Loading Arm, Redundancy*

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1.0 INTRODUCTION

Safety barriers to Liquefied Natural Gas (LNG) systems can take the form of physical and engineered systems or human actions based on specific procedures or administrative controls (De Dianous & Fievez, 2006; Hollnagel, 2008). The safety system is classified into high- and low-level safety systems (Aneziris et al., 2021). The low-level safety systems include boil-off removal, thermal insulation, venting pressure safety valves or rupture discs, high-pressure control systems, reduction or termination of loading, and corrosion protection (Aneziris et al., 2021).

1.1 Safety barriers

According to Aneziris et al. (2021), under their safety barriers categorisation, the current LNG high-level safety barriers design for an LNG terminal usually consist of four main parts: the emergency shut down (ESD), powered emergency release coupling (PERC), cargo control room (CCR), and fire and gas (F&G) detector.

The ESD is designed to minimise the consequences of an incident (SIGTTO, 2021). In an LNG terminal, the ESD is used to shut down, isolate the leaking pipe section, and depressurise the system by stopping the primary pumps and closing the valves to avoid large liquid spills (SIGTTO, 2021). The system is automatically activated in response to signals sent by F&G detectors, process alarms (pressure loss in a pipe), or when an operator manually pushes an ESD button (SIGTTO, 2021). This system acts in response to a loss-of-containment scenario, thus interrupting the release and affecting the consequences associated with the leakage.

The CCR monitors and controls the loading and unloading operations, pumps, heating, cargo conditions, and cargo-handling equipment (Francisco & Miguel, 2012). It is developed based on an integrated automated system that combines the reliability of both operators and stations (Sastry & Seekumar, 2012).

F&G detectors are optical detection devices that respond to the optical radiant energy emitted by fires or LNG leaks. They are responsive to infrared or ultraviolet radiation. The F&G detector system spots the release and sends a signal to the ESD system. The ESD interrupts the process to minimise the impact of the loss of containment. An analysis of the Health and Safety Executive Offshore Hydrocarbons Release Database (2001–2008) revealed that approximately 36% of major gas releases and 69% of significant gas releases were not detected by gas detectors (McGillivray & Hare, 2008).

The PERC is a current unit used in an LNG transfer system (Manntek PERC Brochure, n.d.). In emergency cases such as tsunamis, fire catastrophes, or strong currents that force a tanker to suddenly move away from the berthing line, the PERC detaches the loading arms from the tanker. The action of the PERC combines the activation of the emergency release system valve and the release of the emergency release coupler. As a safety measure, the valves next to the PERC close quickly (usually in less than 5 seconds) after the emergency disconnection has begun. Figure 1 shows the layout of the PERC system.

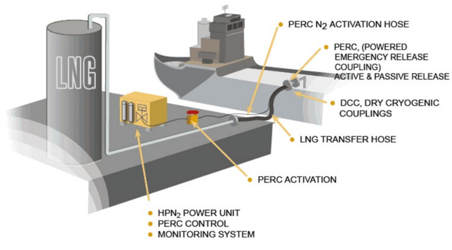

Figure 1: Layout of the PERC System (*Manntek PERC Product Data Sheet Brochure*, n.d.)

1.2 Cause and consequence analysis

Cause-consequence analysis (CCA) is an alternative assessment approach capable of modelling all system outcomes on a single logic diagram. It is a combination of event and fault tree analyses. Event tree analysis shows the consequences and fault tree analysis shows the causes. Hence, deductive and inductive analyses were combined using the CCA approach. CCA aims to identify chains of events that can result in undesirable consequences. Ortmeier et al. (2005) proposed a deductive CCA. The CCA approach has been applied by various research groups, including those in the rail industry (Güdemann et al., 2007). Vyzaite et al. (2006) combined a binary decision diagram with CCA for a non-repairable system, whereas Cleaver et al. (2007) and Woodward and Pitblado (2010) used the CCA approach to evaluate the safety barriers of LNG systems.

Most papers that have been reviewed focus on the performance of the safety barriers and qualitatively integrate them with the risk assessment (Hollnagel, 2008; Rathnayaka et al., 2012; Aneziris et al., 2021). Some studies focused only on ESD systems (Mirzaei Aliabadi et al., 2021). According to the MLA studies performed by Hanggara et al. (2017), Devianto et al. (2018), and Siswantoro et al. (2022), a gap remains in the integration of safety barriers, risk, reliability, and performance studies on the total safety of the LNG MLA terminal system. This study presents a detailed reliability analysis combined with CCA to assess safety barrier performance.

2.0 METHODOLOGY

Figure 2 illustrates the framework used in this study. Failure data obtained from the literature were calculated using the developed algorithm. Simulation results were processed to obtain dynamic failure data by incorporating the results into an Excel file. The obtained results were used to calculate the constant parameters for the reliability model and to construct and calculate the probability of failure using the dynamic fault tree approach. The total failure and reliability profiles of the entire system were then estimated using the data generated from a Monte Carlo simulation (MCS). The failure data were later embedded into a cause-consequence diagram to visualise the overall impact of the failure.

2.1. Estimation of the failure parameters

The failure probability was estimated by first collating failure data from various literature and resources, such as OREDA, SINTEF, and Faradip.Three. These data cover important components that configure safety barrier systems, including the ESD, PERC, CCR, and F&G. As the obtained failure data were based on the failure of a single unit, any component that commonly exists in redundancy is shown as two units in the table. The calculated failures for each system are listed in Tables 1, 2, 3, and 4. This assumption states that the failure of any component within the system contributes to the overall failure of the system. For a system with redundant units, failure was recalculated and later embedded in the overall failure calculation of the system. Using an MCS and the method of moment approach, the parameters of the Weibull distribution as well as the failures of the repairable components were estimated. The failure profile was assumed to be exponentially distributed, unless specified otherwise. This indicates that if the survival time is assessed up to time (t), the failure rate will be constant for all times up to t for irreparable components. The reliability of the overall system was estimated by combining the failures of the repairable and irreparable components.

2.2. Application of cause consequence analysis

CCAs were performed by identifying a scenario that could occur owing to the loss of containment. In this study, the performance of safety barriers in a marine loading arm (MLA) unit was assessed. The previously calculated failure values were inserted into the scenario study, and the probability of an event occurring was evaluated. In the presented case study, the ESD was designed to have an active parallel redundant system. Six distinct scenarios, as illustrated in Figure 3, were considered and estimated as follows:

- P(Sc1&Sc2) = [(P(A)` x P(B)` x P(C)`) x P(D)`]
- P(Sc3) = [P(A)` x P(B)` x P(C)` x P(D)]
- P(Sc4) = [P(A)` x P(B)` x P(C)]
- P(Sc5) = [P(A)` x P(B)]
- P(Sc6) = P(A)

The reliability value for the identical parallel redundant system was calculated using the following equation:

$R_s = 1-((1-R_1) \times (1-R_2))$.

