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# JOURNAL OF Occupational Safety and Health

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# Journal of Occupational Safety and Health



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- Welcomes articles in occupational safety and health related fields.

# Journal of Occupational Safety and Health

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# 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:

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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

This edition includes one remarkable research article entitled "Amplicon Sequencing Reveals Bacterial Diversity of Indoor Air Microbiome in Hospital Buildings." The method of DNA applied in the study is amplicon sequencing, whereby this technique determines the bacterial diversity represented within a sample by reading a specific region of the bacteria's DNA. This could be said to be an important step toward the reassurance of zero infections with regard to healthcare.

This study employed amplicon sequencing to analyse the bacterial community in the indoor air microbiome of Sultan Ahmad Shah Medical Centre (SASMEC), where they found multitudinous microorganisms which included potentially hazardous species like the Methylobacterium spp.

This paper stresses the continuous monitoring of airborne microorganisms to prevent infections, particularly in hospital facilities. State-of-the-art amplicon sequencing technology has enabled researchers to get beyond some of the drawbacks of conventional culturing techniques. These advances in genome sequencing technology now allow for more accurate and unbiased identification of microbial content.

On that note, research conducted by Sultan Ahmad Shah Medical Centre revealed a diverse array of microorganisms that included some potentially hazardous species such as Methylobacterium spp. This goes to show how crucial advanced monitoring techniques are within healthcare facilities.

The knowledge acquired from this study will most definitely enhance the ability in handling biological containment, surveil infectious diseases, and provide cleaner, safer hospital environments. The resources are available to protect patients and medical personnel from these risks of contracting infections from airborne germs when effectively utilising state-of-the-art sequencing techniques. In its totality, this study is a paramount step forward in the never-ending battle to ensure public health safety.

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

# Amplicon Sequencing Reveals Bacterial Diversity of Indoor Air Microbiome in Hospital Buildings

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**ABSTRACT:** *Airborne transmission of pathogens in hospitals poses a significant risk for healthcare-associated infections. Traditionally, assessing microorganisms in hospital air relies on culture methods, limiting the identification process. Advances in genome sequencing technology now allow for more accurate and unbiased identification of microbial content. This study employed amplicon sequencing to analyse the bacterial community in the indoor air microbiome of Sultan Ahmad Shah Medical Centre (SASMEC). Dust samples from 12 randomly selected air-handling unit (AHU) rooms were collected, and genomic DNA was extracted and sequenced targeting the V3 region of 16S rRNA. The Illumina NovaSeq 6000 system performed short-read amplicon sequencing. The results revealed diverse bacterial communities in AHU supply and return units, with Proteobacteria, Firmicutes, and Actinobacteria being the most common phyla. Dominant bacterial species included Methylobacterium spp., Nesterenkonia spp., Rubrobacter A bracarensis, Flavobacteriaceae spp., and Salinisphaera spp., with Methylobacterium spp. posing concerns due to its association with opportunistic infections. The study highlights the importance of using next-generation sequencing and culture-independent methods to monitor indoor air microbiomes. This provides crucial insights for managing biological contaminants, including airborne transmission, and enhances infectious disease surveillance in healthcare settings.*

**Keywords:** *Air Microbiome, Amplicon Sequencing, Bacteria, Culture-Independent Method, Hospital, Malaysia*

## 1.0 INTRODUCTION

The potential transmission of pathogenic microorganisms through air within hospitals has emerged as an increasing concern in the healthcare industry. Airborne pathogens can lead to healthcare-associated infections and diseases, thus exposing patients and healthcare personnel to various health risks. Previous studies have provided insights into the presence of various microorganisms, such as bacteria (Afeera et al., 2023), fungi, and viruses, in hospital environments (Mat Yassim et al., 2021; Ummu Afeera; Zainulabid et al., 2022; Ummu Afeera Zainulabid et al., 2021). Epidemiological studies have shown that exposure to pathogenic microbes increases morbidity and mortality rates in healthcare settings. Exposure to bacterial phyla, including Proteobacteria, Firmicutes, and Chloroflexi, can cause various respiratory infections, such as pneumonia and bronchitis, among hospital occupants (Fakunle et al., 2020). Studies have also shown that the presence of pathogenic bacteria in indoor air may contribute to secondary bacterial infections among immunocompromised patients, thus prolonging hospital stays and increasing death rates (Lee et al., 2021).

Over the years, conventional culture methods have been predominantly used to investigate microorganisms in the air, which, although useful, have limitations in terms of specificity, sensitivity, and comprehensiveness. In this technique, microbial growth depends solely on laboratory culture or media, which may introduce bias since not all microorganisms can be cultured or grown under such conditions (Mucci et al., 2020). This technique is also labourious and time-consuming, as the microbial culture needs to be incubated for 24 to 48 h before the identification process can begin. In addition, some microbes may have special growth requirements, such as high or low temperatures, and some may take longer to grow than others. This has led to the overgrowth of fast-growing microorganisms in the culture medium compared to slow-growing bacteria, resulting in biased and inconclusive findings regarding microbial profiling in indoor air (Adams et al., 2016).

Advances in genome sequencing have led to a paradigm shift in the study of airborne microbes. This new technology eliminates the requirement for a series of culture processes, thus offering more precise and unbiased results in a short analysis time for the identification of microbial communities in indoor air. This technique involves amplicon sequencing, polymerase chain reaction (PCR), and high-throughput sequencing, which enables the complete analysis of genetic material directly extracted from environmental samples (Ökten et al., 2020). The extracted bacterial DNA is subjected to amplicon sequencing, library preparation, and genomic sequencing. These technologies generate vast amounts of sequencing data that can be processed using bioinformatics to reconstruct the diversity and structure of indoor microbial communities (Ghosh et al., 2018).

This study aimed to analyse bacterial communities in the indoor air of the Sultan Ahmad Shah Medical Centre (SASMEC) using genomic sequencing technology. Dust samples were collected from an air-handling unit (AHU) room that was randomly chosen from various wards and clinics within the medical centre. Many patients in wards and clinics are immunocompromised owing to weakened immune systems, making it essential to mitigate the risk and reduce the prevalence of hospital-acquired infections. The AHU acts as a critical component of ventilation systems in various environments, particularly in regulating and circulating air. The collection of dust samples from AHUs serves as a strategic means of capturing a diverse array of microbial communities present in indoor air. Dust is often associated with particles and microorganisms in the air, making it a representative medium for acquiring an indoor microbiome. To the best of our knowledge, the use of dust samples from AHUs for bacterial identification through amplicon and next-generation sequencing (NGS) represents a pioneering approach in microbial indoor air quality research in Malaysia. Previous studies on microbial exposure in AHUs were conducted using active sampling with culture-dependent methods. Using amplicon sequencing, specifically targeting the V3 region of the 16S rRNA gene, and NGS, we enabled a comprehensive analysis of the bacterial composition within dust samples. The identification of bacterial communities directly from bacterial genomic materials extracted from dust samples circumvents the limitations associated with traditional culture methods, thus providing a more accurate and comprehensive profile of the bacterial diversity present in indoor air. Employing the integration of amplicon sequencing and NGS with dust samples from the AHU may become an alternative option for better understanding the sources of microbial contamination and the dynamics of indoor microbial communities to improve indoor air quality and minimise risks to human health.

## 2.0 MATERIALS AND METHODS

### 2.1 Sample collection

Prior to sample collection, a walk-through building inspection was conducted to identify and select the sampling locations. Clinics and wards that utilised air conditioning were included in the sample collection, and those using mechanical ventilation were excluded. To fulfill the inclusion criteria for sample analysis, samples had to be collected from both the indoor air and AHU rooms. Sampling was conducted during office hours from 08:00 to 17:00 (Sarah Fatihah Tamsi et al., 2022). Before sample collection, the AHUs were shut down, and with the help of the hospitals' technical staff, dust samples from the AHU

room were collected using sterile forceps. The samples were placed into sterile 15-mL tubes filled with 5 mL of phosphate-buffered saline (PBS). Ten samples were collected from both the supply and return vents in the selected AHUs. Samples were labelled AS_1–AS_5, indicating AHU supply air numbers 1 through 5, and AR_1–AR_5, representing AHU return air numbers 1 through 5. This labelling system was requested by the hospital management to avoid disclosing the names of specific sampling locations. All the collected samples were transported to the laboratory at room temperature for further analysis.

### 2.2 DNA extraction, library preparation, and sequencing

The dust samples in 15-mL tubes were subjected to homogenisation using a vortex for 5 min before proceeding with the bacterial DNA extraction procedures. Bacterial DNA was extracted using the QIAamp PowerFeacal Kit (QIAGEN, Hilden, Germany), with some modifications (Dean et al., 2022). First, dust samples were placed in a PowerBead ProTube and mixed with 400 µL of CD 1 solution provided by the manufacturer in the extraction kit. The tubes were incubated in a water bath at 65°C for at least 1 h. Subsequently, 400 µL of CD 1 solution was added to each tube and incubated for 15 min for homogenisation before centrifugation. After homogenisation, the remaining procedure was performed according to the manufacturer's protocol. The quality and quantity of the extracted DNA were examined by 1% gel electrophoresis and a Qubit 4 fluorometer (Thermo Fisher Scientific, Invitrogen, USA). The samples were then stored at −20°C for downstream application.

A library for bacterial characterisation was prepared using a polymerase chain reaction (PCR) approach targeting the 16S rRNA V3 region with the primer sequences listed in Table 1. PCR mixtures were prepared by mixing Promega GoTaq Green Mastermix with forward and reverse primers, as well as the DNA template. One tube without the DNA template served as the negative control. The mixtures were then subjected to amplification in an Eppendorf 5331 MasterCycle Gradient Thermal Cycler (Eppendorf, Germany), according to the protocol shown in Table 2. Using 2% gel electrophoresis, the PCR products were visualised and purified using SPRI beads. An index PCR was performed on the purified product to incorporate Illumina-specific barcodes and the remaining Illumina adapter sequences, as shown in Table 3. Finally, an Illumina NovaSeq 6000 (Illumina, San Diego, CA, USA) was used to sequence the amplicon libraries.

**Table 1: Primer Sequences for PCR Targeting the Bacterial 16S rRNA Gene (Ayob et al., 2023; Hasain et al., 2022)**

| Primer | Sequence |
|---|---|
| **341F** | **CCTACGGGNGGCWGCAG** |
| **518R** | **ATTACCGCGGCTGCTGG** |

**Table 2: Protocol for Amplification of Bacterial DNA (Siew et al., 2022)**

| Protocol | Temperature | Duration |
|---|---|---|
| Initial denaturation | **95°C** | **2 min** |
| Denaturation | **95°C** | |
| Annealing | **50°C** | **10 s (30 cycles)** |
| Extension | **72°C** | |
| Final extension | **72°C** | **30 s** |

**Table 3: Protocol for Index PCR (Ummu Afeera Zainulabid et al., 2021)**

| Protocol | Temperature | Duration |
|---|---|---|
| Initial denaturation | **95°C** | **2 min** |
| Denaturation | **95°C** | |
| Annealing | **50°C** | **10 s (8 cycles)** |
| Extension | **72°C** | |
| Final extension | **72°C** | **30 s** |

2.3 Amplicon sequencing and statistical analysis

Amplicon data were generated by overlapping raw paired-end reads with Fastp (Chen et al., 2018), which were then trimmed to remove primers using Cutadapt v4.4. (Martin, 2011). The overlapping readings were imported into QIIME2, where they were denoised, and table counts were constructed using DADA2 (Callahan et al., 2016). Amplicon sequence variants (ASVs) were classified using the qiime2-feature classifier, which was trained on the GTDB 16s rRNA V3 region database (r207 release). The taxonomic categorisation and ASV table were manually formatted before being uploaded to the MicrobiomeAnalyst web server for data visualisation.

MicrobiomeAnalyst 2.0 was used for the statistical analysis of microbiome data to profile the bacterial population identified in indoor air (Siew et al., 2023). The data were filtered using a zero minimum count and a 10% interquartile range. The taxonomic composition of the samples was determined using bar plots at the phylum, genus, and species levels. Certain phyla were included in the phylum abundance if they reported an abundance of 0.5% or more in at least 25% of all samples (Siew et al., 2022). Permutational multivariate analysis of variance (PERMANOVA) was applied for diversity analysis, and the Bray–Curtis dissimilarity index was used to measure significant differences between groups. For the alpha diversity analysis, Chao1 was used to explore bacterial diversity within a group, with p-values $<0.05$ considered significant.

## 3.0 RESULTS

This study primarily focused on profiling the bacterial community in indoor air at a hospital using a culture-independent method and genomic sequencing. Ten dust samples were collected using passive sampling, and high-throughput amplicon sequencing was used to characterise the bacterial composition in the V3 region of the 16S rRNA gene. These findings revealed a wide range of bacterial composition in each sample. Fig. 1–3 show the profiles of bacterial community abundance in the dust samples at the phylum, genus, and species levels, respectively.


**Figure 1: Relative Abundance of the Top Bacterial Phyla Isolated from the Return (AR) and Supply (AS) Vents in the Air Handling Unit (AHU) Room**

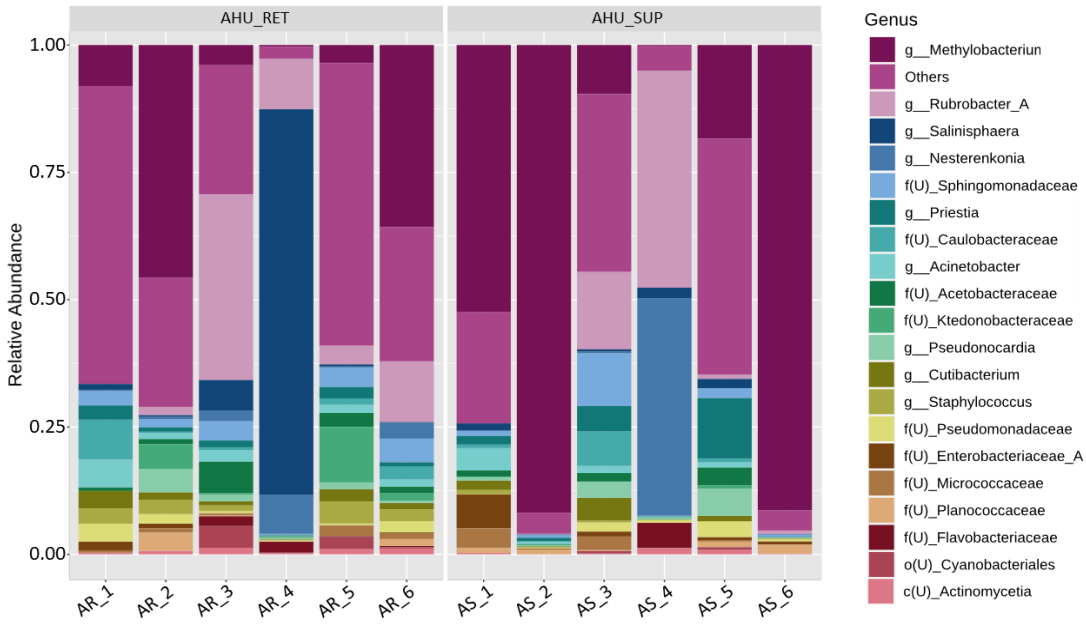


**Figure 2: Relative Abundance of the Top Bacterial Genera Isolated from the Return (AR) and Supply (AS) Vents in the AHU Room**

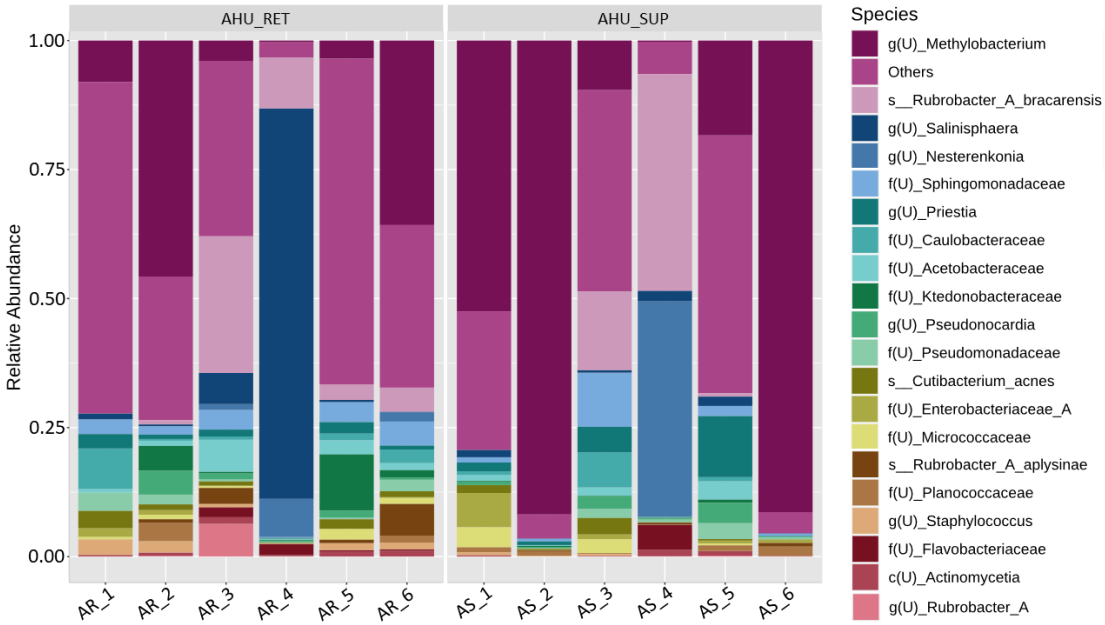


**Figure 3: Relative Abundance of the Top Bacterial Species Isolated from the Return (AR) and Supply (AS) Vents in the AHU Room**

Overall, 11 bacterial phyla, including 21 bacterial genera and 21 bacterial species, were identified in the dust samples. The most abundant bacterial phyla that dominated the AHU supply and return units were Proteobacteria, Firmicutes, and Actinobacteria (Fig. 1). More than 90% of Proteobacteria were found in AHU supply vents AS_2 and AS_6, and over 50% in most AHU return vents, except AR_3 and AR_5, which were dominated by Actinobacteria. Firmicutes were also present in all samples, with 20% in AHU supply vents AS_3 and AS_5. Further examination at the genus level revealed different dominant bacteria across the samples (Fig. 2). The supply vents were primarily dominated by *Methylobacterium* spp., except for AS_4, which was dominated by *Nesterenkonia* spp. (43%). In contrast, in the return vents, *Methylobacterium* spp. and *Rubrobacter* spp. were present in all samples, with high levels of *Salinisphaera* spp. found in AR_4 (76%). As for bacterial species, *Cutibacterium acnes*, *Salinisphaera* spp., *Priestia* spp., *Methylobacterium* spp., *Sphingomonadacae* spp., *Psedomonadacae* spp., and *Caulobacterecae* spp. were present in all collected dust samples with varying levels of abundance (Fig. 3). *Salinisphaera* spp. and *Methylobacterium* spp. dominated the AHU return vents at 31% and 18%, respectively, whereas the supply vents were dominated by *Methylobacterium* spp. and *Nesterenkonia* spp. at 41% and 20%, respectively.

Further analysis of alpha and beta diversity was conducted to examine the diversity of the bacterial air microbiome community in the supply and return vents of the AHUs. The total species diversity of the samples can be referred to as alpha diversity, which is defined as the similarity or distance discovered across sample groups. On the other hand, beta diversity is a metric that may be used to compare the composition or feature similarity of samples. Fig. 4 shows significant results for alpha diversity but not for beta diversity ($p = 0.031$ and $p = 0.259$, respectively).