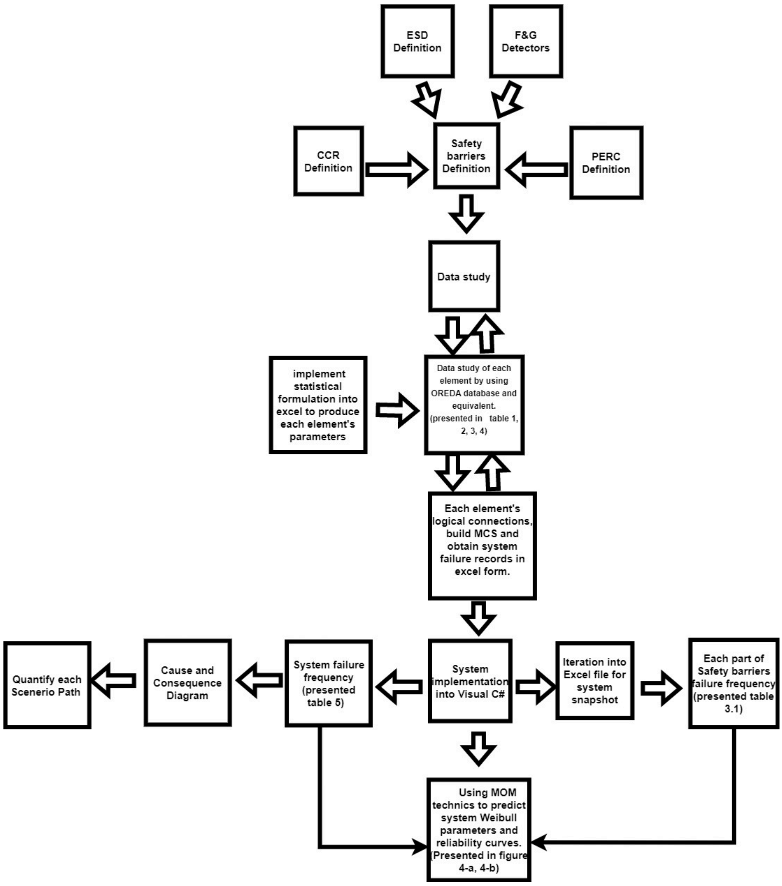

Figure 2: Methodology Framework

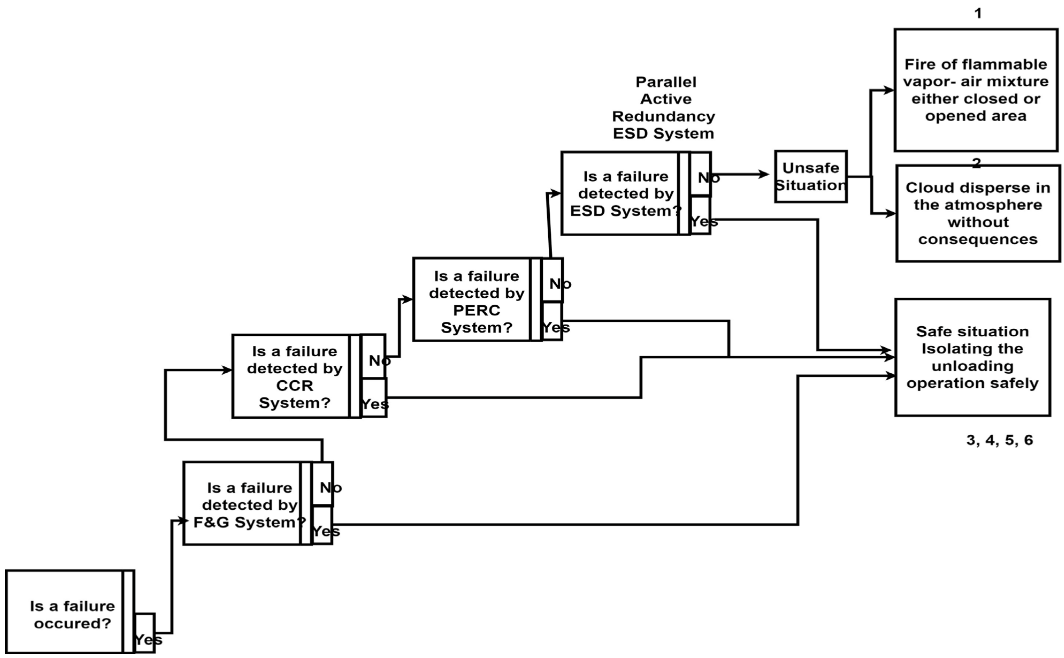

Figure 3: Cause Consequence Diagram of the Marine Loading Arm System with an ESD Redundancy

Table 1 Calculated Failure Rates for Components in Emergency Shut Down System

Component	Type	Redundancy	Failure rate (per year)	Source data	Component	Type	Redundancy	Failure rate (per year)	Source data
Flowmeter	Sensor	2	$4.2x10^{-7}$		Hard wired system (digital output)	Final element	1	$2.6x10^{-4}$	
	Logic unit	2	$2.85x10^{-5}$		Hard wired (safety system input)	Final element	1	$3.5x10^{-4}$	
	Final element	2	$4.23x10^{-6}$		Hard wired system Logic	Final element	1	$2.6x10^{-4}$	
PSV	Final element	1	$2.2x10^{-10}$		PLC analog input	Final element	2	$6.1x10^{-3}$	
ESD Compressor	Sensor	2	$4.2x10^{-7}$		PLC CPU	F.E	2	$3x10^{-2}$	
	Logic unit	2	$2.85x10^{-5}$		PLC digital output	F.E	2	$6.1x10^{-3}$	Faradip.Three
	Final element	2	$1.9x10^{-5}$		Programmable safety system analog	Final element	2	$1.4x10^{-3}$	
	Sensor	2	$4.2x10^{-7}$	OREDA	Programmable safety system CPU	Final element	2	$4.2x10^{-3}$	
	Logic unit	2	$2.85x10^{-5}$		Programmable safety system digital output	Final element	2	$1.4x10^{-3}$	
	Final element	2	$1.9x10^{-5}$		Circuit breaker	Final element	2	$2.6x10^{-3}$	
CMOS Logic part	Final element	1	$6.7x10^{-5}$						
Temperature sensor	Final element	1	$5.6x10^{-08}$						
Logic unit	Final element	1	$7.5x10^{-08}$						
Pressure sensor (Electro-mechanical)	Final element	1	$5x10^{-08}$						
UV/IR sensor	F.E	1	$4.3x10^{-08}$						
ESD shut down relay (Sammarco, 2007)	F.E	1	$5.88x10^{-04}$						
Total system failure rate								**$1.56x10^{-6}$ hour^{-1}.**	

Table 2 Failure Rates for Cargo Control Room System

Component	Redundancy	Failure (λ) per year (Norsk olje & gass, 2018)
Pushbutton	2	$5.0x10^{-5}$
Redundant programmable safety system (PLC and I/O)	2	$3.5x10^{-3}$
Main bore valve incl. DCV and close assist accumulator	2	$1.2x10^{-3}$
Annulus valves and cross-over valves	2	$6.1 \cdot 10^{-4}$
PLC analog input	2	$6.1x10^{-3}$
PLC CPU	2	$3x10^{-3}$
PLC digital output	2	$6.1x10^{-3}$
Ship's pump	2	0.35
Total failure of the CCR system		$3.31x10^{-7}$ $hour^{-1}$

Table 3 Failure Rates for PERC System

Component	Redundancy	Failure (λ) per year (Norsk olje & gass, 2018)
PERC logic unit (I/O)	2	0.0061
Digital output	2	0.0014
Control logic unit/Hard wired system/(analog input)	2	0.0003
PERC logic unit (I/O)	2	0.0061
ESD logic unit	2	0.0002
Circuit breaker	2	0.0026
Relay	2	0.0017
Break-away valve	2	$1.2x.10^{-7}$
Total failure of the PERC system		$1.7x10^{-13}$ $hour^{-1}$

Table 4 Failure Rate of F&G Detectors

Components	Redundancy	1/MTBF λ (/hour)	Data source
Flame detector	2	0.05×10^{-8}	Faradip.Three
Gas detector-IR (SI-111)	2	0.03×10^{-8}	
Gas detector–IR point	2	0.028×10^{-8}	
RS 232 inverter	2	5.79×10^{-6}	
Sensor loop	2	2.7×10^{-6}	
Electronic interfaces	2	2.3×10^{-6}	
Audio/video signalling device	2	4.38×10^{-6}	
Splitter board	2	2.3×10^{-7}	
Hardwire	1	10^{-9}	
Total failure of the F&G detectors		1.53×10^{-11} hour^{-1}	

3.0. RESULTS AND DISCUSSIONS

The failure data for all repairable and irreparable systems were estimated based on data collated from the literature. The failure of a single device was assumed when all the components existing in the duplicate were not explicitly described.