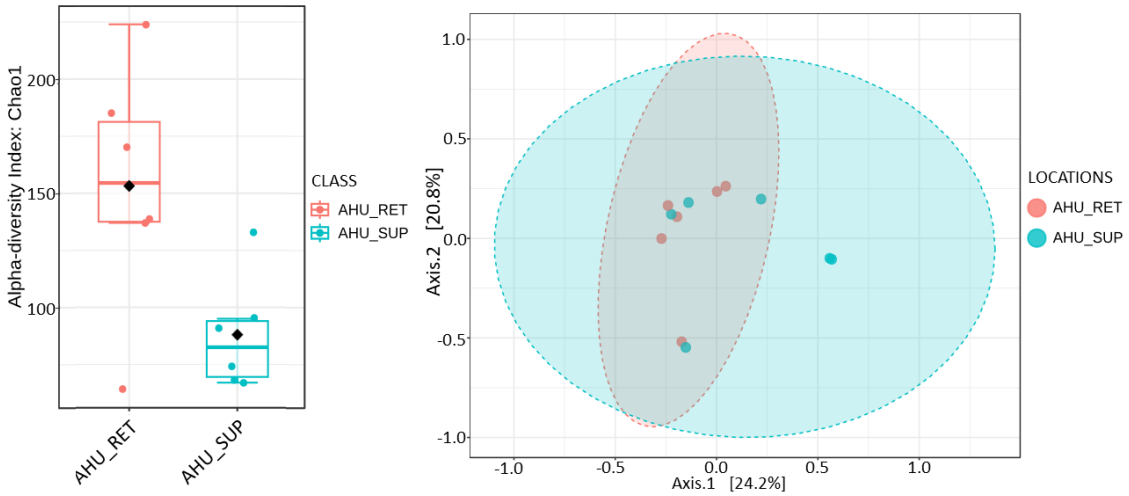


**Figure 4: Results for Diversity Analysis. (A) Significant Alpha Diversity Results (p = 0.031) Using the Shannon Diversity Index. (B) Non-Significant Beta Diversity Results (p = 0.259) Shown as PCoA Plots Using Bray–Curtis Dissimilarity.**

## 4.0 DISCUSSION

In Malaysia, studies on the monitoring of microbiological contaminants in indoor air have been conducted using culture-dependent methods and have reported total bacterial and fungal counts (Aziz et al., 2018; Sarah Fatihah Tamsi et al., 2022). However, a drawback of using culture-dependent methods is that not all bacteria present indoors can be cultivated or cultured, thus leading to inconclusive findings on the profiling of the indoor bacterial community. Advancements in NGS have led to evolutionary changes in air microbiome monitoring. Bacterial genomic material or DNA can be extracted and analysed directly from environmental samples without the need for culture and growth in the laboratory (McCombie et al., 2019). The shift from conventional culture methods to NGS eliminates the limitations associated with traditional techniques and offers a more accurate and comprehensive understanding of microbial communities in hospital air within a shorter timeframe (Ökten et al.,

2020). This methodological advancement is crucial in the context of sudden outbreaks and healthcare-associated infections, where airborne pathogen transmission is a significant concern.

Analysis of the indoor air microbiome in the SASMEC showed diverse bacterial communities in both the supply and return vents of the AHUs. Identification of Proteobacteria, Firmicutes, and Actinobacteria as the predominant bacterial phyla underscores the complexity of the microbial ecosystem in hospital air. The isolation of Proteobacteria and Firmicutes from ventilation systems is of concern because these bacterial phyla may contribute to various respiratory infections, including pneumonia and bronchitis, among hospital occupants (Fakunle et al., 2020). The identification of *Methylobacterium* spp., *Nesterenkonia* spp., *Rubrobacter A bracarensis*, *Flavobacteriaceae* spp., and *Salinisphaera* spp. as the top five bacterial species could have implications for transmission dynamics and potential sources of pathogens in healthcare environments. The high abundance of *Methylobacterium* spp. is particularly alarming, as it can lead to colonisation and bacterial infections in immunocompromised patients, even though it has a low virulence factor. Typically, these species cause mild clinical symptoms, including fever, bacteraemia, peritonitis, and pneumonia (Szwetkowski & Falkinham, 2020). In addition, the presence of gram-negative bacteria, such as *Nesterenkonia* spp. and *Salinisphaera* spp., raises concerns about potential colonisation and asymptomatic bacteraemia, emphasising the need for targeted interventions to reduce the risk of infection (Chander et al., 2017).

In investigating bacterial diversity within the supply and return vents of AHUs in hospital buildings, this study obtained distinct results from the alpha and beta diversity analyses. Alpha diversity analysis, which assesses diversity within specific sample groups, revealed significant differences in species richness or evenness between the supply and return vents (Mahno et al., 2023). In contrast, beta diversity analysis, which examines microbial composition differences between samples, showed no significant dissimilarities, suggesting a high degree of similarity in bacterial communities between the two sites of investigation (Dean Tay et al., 2021). The absence of diversity distinctions implies homogeneity in the indoor air microbiome within the AHU components (Li et al., 2016). To further interpret these results, factors such as effective air filtration, consistent ventilation cleaning, and other environmental variables influencing these findings should be considered. Despite these limitations, this study highlights a rapid and comprehensive culture-independent method for sampling and analysing bacterial diversity and communities present in AHUs in hospitals.

## 5.0 CONCLUSION

In conclusion, the analysis of the indoor air microbiome presented in this study revealed a diverse array of bacterial communities within hospital AHUs, with Proteobacteria, Firmicutes, and Actinobacteria emerging as the dominant phyla. The identification of *Methylobacterium* spp., *Nesterenkonia* spp., *Rubrobacter* A *bracarensis*, unclassified *Flavobacteriaceae* spp., and *Salinisphaera* spp. as the most common bacterial species in dust samples raises concerns, particularly regarding the high abundance of *Methylobacterium* spp., which is known for its association with opportunistic infections, posing a heightened risk for immunocompromised individuals. The presence of *Nesterenkonia* spp. and *Salinisphaera* spp. further underscores their potential for colonisation and asymptomatic bacteraemia. This study underscores the significance of employing NGS and culture-independent methods as vital tools for assessing indoor air microbiomes, offering valuable insights for monitoring biological contaminants in built environments. By enhancing our understanding of the microbial landscape, these findings will contribute to the refinement of strategies for controlling airborne transmission and infectious disease surveillance among patients and healthcare workers, ultimately fostering healthier and safer indoor environments.

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Original Article

# Palm Kernel Pickers: Proposed Tool Designs and their Simulation based on Ergonomic Risk Assessment

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**ABSTRACT:** *This study addressed ergonomic challenges in Malaysia's palm oil industry, particularly its ergonomic risks. The paper examined the manual collection of palm kernels during the oil pressing process. Initial and advanced ergonomic risk assessment (ERA) was employed. The Rapid Entire Body Assessment (REBA) method was applied to assess worker's postures during kernel collection. This study determined that the posture risk is of greater concern than other ergonomic risk factors since the score for posture was 9, exceeding the threshold of 6. The paper proposed two palm kernel picker designs. SolidWorks simulation software, which facilitates the visualisation of a product for fabrication, was applied to develop 3D models of the proposed tools. Finite element analysis (FEA) was used to analyse the proportionally scaled models. Use of the proposed kernel pickers is expected to reduce worker's risk and improve their posture at work. Designs A and B were both simulated using FEA. Tool design A had an efficient design but only one ergonomic aspect, while design B had three ergonomic design aspects, including a curved handle, adjustable tool stick, and a net basket for efficient kernel accumulation. The success of the simulation suggests that we should proceed to the fabrication phase. We suggest that both palm kernel pickers be fabricated to allow comparison between designs and with conventional methods. The project aims to contribute to the sustainability and efficiency of Malaysia's crucial palm oil sector by enhancing the safety and well-being of labourers involved in palm kernel collection.*

**Keywords:** *Ergonomic Risk Assessment, FEA Simulation, Palm Oil Mill, Kernel, REBA, SolidWorks*

## 1.0 INTRODUCTION

The oil palm is one of the most important plantations in Malaysia's agricultural economy. Oil palm plantations play an important role in maintaining the biodiversity of Malaysia's food chain and are among the largest rain catchment areas. In 2022, the total oil palm planted area was recorded as 5.67 million hectares, a decrease of 1.1% from 5.74 million hectares in the previous year (Khayriyyah et al., 2021). Palm kernel oil is more expensive than palm oil. In general, palm kernels have a higher nutrient and oil content than the fruit. Owing to a lack of technology, these recently dropped decisions were poor, causing these palm kernels to be damaged and bad (Khayriyyah et al., 2021). Ergonomics is crucial for palm mill workers who work daily from 8–5 p.m., 8 h per day, in every shift. However, owing to the limited technology in this industry, the agricultural field has been unable to attract younger generations of workers (FFTC Agricultural Policy Platform, 2024). It is essential to ensure that workers maintain good posture, have low levels of fatigue, and a comfortable work environment. This paper assessed the ergonomic risk of the posture of palm mill workers using the Rapid Entire Body Assessment (REBA) tool. The aim of this study was to propose designs for palm kernel pickers. Poor ergonomic hand tool design contributes to biomechanical stress and increases the long-term risk of cumulative trauma, carpal tunnel syndrome disorders, injuries, and musculoskeletal disorders (MSDs).The designed kernel pickers are expected to reduce workers' risks and improve their posture at work. The proposed palm kernel picker designs aim to reduce movement and prevent worsening of the body posture. Many workers take nonergonomic activities in factories and mills for granted, leading to long-term risks. Awareness of ergonomic risk factors (ERF) needs to be increased among workers, especially those involved in difficult manual handling activities.

## 2.0 LITERATURE REVIEW

This section discusses ergonomic concepts and previous studies on palm oil processing, focusing on body posture analysis and methods of maintaining correct posture using the REBA method. The paper discusses the finalisation of a palm kernel picker project, highlighting its benefits, limitations, and previous studies on oil palm mill tools.

### 2.1 Palm Oil Extraction Process

The oil palm milling process produces various products, including cooking oil, palm kernel shells, fibre, and vegetable oil. The oil is used in the food, cosmetic, and biofuel industries. The mill is also involved in the production of starch, vegetable fats, and oils. Unlike other seed processing methods, the palm oil milling process includes stages such as receiving, sterilising, threshing, digesting, pressing of palm fruit, crude oil clarification, and palm kernel recovery. This method is both cost-effective and environmentally friendly. To ensure the quality of the extracted palm oil, fresh palm fruit bunches must be processed within 2 days of harvesting. Subsequently, the fruit is sterilised at high temperatures to soften and kill bacteria, increase the moisture content, and facilitate fruit separation. Threshing and screening are performed to separate the palm fruit from the bunches. The palm fruit is then transported to a digester, where it is combined and boiled to separate the pulp and nuts. A twin-screw hydraulic palm oil presser is used to extract crude palm oil, thereby increasing the production efficiency. The 'dry' method, which uses a mechanical press, and the 'wet' method, which uses hot water to melt the oil, are the two methods used to extract the oil from the digested material. By applying mechanical pressure to the digested pulp, the 'dry' method extracts oil from a mixture of oil, moisture, fibre, and nuts. Oil squeezing has three levels: slow, normal, and high. Fig. 1 illustrates the palm oil extraction process.