3.1 Failure rate of components

The failure rates of each component acting as a safety barrier for the MLA unit are listed in Table 5.

Table 5 Overall Failure Estimates for the Safety Barrier System

Safety barrier component	Overall failure (hour^{-1})	Remarks
ESD	1.56×10^{-6}	Highest failure: ESD pump
CCR	3.31×10^{-7}	
PERC	1.7×10^{-13}	
F&G detector	1.53×10^{-11}	

The ESD system component with the highest failure rate was the ESD pump with an estimated failure rate of approximately 0.0134 per year. LNG unloading line components, such as unloading pumps and valves, contribute significantly to the pressure during ESD activation. Regarding the CCR system, the failure of all redundant pump units is required for overall system failure to occur. However, because most components of a CCR system involve fluid movement, a higher probability of failure may occur. The most reliable component of the safety barrier of an MLA unit is the PERC system. These components are mostly electronic components that have high reliability and exist in redundancy, making failure almost impossible.

3.2 Reliability estimation of the MLA system

An MCS was used to assess the reliability of the MLA system because it can generate random numbers that can imitate the failure behaviour in real processes. The simulation was integrated into the Visual Studio C# algorithm, and the risk frequency was assessed. In this study, an MCS was performed for a one-year service period. As shown in Figure 4-a, within the one-year service period, approximately 8760 iterations were performed, and a reliability curve for each safety barrier was generated. The ESD system with repairable components failed 24 times within 8760 iterations. The samples of time extracted for the failures were 3, 6, 1921, 4163, 4882, and 6918 hours. With these data, the Weibull parameter estimates were determined; the values were β equals 0.6970 and α equals 21761 h. The reliability of the ESD system at the end of its one-year service life was estimated to be 60%. Similar reliability calculations were performed for the CCR, PERC, and F&G systems to obtain their reliability data; they obtained 99% (CCR), 98% (PERC), and 99% (F&G). These data were embedded in the CCD to identify the overall impact of the leakage scenario. For the overall safety barrier system shown in Figure 4-b, a longer service period of 300,000 hours (32.5 years) was assessed. The reliability of the safety barrier system decreased to 60% at the end of 96,000 service hours.

(a) (b)

Figure 4: Reliability Profiles for (a) ESD System and (b) Safety Barrier System

Based on the iterations performed, the ESD system had 24 failures in 8760 iterations (0.27 failures per iteration), while CCR and PERC had one failure each in 15000 iterations (6.67×10^{-3} failures per iteration). The F&G detectors had no failures within a one-year period. For an ESD system, electronic parts have high reliability, whereas mechanical parts fail more frequently. For the overall safety barrier system, the MCS was regenerated 300,000 times, where each iteration was considered as a one-hour service time. The system failed 193 times in 32.5 years. Some time failures were 4, 28, 86 132, 95 118, 162 305, 205 836, 212 940, 285 804, and 299 977. Using the method of moments approach, the parameters for the Weibull distribution of the total system were estimated, and the values obtained were α = 163372 h, and β = 1.35.

3.3 Cause and consequence analysis of the MLA system

The previously calculated reliability values for each system were integrated into the CCD diagram and equations, as described in Section 2.2. Six different failure scenarios or series of events were assessed, and the probability of an event occurring was estimated based on the given scenario.

The first path, designated as Scenarios 1 and 2 and classified as unsafe conditions, can occur when there is a leak or failure that can lead to a loss of containment event. None of these safety barriers can detect failures sequentially. Triggering events can lead to consequences such as fire in either closed or open areas or cloud dispersion in the atmosphere. If there is no ignition source, there might be no further consequences; however, if the wind speed is high and the cloud is moved to a place with a possible fire source, it can be ignited, leading to a vapour cloud explosion. The probability of Scenarios 1 and 2 occurring was estimated at 3.2×10^{-7} (per year).

With the exception of the previously described event, the other event paths were considered safe because at least one safety barrier component could detect the system. The probability of safe events occurring was calculated as follows:

- Event 3: 1.68×10^{-6} (per year). Leak or release events were only detected by the ESD (fourth tier) system.
- Event 4: 1.98×10^{-4} (per year). The event was detected by the PERC (third tier) system and quickly isolated.
- Event 5: 9.8×10^{-3} (per year). This event was detected early by the CCR system and subsequently isolated.
- Event 6: 0.99 (per year). Loss of containment was detected using the F&G system and directly isolated.

From the above scenario, it is evident that for any event detected, the system will be isolated, operation will be stopped, and pressure will be reduced. A sequence of safe operations is important such that the leak source can be identified and repaired accordingly. When the ESD was run in a redundant active parallel system, the reliability value was recalculated; the reliability of the ESD was increased to 84%. With the improvement in the reliability of ESD, the overall probability of an event occurring in Scenarios 1 and 2 was also reduced by a factor of 2.5.

4.0 CONCLUSION

The application of the MCS and adaptation of the method of moments approach were successfully presented in this study when preventive maintenance was not considered. In other words, research can estimate the number of failures that a system will experience if it does not intervene in preventive maintenance. Another important factor in failure is the human factor, which was omitted from this study. With the integration of failure and CCAs, the quantitative values of the event probability with its respective event scenario were assessed under these circumstances. The ESD had the lowest reliability among all safety barrier components in the MLA system. When designed as an active parallel redundant system, the overall reliability of the ESD system improved from 60% to 84%. With this improvement, unsafe conditions such as fire or vapour cloud formation can be prevented by a factor of 2.5. This study demonstrated that predicting the reliability or failure probability of a system by incorporating the failures of basic components and performing simulations over a service period is possible. Comparing the reliability of the safety barrier systems, valves are the most reliable components, whereas mechanical parts, especially diesel engines, are the least reliable. The degree of importance of each element should be investigated in future studies. Finally, by embedding the CCA in the analysis, safety analysts can define and defend the requirements of certain safety barrier components.

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Original Article

Design and Development Research on the Module to Manage Noise Exposure: A Case Exemplar Anchored on the OSHEMT Framework

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ABSTRACT : *This article elaborates on the module development processes with the analysis of exemplary occupational safety, health, environmental management tools (OSHEMT) practices through andragogical approaches as a new parameter to manage cases of hearing impairment caused by noise exposure. This study focuses on the development of an educational module to manage noise exposure in small and medium manufacturing sectors through a modular approach. It employs a mixed-method research methodology, specifically design and development research processes, and analyses data from case exemplars using the OSHEMT framework. The research employs quantitative and qualitative methods. The module development is based on the analysis, design, development, implementation, and evaluation (ADDIE) framework. The study elaborates on the ADDIE instructional design model, particularly during the analysing and evaluation phase. This phase includes the observation of practices in five selected companies, extracting open-ended responses from surveys, and conducting interviews with employees and employers in the selected industries. The study also elaborates on the seven main and sub-tools anchored upon the OSHEMT framework. These include the OSHEMT policy (OSHEMTP), budgeting (OSHEMTB), monitoring committee (OSHEMTMC), facility (OSHF), competency (OSHEMTC), transparency (OSHEMT-T), and reporting and communication (OSHEMTRC). The analysis is based on case exemplars, highlighting andragogical approaches to overcome problems relating to noise in manufacturing industries which negatively impacts employee health, with suggestions for future studies. By leveraging andragogy approaches, OSHEMT can enhance the working environment by managing noise exposure and mitigating employee hearing loss. (203 words)*

Keywords : *Andragogical Approach, Design and Development Research (DDR), Environmental Management Tools (OSHEMT) Health, Manufacturing Sectors, Noise Exposure, Occupational Safety, Small and Medium (SMEs)*

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1.0 INTRODUCTION

1.1 Background and Overview

Recognising the critical importance of occupational safety and health (OSH) implementation in the workplace, particularly within the small and medium enterprises (SMEs) of the Melaka industrialised sector, the state of cleanliness and OSH practices in Melaka have come under scrutiny because of a lack of supervisory culture and non-compliance with regulations (Kha et al., 2020). This study aimed to integrate workplace noise exposure measurements into occupational safety, health, and environmental management tools (OSHEMT), developed by the first author, to serve as a guideline for enhancing OSH practices in the workplace.

1.2 Problem Statement and Rationale

There are approximately 415,000 registered companies in Malaysia with over 200,000 employers in the manufacturing sector. In Melaka, one of Malaysia's states, there are approximately 22,000 employers, of which approximately 1,500 operate within small and medium manufacturing industries or small and medium enterprises, interchangeably abbreviated as SMEs in this study.

Collectively, the manufacturing industries employ 1.5 million workers out of the nation's total of 9 million. However, there has been an annual increase of 10,000 permanent incapacities registered, resulting in a loss of approximately 2.5 billion ringgit per year within this sector, with 88% of incidents attributed to "dangerous acts." According to the Economic Census (2016) and the Department of Statistics Malaysia, all employees exposed to hazardous noise levels (above the action threshold of 85 dB) are required to undergo audiometric hearing tests in accordance with the Factories and Machinery Act, 1989.

A significant knowledge and implementation gap exists regarding occupational safety and health (OSH) requirements in Malaysian manufacturing SMEs, contributing to high rates of workplace accidents and injuries (Yeow et al., 2022). Developing a tailored OSH policy for manufacturing SMEs could be beneficial for addressing these issues. The question is whether there have been any efforts or discussions within the industry or government to develop such a policy (Daim, 2021).

Utilising a modular approach within the design and development research (DDR) framework through an andragogical approach is an effective strategy for simultaneously outlining hazardous elements and their consequences. DDR research methods assist researchers in designing studies and innovating various instrument forms according to the phases involved (Pang et al., 2020; Richey and Klein, 2014).

The DDR process was implemented in the Bukit Rambai Industrial Zone for SMEs, where wood and furniture industries predominate. Based on the objectives of this study, this highly developed industrial zone with high-capacity plants was deemed suitable for determining industrial noise-induced hearing loss.

1.3 Aims, Research Objectives and Research Questions

This study is part of a large-scale investigation focusing on the challenges faced by SMEs in Melaka concerning the promotion of OSH. Non-compliance with regulations such as the OSH Act 1994 and the Factories and Machinery Act 1967 (revised in 1974) potentially contributes to these challenges, impeding SMEs' productivity. Consequently, this study advocates the utilisation of OSHEMT management through a modular approach to increase the awareness of noise exposure.

The primary objective of this study was to underscore the necessity of noise-level measurement techniques in industrial settings, with the ultimate goal of mitigating noise exposure within SMEs to prevent hearing impairment. Simultaneously, it sought to educate employers on the importance of maintaining clean and noise-free environments. Such an approach stands to benefit all stakeholders, including the Melaka State Government and SMEs.

Table 1 indicates that in 2022, there was an increase in the number of manufacturing SMEs reporting permanent disabilities, with only one of these cases attributed to an occupational health issue. Most disability cases involved the hands and fingers, highlighting the necessity for guidance and tools to enhance OSH practices in manufacturing SMEs. OSHEMT has emerged as an optimal guidance and tool for such practices.

Table 1: Melaka Manufacturing SMEs Accidents (Permanent Disabilities) 2022

No	Company	Sector	Date of accident	Remark
1	Bradken Casting (M) Sdn.Bhd	Manufacturing (SME)	26/02/2022	Left finger was broken by a wood-cutting machine
2	Lum Mah Plastic and Printing (M) Sdn.Bhd	Manufacturing (SME)	26/04/2022	Broken hands and crushed thumbs caused by a roller machine
3	Meiden Metal Engineering Sdn.Bhd	Manufacturing (SME)	11/03/2022	Hearing impairment (loss of hearing)
4	Olympic Cable Company Sdn.Bhd	Manufacturing (SME)	29/06/2022 and 07/08/2022	Broken finger caused by wire-making machine
5	Shantawood Mfg.Sdn.Bhd	Manufacturing (SME)	05/02/2022	Left thumb was broken by a wood chipper
6	GHS Food Industries Sdn.Bhd	Manufacturing (SME)	16/12/2022	Small fnger was broken by the production machine

Table 1 indicates that in 2022, there was an increase in the number of manufacturing SMEs reporting permanent disabilities, with only one of these cases attributed to an occupational health issue. The majority of disability cases involved hands and fingers, highlighting the necessity for guidance and tools to enhance OSH practices within manufacturing SMEs. OSHEMT emerges as the optimal guidance and tool for such practices.

The primary objective of this research was to develop management tools, specifically OSHEMT, utilising an andragogical approach with module development anchored on the analysis, design, development, implementation, and evaluation (ADDIE) framework to address noise exposure in the workplace. The research objectives of this study were as follows:

1. **To propose OSHEMT anchored on a modular approach to manage the noise in SMEs.**
2. **To illustrate the DDR processes of the ADDIE module using an andragogical approach for managing noise exposure in SMEs.**

Based on the aforementioned research objectives, the following research questions (RQs) were identified:

(1) How can the OSHEMT framework, anchored in a modular approach, manage noise exposure in SMEs?
(2) What DDR processes are involved in developing the ADDIE module for managing noise exposure in SMEs?

2.0 METHODOLOGY

2.1 Research Framework and Sampling Techniques

The research framework for this study was a mixed research method (Creswell, 2009) which involved DDR, observation, interviews, surveys, and case studies with mixed-mode data analysis (Johnson & Onwuegbuzie, 2004 as quoted by Ng et al., 2020). The study involved healthy respondents between the ages of 20 and 55 years who had worked for at least three years in noisy environments, as recommended by noise monitoring programs.

Sampling technique and pilot study - A case study is an in-depth examination of a subject's natural environment (Yin, 2018), such as an individual, group, location, event, organisation, or phenomenon. The term "case" can refer to an individual (for example, a manager), a group (for example, a work team), an organisation (for example, a business), an association (for example, a joint venture), a change process (for example, restructuring a company), or an event (for example, an annual general meeting). According to McCombes (2019), case studies effectively describe, contrast, evaluate, and comprehend the various facets of a research problem.

A total of 55 respondents were tested based on their work demographics, with the main objective of collecting consistent and reliable information about their working conditions as assessed by their employers. The assessment covered social, demographic, work duration, and work type aspects. The study found that the level of noise control management in the company was moderate; however, there was room for improvement to achieve better OSH and environmental management. For this purpose, organisations need at least one person competent in noise risk assessment (NRA) and DDR by ADDIE to create awareness among employees towards noise management in the workplace.

Employers must also ensure that awareness training is mandated for all employees through OSHEMT and that the seven tools are implemented. The study also examined the OSH management practices of various SMEs operating in Melaka, including Le Hu Feedmill (M) Sdn. Bhd and its four subsidiaries: (a) Le Hu Feedmill (M) Sdn. Bhd (aqua plant), JC Nutrimix (M) Sdn. Bhd, and Bea Agrotech (M) Sdn. Bhd (all located in the Bukit Rambai industrialised district); and (b) Id Multifeed (M) Sdn. Bhd from the Tangga Batu industrialised district.

For the purposes of this research, the case study method was deemed the most appropriate method for addressing the three RQs. It was determined that SMEs in the animal feed manufacturing sector in Bukit Rambai, Melaka, were suitable for a case study.

The selected SMEs produced animal feed and employed between 50 and 150 employees each. The animal feed manufacturing sector in Melaka, especially in the Bukit Rambai Industrial Area, was expected to play a significant role in the state's economy in 2021. It has bolstered the agricultural and food industries, generated employment opportunities, and attracted investment in the region. The sampling framework for this research comprises a list of all SMEs in the Melaka manufacturing sector registered with the Department of Occupational Safety Health (DOSH).