### 2.2 Ergonomics

Ergonomics involves the design of jobs to suit workers, thereby enhancing their safety and efficiency. The implementation of ergonomic solutions can improve worker comfort and productivity. This is vital because the musculoskeletal system is affected by factors such as awkward posture, extreme temperature, and repetitive movement, which can lead to symptoms such as fatigue, discomfort, and musculoskeletal disorders. According to a previous article, ergonomics and human factors apply the knowledge of human abilities to design systems, organisations, jobs, machines, tools, and consumer products for safe and efficient use. Ergonomic applications have evolved with advances in knowledge and research on global human challenges. Ergonomics makes workers' lives easier and safer, and contributes to improved sleep quality. Prioritising safety as a value rather than merely a priority is crucial for preventing injuries, retaining positive company outcomes, and avoiding worker compensation claims. Hagberg et al. (1995) distinguished between ergonomic and human factors in the workplace by focusing on how work affects employees and risk factors. However, ergonomics focuses on designs that minimise human error. Risk factors include actions or conditions that increase the likelihood of musculoskeletal injury. However, it is difficult to determine

the link between exposure to risk factors and musculoskeletal injury. Ergonomic risk factors include repetitive awkward postures, forceful motion, direct pressure, vibration, extreme temperatures, noise, and work stress.

Awkward posture refers to body positions that deviate significantly from a neutral stance during work, making the muscles less efficient and requiring more effort. Examples include twisting, bending, reaching, pulling, or lifting, as well as working with the hands above the head or in positions where the neck or back is bent by >30° without support (Yale Environment Health and Safety, 2018). The finding of this study, that there is a high awareness of awkward posture, is promising. This awareness could be the foundation for creating programs or health-promoting strategies to address awkward posture and repetitive motion, which contribute to musculoskeletal disorders. Physical factors such as prolonged standing, sitting, and uncomfortable posture are linked to musculoskeletal disorders, especially among females (60.7%) and rural dwellers (56.7%).

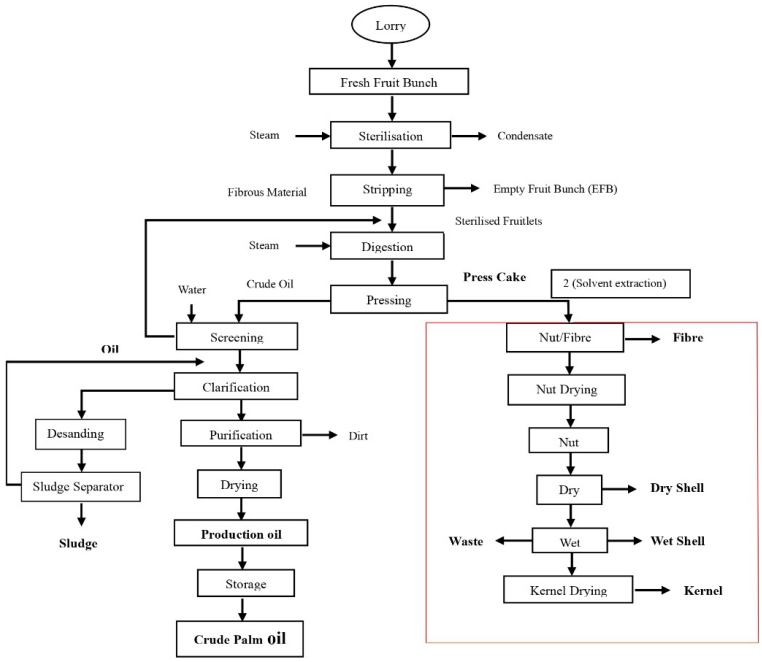


**Figure 1: The Palm Oil Extraction Process**

## 2.3 Ergonomic Risk Factors (ERF)

According to Hagberg et al. (1995), the terms “ergonomics” and “human factors” are used interchangeably in the workplace. Both describe the workers’ interactions with job demands. The distinction is that ergonomics focuses on how work affects workers, whereas human factors focus on designs that reduce the possibility of human error. By addressing traditional and environmental risk factors, workers can be kept injury free (Bongers et al., 2002). The risk factors include actions or conditions that increase the likelihood of musculoskeletal injury. The literature on applied ergonomics recognises a small set of common physical risk factors across many occupations and work settings. The relationship between exposure to risk factors and the risk of musculoskeletal injury is difficult to define. Although physical risk factors are important first-line risk factors, other plausible factors such as organisational and psychosocial factors may cause disorders or indirectly influence the effects of physical risk factors (Hagberg et al., 1995).

Ergonomic risk factors are workplace situations that cause body wear and tear, and can result in injury. Examples include repetition, awkward posture, forceful motion, stationary position, direct pressure, vibration, extreme temperatures, noise, and work stress. Awkward posture refers to body positions that deviate significantly from the neutral posture while

performing work activities. When a worker assumes an awkward posture, the muscles work less efficiently and must exert more force to complete the task.

Work tasks with high-force loads require greater muscle effort, leading to fatigue and MSDs. The amount of physical effort required to perform a task, such as heavy lifting, or maintain control of equipment or tools, is referred to as force. The amount of force required is determined by the type of grip, object weight, body posture, activity type, and task duration. Forceful motion places great strain on the muscles, tendons, ligaments, and joints. Increasing force necessitates increased body demands, such as increased muscle motion, as well as other physiological changes required to sustain the increased effort. Prolonged or recurring activities of this type can cause not only fatigue but also MSDs if there is insufficient time for rest or recovery (Leffers, 2013).

Vibration is also an ergonomic risk factor, because when a specific body part meets a vibrating object, such as a powered hand tool, exposure to local vibration occurs. Whole-body vibration exposure can occur while standing or sitting in/on vibrating environments/objects, such as when driving heavy-duty vehicles or operating large machinery (Yale Environmental Health & Safety, 2018). According to Benos (2020), a review of ergonomics in agriculture found that machines used in agriculture with driving seats appear to be associated with painful lower back disorders, whereas handheld machines appear to be associated with upper extremity disorders. Whole-body vibration (WBV) and hand-arm transmitted vibration (HATV) are the primary causes of such disorders. However, personal characteristics, awkward posture, mechanical shock, and seat discomfort are also recognised causes of MSDs. Current ergonomic interventions are primarily aimed at reducing vibrations and improving operator comfort. Nonetheless, more collaborative efforts among physicians, ergonomists, engineers, and manufacturers are required to develop new ergonomic technologies and raise worker awareness regarding the risk factors involved.

Repeatedly performing the same motions places strain on the muscles and tendons. The severity of the risk is determined by the frequency with which the action is repeated, speed of movement, number of muscles involved, and the required force. Fatigue and muscle-tendon strain can accumulate if motions are repeated frequently within a few seconds and for long periods, such as an 8-h shift. The tendons and muscles frequently recover from the effects of stretching or forceful exertion if sufficient time is allowed between them. When awkward postures and forceful exertions are involved, the effects of repetitive motion on the performance of the same work activities are exacerbated. The risk factors for repetitive actions can also vary depending on the body area and specific actions being performed (HSE, 2019).

According to BostonTec (2021), static posture is the condition of remaining in the same posture or position for extended periods, typically while working. It has the potential to reduce blood flow and damage the muscles. Furthermore, a static posture can have an impact on the nerves, ligaments, blood vessels, and tendons. It is an ergonomic risk factor that may contribute to the development of MSDs. Static posture, whether sitting or standing for a long time, accompanied by repetitive movement, can cause soreness and fatigue. Furthermore, the back, shoulders, neck, legs, and wrists can experience stiffness and discomfort depending on the posture, work duration, and exertion level.

Contact stress is caused by contact between soft body tissue and a hard or sharp object, such as workstation edges, tools, machinery, products, or the floor. Contact abrasions most commonly affect the soft tissues on the fingers, palms, forearms, thighs, buttocks, shins, and feet. This contact may result in pressure being applied to a small area of the body such as the wrist or forearm, which can restrict blood flow, tendon and muscle movement, and nerve function.

Contact stress can cause MSDs when the tendons, nerves, or blood vessels in vulnerable areas are compressed. It can limit tendon movement, requiring more effort and potentially resulting in tendon and surrounding tissue inflammation. Contact stress, which causes a sharp push into deeper tissues, can reduce the blood flow and cause early muscle fatigue. The Occupational Safety and Health Administration (OSHA) Computer Workstations Etools document (2003) defines contact stress as internal stress caused by stretching or bending a tendon, nerve, or blood vessel around a bone or tendon. External contact stress occurs when a part of the body rubs against a workstation component such as a chair seat pan or desk edge. Consequently, nerves may be irritated or blood vessels constricted. According to published research, contact stress is a fairly well-identified risk factor for medium to heavy, repetitive, and manual job tasks, but there is little convincing evidence that it is a significant risk factor for computer users.

People in systems interact with their surroundings, and environmental ergonomics is concerned with how they interact with their surroundings from an ergonomic standpoint. Although many studies of human responses to the environment (light, noise, heat, cold, etc.) have been conducted over hundreds of years, it is only with the development of ergonomics as a discipline that the unique features of environmental ergonomics are beginning to emerge. Examples include societies and conferences on specific aspects of the environment such as noise, lighting, and vibrations (Mazalan & Shafie, 2021). The International Organisation for Standardisation (ISO) and European Standards Organisation (CEN) have made significant contributions to

environmental ergonomics. However, the existence of established standards committees on noise, vibration, lighting, and other areas has slowed progress because they frequently take a product- or manufacturer-oriented perspective that is not human-centred and does not lend itself to an integrated ergonomics approach. However, this is not a static position, and it is being increasingly recognised that people experience whole environments, and that ergonomic methods are necessary for effective practical application (Parsons, 1995).

The palm oil industry contributes to global oil and fat production. Indonesia and Malaysia are the two largest palm oil producers worldwide. This industry involves over a million people; however, little information is available regarding the health and safety of their jobs. MSD risk variables are assessed using assessments, observations, video analyses, and electromyography measurements. MSD are caused by the method of activity and incorrect posture. MSDs affect muscles, joints, tendons, ligaments, and nerves. They may develop over time or occur suddenly owing to overload. Lifting heavy items; bending; reaching overhead; pushing and pulling heavy loads; working in awkward body postures; and repetitively performing the same or similar tasks can expose workers to risk factors. Exposure to these MSD risk factors increases the risk of injury in workers (HSE, 2019). Based on a study by the World Health Organisation, according to a recent analysis of the Global Burden of Disease (GBD) 2019 data, approximately 1.71 billion people worldwide are affected by musculoskeletal conditions such as low back pain, neck pain, fractures, other injuries, osteoarthritis, amputation, and rheumatoid arthritis (Cieza et al., 2021).