The sampling methods were based on the company's audiometric test reports conducted by a noise contractor according to the OSH Noise Regulations, 2019. Factors such as participant exposure to noisy work areas, duration of employment, and age were the primary considerations for the audiometric test. Furthermore, the internal and external noise risk assessment results were included in the data analysis, encompassing 27.5% of the total employees of the companies participating in this research. This comprehensive approach facilitated the acquisition of better results by drawing on work environment, DOSH information, OSHE WhatsApp groups, and company staff details.

2.2 Respondents Involved in Data Collection and Analysis

Le Hu Feedmill Sdn. Bhd is an animal feed manufacturing company located in Bukit Rambai that has operated for over 15 years. The company employs 200 employees, including foreign workers from Nepal, Bangladesh, and Myanmar.

Operating as a single manufacturing unit that runs 24 hours a day, the Le Hu Feedmill stands out among other businesses in the area, which typically operate for approximately 16 hours. However, similar noise generation issues have arisen in neighbouring firms because of a lack of knowledge and skills in OSH management.

The respondents for this study were from the industrialised areas of Bukit Rambai and Tangga Batu, where local animal feed is produced. The primary aim of this study was to advocate for a better approach to enhance compliance with regulations and provide advice to DOSH officials based on the research objectives. These refined regulations will subsequently be enforced, offering these organisations significant potential to enhance their OSH practices and the quality of their surroundings. Our findings can be translated into guidelines that can raise awareness and upgrade their OSH management systems.

3.0 ANALYSIS AND DISCUSSIONS

3.1 The Management of Noise Exposure using the OSHEMT Framework Anchored on a Modular Approach (RQ1)

In response to RQ1, a study was conducted involving five businesses as participating companies. The analysis revealed that Le Hu Feedmill (aqua) had the highest percentage of failures in the audiometric test (total fail manpower 12 / total test manpower 14 × 100 = 85.71%), followed by Bea Agrotech (83.33%) and Id Multifeed (70%). Hearing loss in the right ear was highest at JC Nutrimix with (hearing impairment right ear 3 / total fail manpower 6 × 100 = 50%), followed by Le Hu Feedmill and Id Multifeed at 42.86%. Hearing loss in the left ear was highest at Le Hu Feedmill (aqua) with (hearing impairment left ear 4 persons / total fail manpower 12 persons = 33.33%), followed by Bea Agro trade and JC Nutrimix at 20% and 16.67%, respectively.

The analysis of data on hearing loss affecting both ears showed that Le Hu Feedmill (hearing impairment both ears 4 persons / total fail manpower 7 persons × 100 = 57.14%) and Id MultiFeed were contributors at 42.86%, followed by JC Nutrimix with Le Hu Feedmill (Aqua) at 33.33%. The study also showed that individuals with six to ten years of service at Le Hu Feedmill Sdn. Bhd had the highest failure rate (years of service 5 persons / total fail manpower 7 persons × 100 = 71.43%), with Le Hu Feedmill (aqua) and JC Nutrimix being the highest contributors at 66.67%, followed by Bea Agrotech at 60%. Refer to Table 2 and Figs. (b) and (c) for more detailed information.

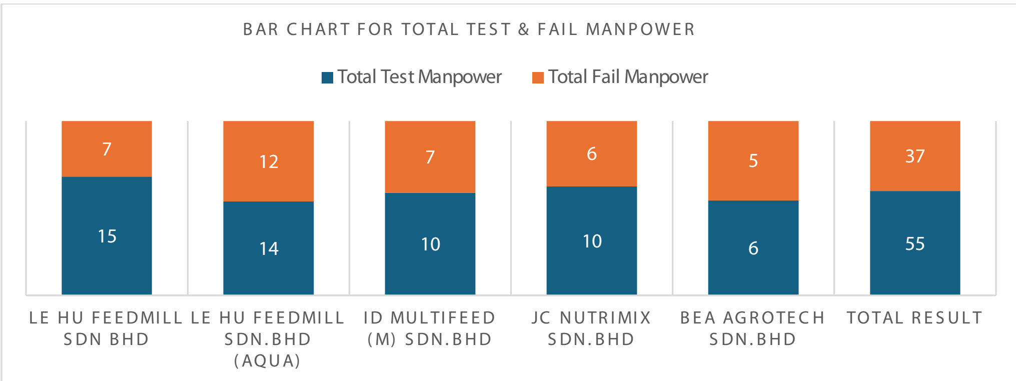

Figure (a): Total Audiometric Test and Fail Manpower

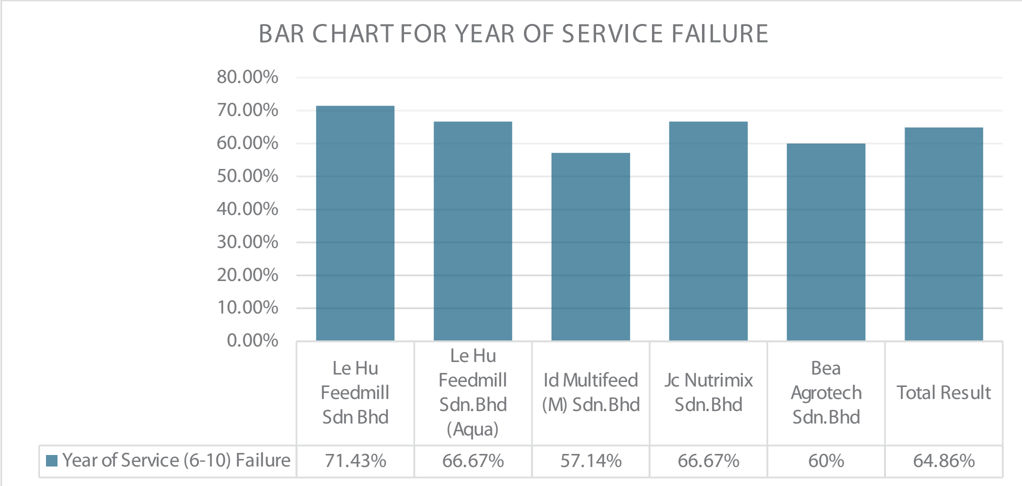

Figure (b): Year of Service Failure

Table 2 Audiometric Analysis Result on Five Small and Medium Company at Bukit Rambai Industrial Area

Study Item	Le Hu Feedmill Sdn Bhd	Le Hu Feedmill Sdn.Bhd (Aqua)	Id Multifeed (M) Sdn.Bhd	Jc Nutrimix Sdn.Bhd	Bea Agrotech Sdn.Bhd	Total Result
Total Test Manpower	15	14	10	10	6	55
Total Fail Manpower	7	12	7	6	5	37
Total Fail%	47%	85.71%	70%	60%	83.33%	67.27%
Year Of Service (6-10) Fail	5 = 71.43%	8 =66.67%	4 =57.14%	4 =66.67%	3 =60%	24 =64.86%
Hearing Impairment Both Ears	4 = 57.14%	4 = 33.33%	3 = 42.86%	2 = 33.33%	2 = 40%	15= 40.54%
Hearing Impairment Right Ear	3 =42.86%	4 =33.33%	3 = 42.86%	3 = 50%	2 =40%	15= 40.54%
Hearing Impairment Left Ear	NIL	4 =33.33%	1 =14.28%	1 = 16.67%	1= 20%	7 = 18.92%

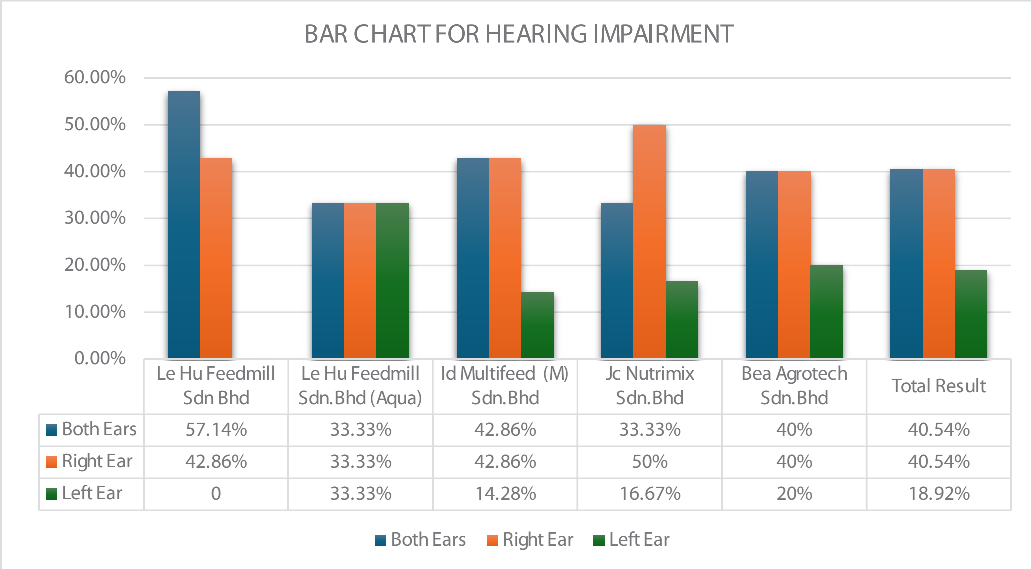

Figure (c): Hearing Impairment

The necessity of OSHEMT for managing noise exposure is of paramount importance. The researchers recommend that companies conduct awareness campaigns to educate their employees about the prevention of long-term hearing loss. Employers should also analyse the ergonomic aspect to prevent recurring problems, as it is a major concern for employees who may not be able to work in a noisy environment for more than four hours at a time. In noisy workplaces, job rotation for various personnel is required based on a predetermined amount of time.

Managements should also conduct engineering studies to eliminate actual sources of noise, such as machinery, by investing in more advanced technologies to reduce workplace noise pollution. While employers may provide earplugs capable of covering noise of up to 105 decibels, if noise exposure exceeds 135 decibels, employees remain exposed to 30 decibels of noise at work. Continuous exposure can lead to hearing loss over time. To mitigate this problem, noise sensors and warning alarms should be installed, activating whenever noise levels exceed a certain threshold; ultimately, the power to the units producing excessive noise should be switched off. The licencing authority should oversee the entire process to ensure compliance.

The commitment of top management is crucial for implementing actions related to company safety, environmental policies, and OSH. Without their dedication, all efforts are likely to fail. It is imperative to adhere to directives such as amendments to regulations such as the Environment Clean Air 2004 to 2014 and Noise Regulation 2019. Organisations must practice OSHEMT to manage noise exposure comprehensively, including policies, budgeting, competency, facilities, internal and external communications, and OSH environment committees.

Manufacturing SMEs must assess their occupational safety and pollution control through human resource management and development, including policies, procedures, training, education, motivation, rewards, internal committees, internal and external audits, OSH, and environmental promotion. This entails noise conservation training, NRAs, and ergonomic risk assessment. All educational and training processes should be integrated into ADDIE or andragogical processes to develop competency in the workplace. This approach enhances employee motivation to achieve safety, health, environmental, and productivity goals in the work area.

Psychosomatic or intrinsic rewards such as respect and gratitude play a crucial role in encouraging workers and improving their performance. Therefore, to empower an organisation, the person in charge must also be empowered to fulfil their duties. Genuine appreciation and recognition are inherent benefits that motivate and enhance performance. As part of the motivation concept, intrinsic motivation should be fostered, which in this study refers to employees performing tasks themselves and practising OSHEMT to sustain OSH management (Abdullah et al., 2016).

Module Development for OSHEMT.

Figure 1 illustrates OSHEMT, which comprises seven components for monitoring industrial workplace compliance with OSH environmental standards. These tools are connected with OSH practices that enhance the OSH environment. For instance, clean production (CP) promotes good health and a healthy environment, while a safe environment fosters productivity and efficiency.

Safe and clean practices, such as proper waste schedule management, can facilitate reuse through recycling, storage, and inventory management, aided by an electronic schedule waste inventory system. A safe workplace ensures healthy working conditions and encourages employees to perform optimally. CP and a secure environment are recognised as the preferred methods for achieving efficient resource utilisation, protection, and effluent avoidance. The OSHEMT module is crucial for managing noise exposure in manufacturing SMEs.

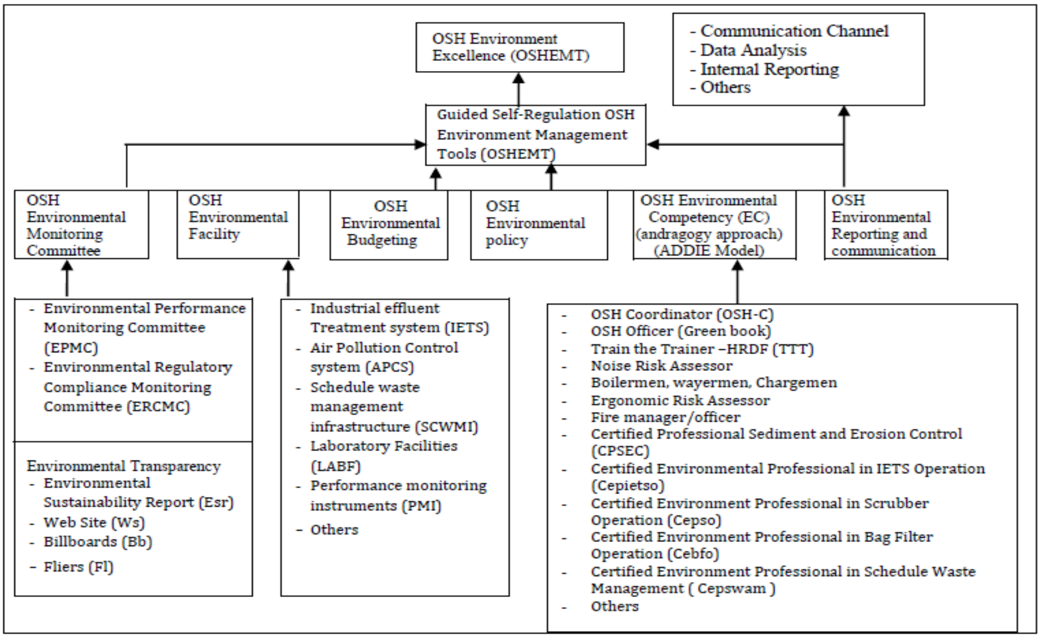

Figure 1: OSHEMT Main and Sub Tools

The above sub-tools underscore the importance of manufacturing units being cognisant of them as they serve as the primary means of achieving compliance with regulations. For instance, they should ensure the training of a certified OSH coordinator (OSH-C) to effectively manage OSH matters, and consider providing training or appointing an assessor for NRAs in the workplace. Employers should recognise the significance of having an individual certified in Train-the-Trainer (TTT) programmes to oversee internal training initiatives.

Moreover, there should be a focus on prioritising the training of more certified individuals within the workplace to enhance motivation and improve employees' skills and knowledge through andragogy and an understanding of the ADDIE framework. Employers may also opt to hire competent personnel, such as a certified person in schedule waste management (CEPSWAM) and an OSH-C with TTT qualifications to manage the OSHEMT noise environment in the workplace.

3.2 The DDR processes in the development of ADDIE module to manage noise exposure in the SME (RQ2)

In response to RQ2, a module was developed utilising the ADDIE model. This instructional design paradigm facilitates the organisation and streamlining of course material creation through five stages, which encompass the DDR process.