Although the prevalence of musculoskeletal conditions varies with age and diagnosis, individuals of all ages are affected. High-income countries are the most affected in terms of the number of people (441 million). While the prevalence of musculoskeletal conditions increases with age, younger people are more frequently affected during their prime-earning years. Because MSDs affect the muscles, joints, tendons, ligaments, bones, and nerves, their effects include tendinitis, carpal tunnel syndrome, osteoarthritis, rheumatoid arthritis (RA), fibromyalgia, and bone fracture. The severity of MSDs varies. In some cases, it can cause pain and discomfort, and interfere with daily activities. Early detection and treatment can help reduce symptoms and improve overall prognosis. Symptoms of MSDs include recurrent pain, stiff joints, swelling, and dull aches. They can also affect major areas of the musculoskeletal system, including the neck, shoulders, wrists, back, hips, legs, knees, and feet. Patients with MSDs may have a limited range of motion or difficulty completing routine tasks in the workplace (Morrison, 2018).

### 2.4 Kinovea Software to Measure Body Angles

Kinovea is a free computer-based two-dimensional motion analysis software that measures kinematic parameters in videos without using markers. It has been used to analyse running or vertical jumping in athletes and a strong correlation exists between Kinovea interrater reliability and the initial contact phase during running. The software has also been used to examine the range of motion of the cervical spine in the sagittal plane and determine the kinematics of the wrist joint. Parra et al. (2018) explored the use of two tools for oil palm harvesting and pruning: the sickle and the Malaysian pole. The sickle was used for palms taller than 4 m, whereas the Malaysian pole was a chisel for palms shorter than 4 m. While advances in this field have focused on productivity, motorised tools have been proposed to reduce task duration. However, these machines increase the momentum that workers must consider because of the length of the handle and the manoeuvring required to cut down bunches. Biomechanical stress was measured by observing the corporal positions of the workers while using each tool. The angles between the limbs and corporal planes were measured using a free-body diagram.

In another study (Mathew et al., 2017), this software was used to investigate the ankle, knee, and hip joint angles in older adults at various stages of the gait cycle. Kinematic asymmetries in the participants' gait patterns were cited by the authors as restrictions on hip extension. Therefore, the literature supports the use of Kinovea software in both sports and clinical settings. Therefore, a preliminary study of reliability and validity was conducted. Fernández-González et al. (2020) assessed the inter- and intra-rater reliability of Kinovea when registering the hip, knee, and ankle angles during the initial contact phase of walking, and investigated the agreement by comparing the angles obtained using Kinovea with those obtained using a three-dimensional motion capture system. It showed that Kinovea Software is suitable for the measurement of body angles for body posture assessment.

### 2.5 The Rapid Entire Body Assessment (REBA)

The REBA, a systematic process used to evaluate and analyse ergonomic risks associated with various work tasks, is an alternative to Kinovea. It is frequently used in occupational health and safety to evaluate workstation ergonomics and to identify potential areas for improvement. The REBA is a tool for assessing the risk of MSDs associated with specific job tasks. It is a whole-body screening tool that assesses biomechanical and postural loading of the body using a systematic procedure, while

allowing for multiple assessments per task or job. The advantages of this tool are that it is simple, quick, and requires little equipment. The REBA evaluates the entire body and can be used to evaluate any task (Morrison, 2018), however, it can only assess one posture at a time, and may exclude high-risk aspects of the task. Joshi and Deepthi (2020) conducted an analysis of the REBA and found that it considers all body parts, loads handled, and coupling types, making it the simplest and most widely used method. However, it is less helpful for assessing manual material-handling tasks. Deepthi's research highlights the popularity of REBA owing to its ease of use and speed, and its use in various sectors to determine relative risk levels for tasks. Table 1 summarises previous research using tools related to the Rapid Upper Limb Assessment ((RULA) and REBA.

**Table 1: Previous Research Works Using Tools Related**

| No | Author/s | Title | Method | Findings |
|---|---|---|---|---|
| 1 | Fazi *et al.,* (2019) | Risks assessment at automotive manufacturing company and ergonomic working condition | • RULA | Automotive industry management faces hazards in assembly lines and to workers owing to inappropriate tasks and unsafe workplaces. Research using interviews, observation, videotaping. and RULA identified occupational risks and recommended ergonomic working conditions. |
| 2 | Mohamaddan *et al.,* (2021) | Investigation of oil palm harvesting tools design and technique on work-related musculoskeletal disorders of the upper body. | • RULA<br>• CATIA software | The study identified work-related musculoskeletal disorders (WMSDs) in harvesters' shoulders and trunks, indicating the need for immediate tool changes (RULA score = 7). |
| 3 | Wibowo and Mawadati, (2021) | The analysis of employees' work posture by using REBA and RULA. | • RULA<br>• REBA | The study examines employees' work posture using the REBA and RULA, by calculating angles on the back, neck, and leg. Results show a RULA score of 7 and REBA score of 11. Immediate improvement is recommended to prevent injuries owing to incorrect posture. |
| 4 | Saulia *et al.,* (2022) | Postural analysis in design evaluation of oil palm loose fruit collector machine. | • REBA | A roller-shaped machine with elastic spikes clamped loose oil palm fruit, thereby increasing productivity and workplace safety on farms. The angles of the neck, torso, legs, upper arms, forearms, and wrists were measured and the machine scored 2–5 on the REBA scale. |
| 5 | Sulaimana *et al.*, (2023) | Design of harvesting tool using ergonomic approach for musculoskeletal discomfort prevention in low-cost farming system: A case study of Korean melon (Cucumis melo var. Makuwa). | • RULA<br>• OWAS | The study revealed manual harvesting by labourers. Korean melons at lower levels created work-related MSD risks. The harvesting process involved cutting, collecting, lifting, and moving, with OWAS and RULA scores of 4 and 7, respectively. |

RULA: Rapid Upper Limb Assessment; REBA: Rapid Entire Body Assessment; MSD: musculoskeletal disorders; OWAS: Ovako Working Analysis System

## 2.6 SolidWorks Software

The improved, ergonomically designed tools for palm kernel pickers were sketched in SolidWorks (Dassault Systèmes, Waltham, MA, USA), an effective computer-aided modelling application. SolidWorks was used to design the mechanical structures from start to finish. Software, such as Finite Element Analysis (FEA) software, was initially used for project management and simulation, as well as for planning, visual ideation, modelling, feasibility assessment, prototyping, and feasibility assessment. SolidWorks software was then used to create mechanical, electrical, and software components, using static structural analysis, which is a type of FEA. This type of FEA analyses proportionally scaled models. The test maintains that any structure that is sound on a small scale can handle the same interactions and produce the same results as a full-scale structure. It is a static simulation that uses and develops stress data, as well as the Von Mises stress and safety factor. Von Mises stress analysis is an essential tool in FEA simulation, helping identify and resolve structural issues, improving worker

comfort and usability, and assessing the structural integrity and potential failure of materials under various loading conditions. The data were analysed and compared in terms of ergonomics and material quality (Parra et al., 2018).

Several ergonomically designed tools have been created to improve the working conditions of palm oil mill workers in the plantation industry. Numerous studies have been conducted on ergonomic cutting tools for the harvesting of bunches of oil palm fruit. One study designed an oil-palm fruit collector. A study conducted by Parra et al. (2018) designed a fruit-palm bunch-cutting tool system for harvesting. Harvesting and pruning were performed using two different tools, both of which had a long handle attached to a blade. The effectiveness of the tool varied depending on the blade shape. The sickle was used for palms taller than 4 m, whereas the Malaysian pole was a chisel used for palms shorter than 4 m. Advances have been made in this field, but they have prioritised productivity over user health. The use of motorised tools has been proposed to reduce task duration. However, these machines result in an increase in the momentum that the worker's bodies must endure. Therefore, the purpose of this study was to compare the stress on the lower back when cutting fruit bunches using a traditional tool and a new cutting tool proposed using a biomechanical analysis simulated by JACK Siemens. The tools were evaluated at three different levels: 1) when the operator was carrying the tool, designated as 0°; 2) when the operator raised the tool to 70°; and 3) when the operator began to pull on the tool, designated as 70° + force. Fig. 2 shows the new oil palm cutting tool system, and Fig.3 shows the different levels of measurement.

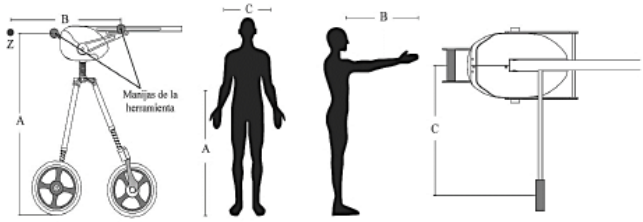


**Figure 2: New Oil Palm Cutting Tool (Parra et al., 2018)**

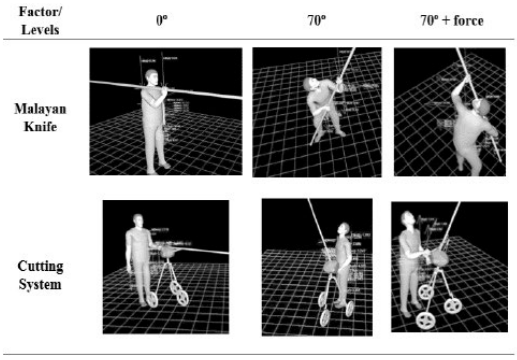


**Figure 3: The Different Levels for Each Measurement (Parra *et al.*, 2018)**

Saulia et al. (2022) conducted a postural analysis for the design evaluation of a loose oil palm fruit-collection machine. Loose fruit scattered on the ground must also be collected. However, this activity is considered less productive and time-consuming, and causes several problems, such as fatigue and a variety of symptoms related to unsafe working posture. The worker manually picks up and collects loose oil palm fruit that are scattered on the ground and is required to maintain a high-intensity, bent posture. This activity should be evaluated in the workplace because it is a key ergonomic risk indicator.

This study developed an ergonomic machine in the form of a roller equipped with elastic spikes on its entire surface. This unit applied the principles of elasticity and strength to clamp loose oil palm fruit and collect them in a container. The machine was designed for use on farms, to increase productivity and ensure workplace safety. Fig. 4 shows the loose oil palm fruit collector.

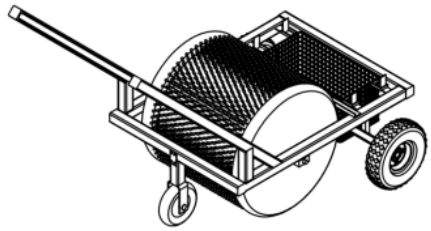

**Figure 4: Loose Oil Palm Fruit Collector (Saulia *et al.*, 2022)**

Ergonomic compatibility with users was also considered during the design and manufacture of the loose oil palm fruit-collector. Working posture and vision, which are important human factors, were incorporated into the machine's design analysis. This project used the RULA to analyse posture when using the loose oil palm fruit-collector and CATIA software (Dassault Systèmes, Waltham, MA, USA) for machine design. The purpose of this project was to determine the level of risk of the working posture during loose fruit collection using a loose oil palm fruit-collector called the ERBRON-C. A REBA evaluation of prototype users was performed to ensure design compatibility. In this project, the actual process of collecting oil palm leaves with ERBRON-C had a REBA score of 2–5, indicating a low-to-moderate risk level; therefore, the posture assessment at the design stage differed little.

## 3.0 METHODOLOGY

This section describes the research methodology used to answer the research question, and to describe the research approach, primary data collection process for secondary research, data analysis tools used, and limitations of the adopted research method. Fig. 5 shows the conceptual design methodologies applied to the palm kernel pickers. According to Eby (2022), the project design cycle consists of seven steps: situation analysis, design process, submission and approval, implementation and monitoring, appraisal, final evaluation, and implementation and monitoring. This study is currently in stage 2 and the design process is based on situational analysis. This study is still at an early stage of the design cycle and requires approval from experts and end users. The paper began with the identification of problems, data collection, and analysis, with project planning being crucial for efficient and accurate results. Fig. 6 shows the study flowchart.

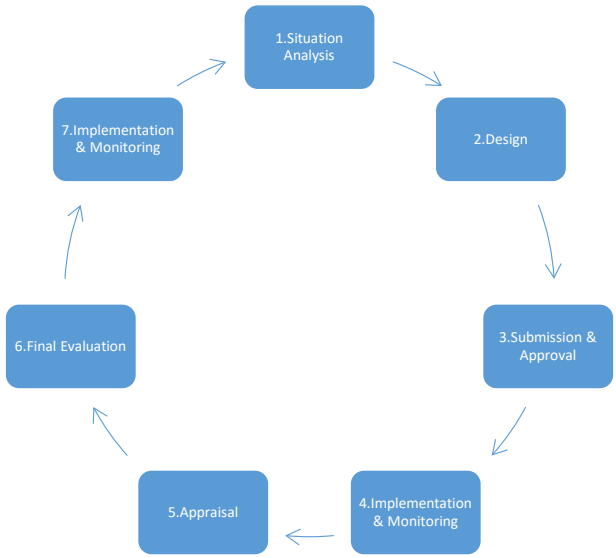


**Figure 5: Project Design Cycle Diagram (Eby, 2022)**

### 3.1 Kinovea Software

Kinovea is software that analyses angles and body motion in videos or pictures. This helps identify the correct posture angle in worker photos before using the REBA. The software can accurately measure distances of up to 5 m and angles of 45–90°, with a 90° angle recommended for optimal results. This project used Kinovea's goniometer tool to measure the angles of body segments during specific tasks or movements, aligning with REBA's principle of assessing posture and joint angles to evaluate ergonomic risk. By visually inspecting and measuring these angles, users can compare them with the ergonomic guidelines and reference values in the REBA to determine the potential risk levels associated with specific body postures or movement patterns.

### 3.2 Initial Ergonomic Risk Assessment (ERA)

The initial ERA is the first step in planning and carrying out an ergonomic workplace evaluation. An initial ERA is a tool used to systematically evaluate and capture potential ergonomic hazards in the workplace. It aids in the identification of areas of concern and provides a structured approach for the management of ergonomic risk. Table 2 presents the initial ERA.

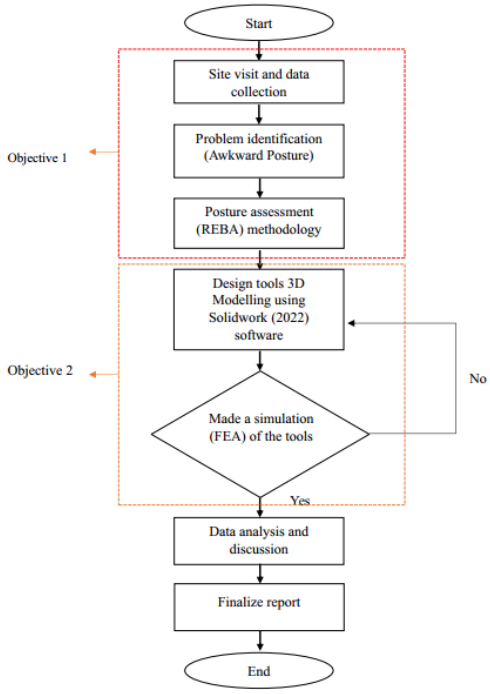


**Figure 6: Study Flowchart**

**Table 2: Initial ERA Form**

| Risk factors | Total Score | Minimum requirement for advanced ERA | Result of Initial ERA | Pain or Discomfort due to Risk Factors determined in Musculoskeletal Assessment | | Need Advanced ERA? (Yes/No) |
|---|---|---|---|---|---|---|
| Awkward Postures | 13 | ⩾ 6 | **9** | If YES, please tick (√) which part of the body (Yes/No) | | **Yes** |
| Static and Sustained Work Posture | 3 | ⩾ 1 | 0 | Neck<br>Shoulder<br>Upper back | /<br>/<br>/ | No |
| Forceful exertion | 1 | 1 | 0 | Upper arm<br>Lower back | /<br>/ | No |
| Repetition Motion | 5 | ⩾ 1 | 0 | Forearm<br>Wrist<br>Hand | /<br>/<br>/ | No |
| Vibration | 4 | ⩾ 1 | 0 | Hip/buttocks<br>Thigh | -<br>/ | No |
| Lighting | 1 | 1 | **1** | Knee<br>Lower leg | -<br>/ | **Yes** |
| Temperature | 1 | 1 | 0 | Feet | - | No |
| Ventilation | 1 | 1 | 0 | | | No |

| | | | | |
|---|---|---|---|---|
| Noise | 2 | ⩾ 1 | 0 | No |

ERA: Ergonomic risk assessment

### 3.3 Rapid Entire Body Assessment (REBA)

The REBA is an ergonomic assessment tool that uses a worksheet to evaluate whole-body postural MSD and job task risks. It assesses posture, forceful exertions, movement type, repetition, and coupling, and requires no advanced ergonomic training or expensive equipment. The tool assigns scores to the wrists, forearms, elbows, and shoulders. The worksheet is divided into Parts A and B. Fig. 7 shows the REBA worksheet used in this study.

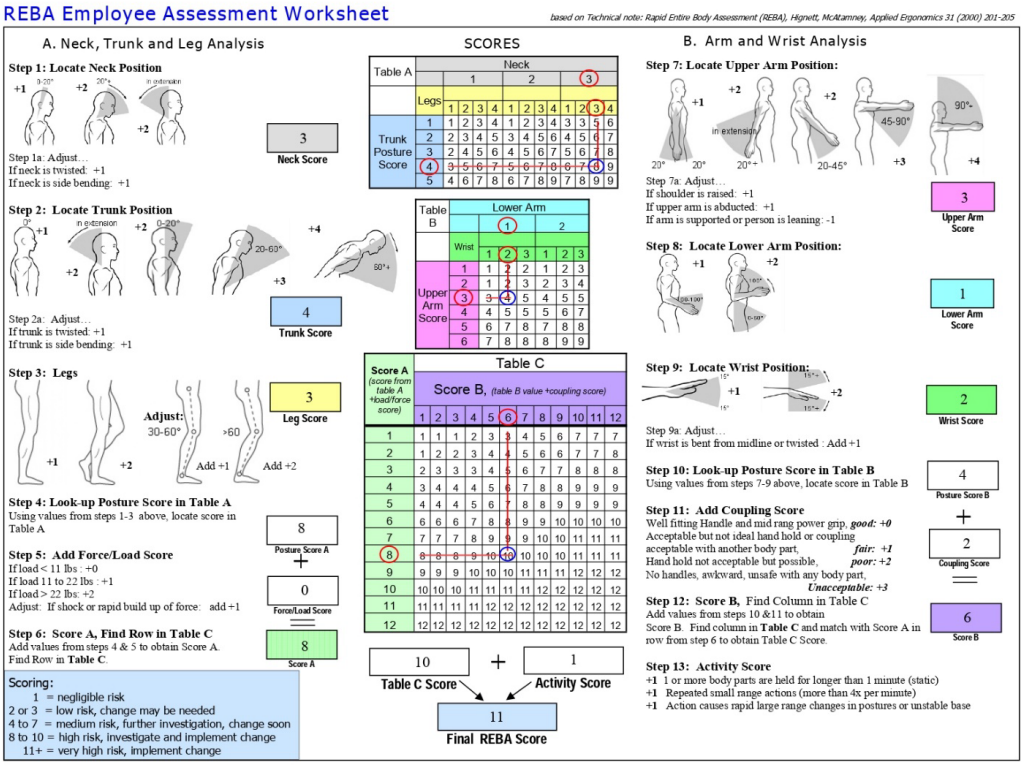


**Figure 7: REBA Worksheet**

### 3.4 SolidWorks

This project used SolidWorks simulation software to improve the ergonomic tool design. Two ergonomic tool designs were proposed, and FEA simulations were performed to simulate them. The simulation data were compared to determine the most suitable tool for the task.

### 3.5 Finite Element Analysis (FEA)

Static structural analysis, a type of FEA, was used to analyse the proportionally scaled models. The test maintains that any structure that is sound on a small scale can produce the same results as a full-scale structure. The results were simulated using FEA of the two proposed design tools. This static simulation uses and develops stress data, as well as the Von Mises stress and safety factor. The data were analysed and compared in terms of ergonomics and material quality.

## 4.0 DATA ANALYSIS AND RESULTS

### 4.1 Site Visit Observation

Kilang ABC Sdn Bhd, located in a forest surrounded by oil palms, is a raw materials industry that falls under the Department of Corporate Relations, Malaysia. Observations and meetings with assistant engineers revealed that the mill had multiple sections dedicated to palm oil processing. The project focused on the pressing section, and on workers' performance of their duties.

### 4.2 Ergonomic Issues

#### 4.2.1 Awkward Posture

The project analysed the posture of workers in the pressing machine section at Kilang Kelapa Sawit ABC Sdn Bhd. The observations revealed awkward postures and the use of inappropriate tools, particularly for the collection of scattered kernels. The REBA method was employed to assess the ergonomic risks associated with upper-extremity MSDs. Fig. 8 shows an image of a worker's awkward posture at the workstation.