The term andragogy is synonymous with adult education, referring to any form of adult learning (Kearsley, 2010). The ADDIE model serves as an instructional design methodology aimed at systematising and restructuring towards goal realisation. ADDIE is an acronym for the five stages of progress: analysis, design, development, implementation, and evaluation (Quigley, 2019). These modules are essential for creating a sustainable working environment that motivates both employers and employees regarding noise exposure management in their workplace, as per this research.

As depicted in Figure 2, employers play a crucial role in enhancing employees' skills and knowledge through the andragogical approach and ADDIE model. The initial process, 'Training Needs Analysis' (TNA), which involves analysing the need or objective for the company towards OSHEMT progress, is pivotal. It is imperative to hire or train certified TTT individuals to manage the OSHEMT progress.

Before developing any content or training strategies, the company must analyse the current situation regarding training, information gaps, and so forth and commence with a series of questions to understand the current condition and readiness for the guidance program. The instructor adopts the role of a facilitator, guiding the workforce to familiarity and actively involving participants in knowledge development, rather than merely presenting them with information (Knowles, 1984). In this context, only certified TTTs can execute training strategies through TNA.

The design phase ensues after identifying the type of need in the OSHEMT process. Learning experiences from the previous phase are leveraged to make practical decisions regarding strategy, delivery methods, structure, duration, assessment, and feedback. These decisions involve creating a master plan for courses in prototype form and discussing the value of training with management. This approach aids in designing progress for adult learners who need to build an expanding storehouse of knowledge that evolves into an ever-growing resource for wisdom. Experiential learning, which includes errors, lays the foundation for knowledge activities. For instance, only individuals involved in schedule waste management in the workplace can fully comprehend the necessary requirements.

ADDIE creates skilled and knowledgeable employees. This is an opportunity for working adults to gain more skills to improve their safety and health in the workplace. For example, when more employees are exposed to noise-protection skills and knowledge, the risk of hearing impairment decreases in the long term. The role of a competent person is to monitor and inspect the use of personal protective equipment (PPE) among employees, and continuously educate them through caution points and signage. Competent persons with management commitment must conduct training for concerned employees based on TNA. This will help them achieve their target of producing skilled workers at the right time and place with the right employees.

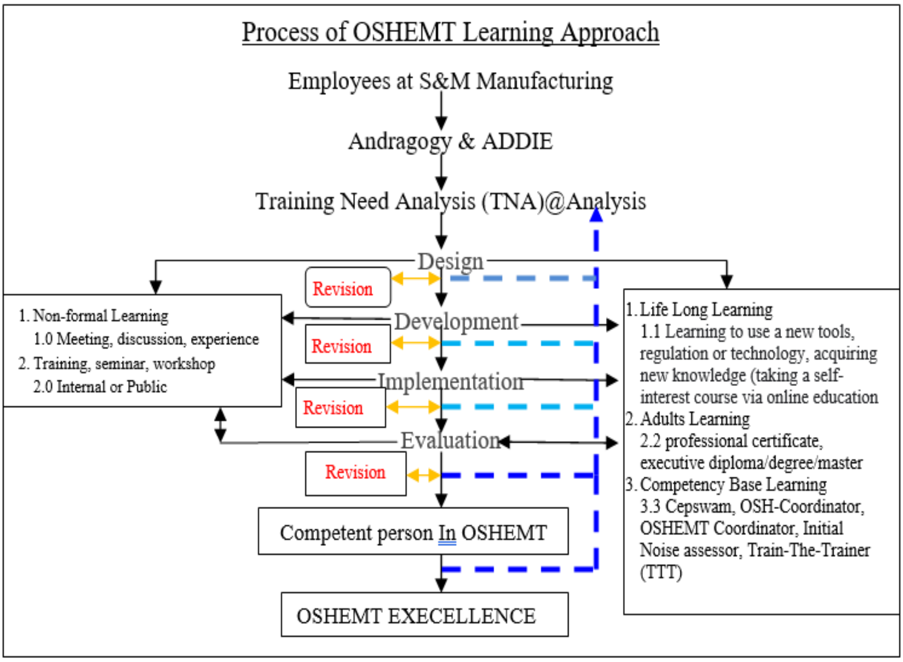

Figure 2: Process of Andragogy and ADDIE for Competency in OSHEMT.

Based on a master plan for the courses in prototype form and after discussions with company management, it becomes a pivotal document used to develop the progress of OSHEMT learning. Every aspect of lesson progression should align with the design chapter, and any requested additions should be prioritised and refined to enhance the course's appeal. Although seemingly insignificant, this has a substantial impact on the comfort level during the course.

Therefore, the improvement process must be iterative. Once a course has been produced, testing must be performed to ensure that there are no fundamental errors. Test cases should also examine the course procedures. Navigation is a significant concern at this stage. Most of the issues encountered by learners are related to how the course is constructed in the authoring instrument. At this stage, course content that aligns with the design stage in a master plan should be developed to achieve the desired learning outcomes for employees. The Environmental Institute Malaysia has developed course content to facilitate the adult learning process (EIMAS, 2017).

Once the training syllabus is complete and the course content has been thoroughly tested and approved, learners can implement it. Decisions made in the design chapter dictate how this is executed. One of the most effective ways to avoid issues during the implementation stage is to conduct a pilot course before releasing the content to the entire audience. The primary objective of andragogy and ADDIE is to provide a structured approach for developing training packages.

However, it also serves as a powerful framework for optimising the production of subsequent iterations. Receiving feedback on each course segment is crucial for future improvements. A great method for gathering feedback is asking participants to complete surveys at the end of their course. This can be integrated into the course using various analytical methods. Employees should be aware of what is best for their future, and enhancing their skills and knowledge will improve their quality of life and career prospects.

OSHEMT Policy - The OSHEMTP of prosperous companies uses a strong and clear statement to express their commitment to OSHEMT for their human capital, clients, suppliers, and the community. The OSHEMTP is made available to all relevant groups and implemented in the standards of work practices and business decision-making processes, and cascades down to the supply chain. This policy integrates OSH and environmental policies and requires top management commitment to achieve the organisation's aims and vision in OSHEMT. The policy should be structured as follows:

- **Attracted to the workforce and their advisory council. This is a process of analysing the organisation's vision and goal towards OSHEMT with all parties' involvement.**

- **Stated in clear, unmistakable terms. This is the process of designing a proper policy to bring a clear message from top management towards OSHEMT in the workplace.**

- **Signed by the highest-ranking person in the association. This is a process of policy development in which the top management proves their commitment by signing the policy.**

- **Keep abreast with the latest information. At this stage, top management must always be updated on any information regarding OSHEMT, such as regulation updates, training information, and competency upgrading. The latest regulations should be implemented to conform to these requirements.**

- **OSHEMT achievements are communicated to the workforce, as well as anyone or any team who is interested in or affected by them. This is a process of delivering the company vision and objectives on OSHEMT through an andragogical approach, such as meetings, seminars, training or life-long learning, adult learning, and competency-based learning. The OSHEMTP must be understood by the entire workforce to confirm its achievements.**

- **Adherence to regulations in all works performed. This stage evaluates whether employees adhere to the OSHEMTP. The evaluation or renewal process shall be performed at least once every two years or when necessary.**

OSHEMT Budgeting - An adequate budget must be allocated exclusively to fulfil the OSHEMT regulatory requirements and other OSH-linked initiatives. During the conceptual phase, resources must be made accessible to design and upgrade OSH surveillance capabilities. Throughout the operational phase, resources should be allocated for the effective management and maintenance of OSHEMT control systems as well as for monitoring OSH hazards resulting from company or project expansion in the industry. The OSHEMT also encompasses the costs of upgrading the OSHEMT equipment, providing personnel training, and acquiring standard surveillance or monitoring devices. Budgeting is essential for cultivating more skilled workers through the ADDIE process, as shown in Figure 2.