**Figure 8: Awkward Posture of the Worker**

The results indicated a medium-to-high risk level, especially in palm mills where workers faced challenges in efficient kernel collection. The analysis considered various body regions such as the neck, trunk, legs, arms, and wrists. Specific angles and movements were evaluated by assigning a score to each region. The combined score indicated a high risk in neck, trunk, and leg analyses, as well as in upper arm, lower arm, and wrist analyses. The ergonomic assessment highlighted issues such as neck angles exceeding 20°, forward and twisted trunk positions, and leg bending. The final posture score suggested a critical situation requiring ergonomic tools to prevent MSDs. The analysis culminated in a REBA score of 11, indicating a severe level of risk, prompting the recommendation of appropriate design tools to mitigate MSD risks.

4.3 Proposed Design

Owing to the lack of modern and suitable tools to speed up the cleaning process, kernels are collected slowly. This project developed ergonomically designed tools to ensure that workers collected kernels in good posture, which would decrease the risk of MSDs.

4.3.1 Proposed Tool Design A

This project showcases two tools developed to improve productivity in the fruit-harvesting industry. The Fruit Roller Picker, with a trigger in the hand, reduces time and improves ergonomics. Manufacturers play a role in disseminating information and training workers, thus ensuring a better user experience. Fig. 9 shows tool design A.

**Figure 9: 3-Diagram of Tool Design A**

4.3.2 Proposed Tool Design B

Tool design B has an ergonomic handle and a basket for the collection of rolling palm kernels. The stick can be adjusted to fit the height and working posture of the user. This tool allows workers to collect excess palm kernels without removing the oil palm seeds. The tool collects 1–2 kg each time and the process can be repeated without affecting ergonomics. Despite its limited size, it maintains the worker's posture for an extended period despite the tool's limited number of data points. Fig. 10 shows tool design B.

**Figure 10: 3-Diagram of Tool Design B**

4.4 SolidWorks

4.4.1 Finite Element Analysis (FEA)

The project used SolidWorks, 3D CAD software with a FEA module, and SolidWorks Simulation to simulate and analyse the structural behaviour of the components in tool designs A and B, focusing on the stress values and displacement.

For tool design A, simulations were conducted on the trigger and roller picker components. Under a 100N load, the trigger showed Von Mises stress values and a safety factor of 2.000. The roller picker, subjected to a 10N load, exhibited deformation with stress values ranging from 0.000–344.819 MPa and a safety factor ranging from 1.196–2.000.

Tool design B components, including the basket net, holder, and assembly, underwent simulations with a 100N load. The results indicated the stress values, safety factors, and displacement. A simulation of the basket net with a 30N force yielded stress values of 0.000–0.202 MPa and a safety factor of 2.000. The results suggest that improvements in materials, geometry, and force minimisation would enhance the analysed values. The simulations provided valuable insights into the structural integrity and performance of the designed components under the specified conditions. Fig. 11 and 12 show the trigger and roller picker, respectively, of the FEA simulation of tool design A. Fig. 13–15 show the handle, cover, and basket net, respectively, of the FEA simulation of tool design B.

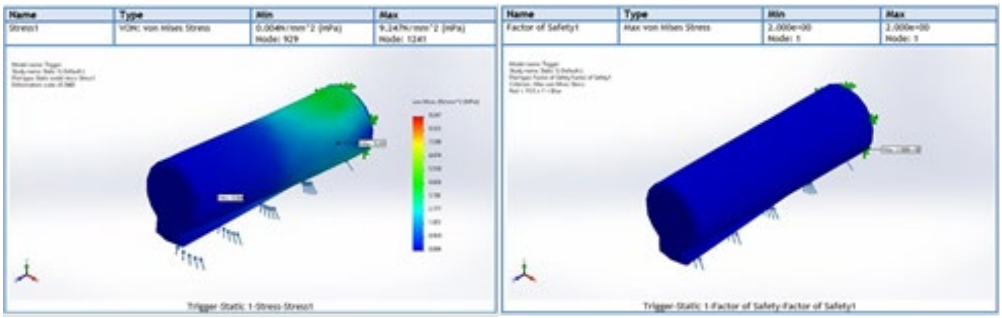


**Figure 11: Trigger**

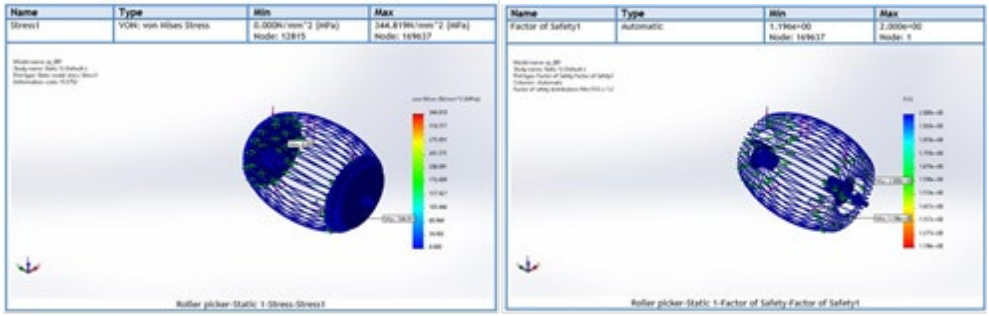


**Figure 12: Roller Picker**

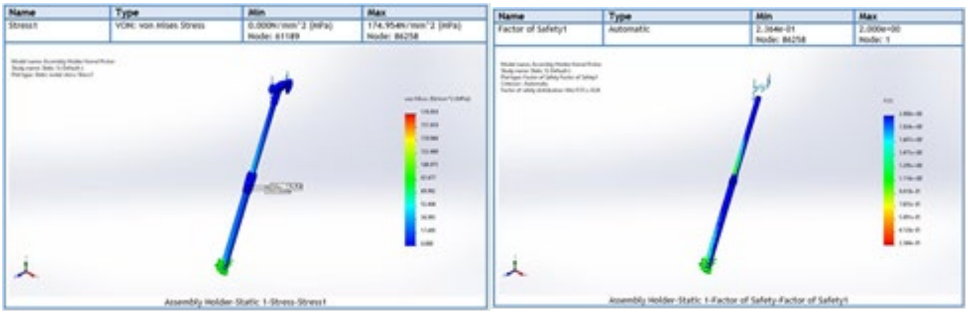


**Figure 13: Handle**

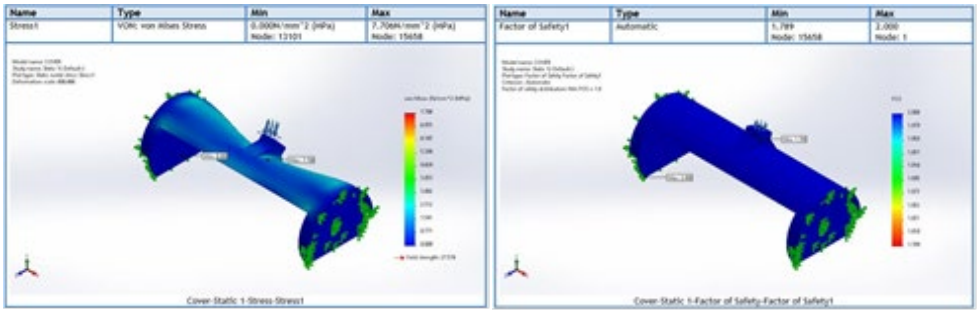


**Figure 14: Cover**

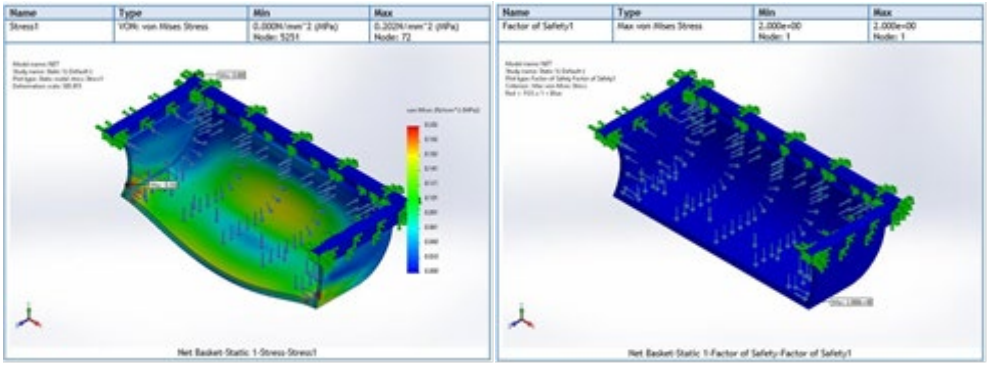


**Figure 15: Basket Net**

## 4.5 Comparison of Tool Designs A and B

### 4.5.1 Ergonomics

Ergonomics is the design of tools and systems that enhance human well-being and system performance. Key aspects included the assessment of handle design, weight, grip surface, controls, adjustable features, visibility, lighting, worker interface, anthropometrics, and safety features, using FEA.

4.5.2 Material Quality

Material quality is crucial in industries such as manufacturing, construction, and electronics because it affects their performance, durability, and suitability for specific applications. Von Mises stress is influenced by the material used, and an ergonomic design must be used to ensure structural integrity and worker safety. Two ergonomic tool designs were used: A, which was based on Von Mises stress data and the safety factor, and B, which used FEA for key components. Tool design A used 1060 alloy and acrylonitrile butadiene styrene polycarbonate (ABS PC), which is influenced by the application, design requirements, and manufacturing processes. Table 3 presents a comparison of tool designs A and B.