OSHEMT Monitoring Committee - To foster collaboration and promote OSHEMT compliance, two observation committees should be established and developed: one at the operational level and the other at the regulatory level. At the operational level, the committee is led by a higher administrator of the organisation and consists of the OSHEMT performance evaluation committee which meets monthly or at least once every three months to review the OSHEMT progress towards achieving its goals. At the regulatory level, the committee is known as the OSHEMT regulatory compliance monitoring committee which meets at least once a year and is chaired by the chief executive officer to analyse, design, develop, and evaluate the outcomes.

OSHEMT Facility - The ADDIE model is used for the analysis, design, and development of the OSHF, which includes an industrial treatment system, best management strategies, and support facilities. It also involves an annual audiometric test for affected workers, noise monitoring, and evaluation equipment to ensure technical control limits for workplace noise pollution, an online measurement system, and PPE. A noise reduction training seminar or workshop (using an andragogical approach) is also crucial. These components must not be compromised and must be integral to the company's overall infrastructure planning and development.

OSHEMT Competency - Personnel who play a vital role in discharging various OSH and environmental tasks within a business must possess the necessary skills. Examples include an OSH-C, confined space entry supervisor, and verified OSH instructor. The organisation must analyse, design, and develop a comprehensive curriculum to produce competent individuals and qualified support personnel to ensure complete compliance with DOSH and Department of Environment regulated activities. The types of competent individuals are presented in Table 3.

Table 3 Environmental Competency Status in Melaka

No	Type of Competency	No. of Competency Person in Melaka	Remark (1500 Melaka Small & Medium Manufacturing)
1.	Certified Environmental Professional in Scheduled Waste Management (CEPSWAM)	65(2018) 161 (2021)	65/1500×100= 4.33%(2018 EIMAS data) 161/1500·100=10.73% (22/5/2021 –EIMAS data)
2.	Certified Environmental Professional in Bag Filter Operation (CePBFO)	5	5/1500·100 = 0.33%
3	Certified Environmental Professional in the operation of Industrial Effluent Treatment Systems (Biological Processes – Activated Sludge Process)Cepietso(Bp)	11	11/1500·100= 0.73%
4.	Certified Environmental Professionals in the operation of Industrial Effluent Treatment Systems (Physical-Chemical Processes)Cepietso(Pcp)	22	22/1500·100= 1.47%
5.	Certified Environmental Professionals in the treatment of Palm Oil Mill Effluent (Ceppome)	4	4/1500·100 = 0.27%
6.	Certified Environmental Professional in Scrubber Operation (Cepso)	9	9/1500·100 = 0.6%
7.	Certified Environmental Professionals in Sewage Treatment Plant Operation (Cepstpo)	5	5/1500·100 = 0.33%

Data from: www.eimas.doe.gov.my 25/5/2018 & 22/5/2021

Tables 3 and 4 illustrate that promoting the andragogical approach and ADDIE model is timely for the Melaka manufacturing SMEs sector. In 2018, only 4.33% of this sector held the CePSWaM certification, which increased to 10.73% by May 2021. Furthermore, only 30 individuals in this sector possessed an OSH certification, accounting for 4.33% of the workforce. This indicates the industry's need to commit to increasing the number of skilled employees in the workplace through HRD Corp. funding and producing more competent employees, especially in NRA, OSHEMT, CePSWaM, and OSH-C. These statistics were obtained from the Environment Institute of Malaysia and DOSH using the MYkkp system.

Table 4 OSH-C Competency Status in Melaka

No	Type of Competency	No.of Competency Person in Melaka	Remark (1500 Melaka Small & Medium Manufacturing)
1.	Occupational Safety Health Coordinator (OSH-C)	30	30/1500X100= 4.33% (2021 MYkkp data 22/5/2021)

Data from: MYkkp 22/5/2021

OSHEMT Reporting and Communication - This is the process of implementing OSHEMT progress developed by the top management of the organisation through OSHEMTRC instruments. For instance, protocols for reporting accidents or near misses, safety operating procedures, emergency action plans, and team progress must be shared with all employees to obtain better feedback or results. This procedure can be conducted visually, verbally, or electronically through email, phone, WhatsApp, memos, warning signs, meetings, or training. This process is based on an andragogical approach involving the adult learning process. It is important to develop appropriate channels to assess the adequacy of OSHRC components.

OSHEMT Transparency - An organisation may evaluate its OSHEMT progress and consider implementing OSHEMT-T using the best available option that suits its situation, such as an electronic system, WhatsApp, biller board, and flyer issuance. The organisation should also provide details of the planned start date for OSHEMT-T implementation and evaluate its progress regularly. It is crucial to share relevant information about the organisation's OSHEMT management, such as total accident cases, healthcare, and noise exposure status, transparently with employees and the community, without any concealment. This will help employers accurately assess OSHEMT progress and make future improvements based on honest feedback. Researchers believe that by utilising this OSHEMT technology, small and medium manufacturing companies can effectively reduce and regulate loud noise in the workplace.

4.0 CONCLUSION

4.1 Summary and Implications/Significance

This article discusses a segment of a larger study that aimed to create a noise-free environment in SMEs. The study employed the ADDIE model of instructional design, incorporating mixed-method research involving both quantitative and qualitative data analysis, particularly during the analysing and evaluation phases of ADDIE. This study involved observing industrial practices, conducting open-ended response surveys, and interviewing employees and employers of five companies.

Producing more skilled or competent employees is crucial to foster awareness of noise management in the workplace. Management commitment plays a pivotal role in budgeting through HRD Corp. for training, seminars, and motivation, including annual audiometric tests and noise engineering control methods.

The OSHEMT process through ADDIE and andragogy is an ongoing endeavour, based on TNA, aimed at cultivating skilled or competent individuals in the workplace. Employers must implement administrative and PPE controls for short-term noise management

Audiometric analysis of the survey data revealed that 57.14% of workers at the Le Hu Feedmill suffered from hearing impairment in both ears, marking the highest record. This finding correlates with the highest number of samples with six to ten years of service, indicating that work duration is a contributing factor to audiometric test failure. Furthermore, the study found that industrial practices often failed to comply with legal requirements and lacked a sufficient management culture, as indicated by scrutiny and interview findings. Case examples were analysed to identify andragogical approaches to address these issues and provide suggestions for improvement.

The results revealed that noise in manufacturing industries negatively impacts employee health, resulting in a high prevalence of hearing loss among the respondents. By leveraging andragogy approaches, such as CePSWaM OSH-C competence practices, noise risk assessors, TTT, and ADDIE, OSHEMT can enhance the working environment by managing noise exposure and mitigating employee hearing loss. This study recommends that employers conduct NRAs to gauge noise exposure levels in the workplace, particularly in response to noise complaints.

If the background noise exceeds the permissible exposure limit of 82 dBA, noise reduction measures must be implemented, and personnel exposed to excessive noise levels should undergo audiometric evaluations along with medical examinations. Only qualified noise risk assessors who have undergone competence-based learning can conduct NRAs such as initial or advanced NRAs. The results of all dimensions and noise observations should be recorded for seven years. Finally, managers should develop engineering or administrative control systems based on the NRA results and provide earplugs to all employees exposed to noise.

4.2 Limitations and Recommendations

However, this study acknowledges the limitations of the number of variables considered, which may not fully encompass all the factors affecting SMEs' OSHEMT results. This review relied solely on correlation studies and connection reviews. Future studies could explore inferential methods to test hypotheses with larger, more representative data from small and medium-sized businesses located in the Bukit Rambai Industrial Area or the Melaka SMEs manufacturing sector. It is crucial for employers to implement ADDIE when practising OSHEMT in the workplace to attain a cleaner, noise-free work area.

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