**Table 3: Comparison of Tool Designs A and B**

| No | Type | FEA/Others | Tool Design A | Tool Design B |
|---|---|---|---|---|
| 1 | Ergonomics | Von Mises Stress & Safety Factor | The project used FEA to determine the force applied when pressing the trigger of the assembly roller picker. FEA analysis was used for parts that made contact with the body, such as armrests, and for the worker's body posture. The trigger was found to exceed the yield strength limit of 62 MPa, indicating a safe level. Tool design A was found to be safe due to its safety factor of 2. | FEA analysis was used to assess the worker's body posture with respect to the assembly handle, cover, and basket net parts. The analysis ensured that the yield strength was not exceeded by the forces placed on the tool, ensuring that the basket net's Von Mises tension value did not exceed the yield strength. The study found that the force applied to the parts affecting hand and body posture were at a good level, indicating durability. It was determined that damaged basket mesh could increase the probability of dropped kernels during carrying or emptying. The tool was considered to be safe with a maximum safety factor value of 2 |
| | | Others | This tool had a perfect weight distribution and mass balance, which are important factors in providing comfort to workers. Tool design A was light, easy to use, and could be carried anywhere. | The kernel picker tool emphasized user safety and comfort with an adjustable design to prevent bad posture and a secure handle to reduce the risk of injury. A cover closed the brush for user convenience, while the sack-shaped basket net prevented kernel spills. It was suitable for long-term agricultural use. The ergonomic design minimised physical stress during repetitive tasks, promoting worker well-being. Durable materials in the basket net extended equipment life, reducing replacement needs, and the strong yet flexible mesh ensured natural body movement during kernel collection in agricultural settings. |
| 2 | Material Quality | Von Mises Stress & Safety Factor | The material used on this tool was analysed in terms of Von Mises stress and safety factor. Two force-based components of tool design A, the roller picker and trigger, were simulated to prevent cracking or breaking. The roller picker had a Von Mises stress value ranging from 0.000–344.819 MPa, with a modulus of elasticity greater than the maximum stress value. This indicates that the elasticity level did not exceed the limit that would cause the component to rupture. The trigger also had a Von Mises stress range and a modulus of elasticity greater than the maximum stress value, ensuring that the tool components will not rupture or be easily damaged. The safety factors for both components indicated their safety. | This tool also underwent analysis of the material used. Three components of tool design B were simulated: the holder, cover, and basket net. The stress values of the three parts analysed were found to be below the yield strength of the material. The safety factors were also within the safe range. |
| | | ABS PC | The trigger is constructed using ABS PC material that provides a good balance of toughness, impact resistance, and heat resistance. The cost of ABS PC can vary depending on factors such as the ABS PC ratio | ABS PC is a composite material that combines ABS and polycarbonate properties, offering high tensile strength, impact resistance, and toughness. Its durability and cost are influenced by factors such as the ABS PC ratio, formulation, |

| | | |
|---|---|---|
| | and its specific formulation. The impact resistance of ABS PC improves design efficiency, particularly in applications where the material may be subjected to physical stress or impact forces. | and additives. The cost-effectiveness of ABS PC should be evaluated based on performance and durability for specific application requirements. ABS PC is versatile and offers good impact resistance, making it suitable for various applications. The design process should consider material properties, intended use, and manufacturing constraints, with prototyping and testing. |
| AISI347 Annealed Stainless Steel | AISI 347 annealed stainless steel, valued for strength and durability, is selected for force application despite its higher cost. Its robustness ensures reliability, making it well-suited for long-term performance in applications requiring resistance to high temperatures and corrosion. | - |
| 1060 Alloy Steel | - | The 1060 alloy, a pure aluminium variant, is prized for its high electrical conductivity, corrosion resistance, and workability. Although it has lower mechanical strength (yield: 27.6 MPa, tensile: 68.9 MPa, modulus: 69 GPa), it is extensively utilized in electrical and chemical industries where electrical conductivity and corrosion resistance strongest matches. |

ABS PC: acrylonitrile butadiene styrene polycarbonate; FEA: finite element analysis

## 5.0 DISCUSSION

This study analysed and compared tool designs A and B, with a focus on ergonomic design, material quality, and FEA insights. We examined tool design A, which used ABS PC and AISI 347 annealed stainless steel, and tool design B, which used a 1060 alloy and ABS PC. The analysis revealed that tool design A had an efficient design but only one ergonomic aspect, whereas tool design B had three ergonomic design aspects, including a curved handle, an adjustable tool stick, and a net basket for efficient kernel accumulation.

Von Mises stress data were used to determine tool durability, and both tools met the established safety standards. The choice between AISI 347 stainless steel and the 1060 alloy depends on their application and requirements, with AISI 347 stainless steel being preferred for corrosion resistance and the 1060 alloy for strength and stiffness. The final decision should be based on an in-depth analysis of the key factors. Tool design B excelled in ergonomic design and benefited from the mechanical properties of the 1060 alloy, making it a strong competitor in the market.

## 6.0 CONCLUSION

In summary, this study aimed to investigate the ergonomic postures of workers in palm oil mills, particularly during the collection of kernels scattered on the floor. The project successfully assessed workers' postures using both initial and advanced ERA using the REBA method. The second goal was to propose a design tool to address MSDs and ergonomic issues among workers, to improve well-being and efficiency. Usability testing and employee feedback will confirm the positive impact of these ergonomic interventions, with an emphasis on improved comfort and reduced physical strain. This project promotes the incorporation of these solutions into palm oil mills and emphasises the importance of comprehensive training programs. We suggest that prototypes be fabricated to facilitate the comparison of postures before and after use of the proposed tools.

## ACKNOWLEDGEMENT

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Original Article

# Predicting Stress Response to Gelam Oil Therapy Using Electroencephalography and Heart Rate Variability

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**Article history**

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**ABSTRACT :** *Every year, more than one million people worldwide die from suicide, which is attributed to depression in 6.7% of cases. These incidents often stem from life-related stresses that can progress into more severe mental health challenges, potentially leading to mental disorders. High levels of depression, anxiety, and stress are prevalent mental health issues that quietly infiltrate various aspects of people's lives, eroding their well-being. Early recognition and detection are essential for gaining a better understanding and implementing timely interventions to prevent further deterioration into mental disorders and associated complications. However, early recognition and detection alone are insufficient to prevent mental disorders. Effective therapeutic sessions are necessary to address and manage these conditions. Nonetheless, evaluating a patient's progress in therapy can be a challenging and somewhat ambiguous task, influenced by the biases and theoretical training of the clinicians involved, often yielding uncertain or unmeasured results. Therefore, this research aims to investigate how patients respond to therapy using data from electroencephalography (EEG) and heart rate variability (HRV) signals. This study introduces a therapeutic approach using sensational oil derived from the Gelam tree. Therapy sessions and consultations will be conducted for workers in the Kuala Terengganu region. During these sessions, EEG and HRV signals will help detect the levels of alpha and beta waves, enabling the recognition of physical signs and symptoms of stress and anxiety by interpreting visual and auditory cues using a mind-body technique. The findings from questionnaires, EEG, and HRV data will be combined and analysed using statistical methods. This combination of quantitative, qualitative, experimental, and statistical methods is expected to yield the following results: 1) predicting responses to therapy, 2) determining the timing and extent of response to therapy, and 3) assessing the suitability of the therapy approach. Overall, aroma therapy has been found to demonstrate great efficacy in inducing deep relaxation. Ultimately,*

*this research aims to tailor therapy to each patient's specific needs, contributing to the promotion of mental health within the community and fostering a healthier, mentally resilient generation.*

**Keywords :** *Mental Health, Therapeutic Sessions, Aroma Therapy, EEG, HRV*



## 1.0 INTRODUCTION

Currently, one of the major concerns affecting society revolves around issues related to mental health. Mental health encompasses a spectrum of challenges associated with how individuals react, think, behave, interact, and experience emotions relative to others. Conversely, it may manifest as a reduced sense of enjoyment, happiness, and interest, accompanied by a low mood intertwined with behavioural, cognitive, and emotional symptoms, as outlined by the Mental Health Foundation in 2016. Furthermore, mental illnesses can be classified as brain disorders influenced by both genetic and environmental factors, as posited by The National Institute for Mental Health (NIMH) according to the World Health Organization (WHO) in 2013. Vos et al. (2016) reported that mental health problems pose a considerable global burden. The repercussions of mental issues extend beyond the affected individuals, as they also have an influence on the lives of their families and friends. Approximately 25% of Europeans have experienced mental health issues at least once in their lives. Furthermore, research suggests that Australian individuals are contending with mental health challenges, as reported in the National Preventive Health Strategy of 2021, indicating that approximately one in five Australians aged 16–85 years will experience a mental disorder at some stage in their lives.

Malaysia, similar to numerous other nations, faces mental health challenges, particularly within its workforce. According to the Malaysian Ministry of Health, one in three Malaysians aged ≥16 years grapples with mental health issues, and this figure continues to escalate annually. For instance, a study performed by Mohamed et al. (2022) focused on the mental well-being of Malaysian police officers, revealing alarming statistics. Among police officers, 41.1% reported moderate depression, 45% moderate anxiety, and 31.8% moderate stress. They concluded that a considerable majority of police officers experience moderate to severe levels of depression, anxiety, and stress. In a separate endeavour, Azmi et al. (2021) scrutinised Malaysia's existing laws and policies concerning mental health in the workplace, drawing comparisons with those in developed Commonwealth countries, such as the UK. Their study emphasised the need for a comprehensive legal framework and effective policies in Malaysia to support mental health and well-being at work. A comparison with the UK revealed that Malaysia could gain valuable insights from the UK's experiences in addressing mental health issues, indicating a gap in Malaysia's current approach. Abdullah et al. (2020) examined psychosocial factors, including decision latitude, social support, and working conditions, contributing to mental illness among employees of private development companies in Malaysia. Their findings suggested that providing employees with ample decision latitude (freedom to make decisions) can prevent mental illness, ultimately leading to increased overall productivity.

Early recognition and detection play a crucial role in gaining a better understanding of individuals' mental status and implementing prompt interventions to prevent the progression of mental disorders and associated complications. However, relying solely on early recognition and detection is insufficient for preventing mental disorders. Effective therapeutic interventions are indispensable for managing these conditions. Nonetheless, assessing a patient's progress in therapy poses challenges, often resulting in uncertain or unquantifiable outcomes, influenced by the biases and theoretical orientations of the clinicians involved. In light of these challenges, this study aims to explore how patients respond to therapy by leveraging data obtained through electroencephalography (EEG) and heart rate variability (HRV) monitoring. Furthermore, this study aims to introduce a therapeutic approach that incorporates the use of sensational oil derived from the Gelam tree. Therapy sessions and consultations will be administered to workers in the Kuala Terengganu region. Throughout these sessions, EEG and HRV signals will be utilised to detect alpha and beta wave levels, facilitating the identification of physical signs and symptoms of stress and anxiety. This will be achieved through the interpretation of visual and auditory cues using a mind-body technique. The findings obtained from the questionnaires, as well as the EEG and HRV data, will be amalgamated and subjected to statistical analysis.

## 2.0 LITERATURE REVIEW

Numerous studies have investigated mental health challenges among service workers, shedding light on the prevalence of conditions, such as anxiety, depression, and stress. For example, in Malaysia, a recent study revealed that 28.6% of medical officers experience anxiety, 10.7% report depression, and 7.9% face stress. These figures align with the psychological distress rates observed in Western nations, which range from 7 to 29% (Sen et al., 2010). Nordin et al. (2022) found that individuals working in hospitals face a significantly higher risk of depression and anxiety than those working in peripheral healthcare services, with factors, such as extended working hours and 24-h on-call duties, contributing to this disparity. Additionally, a local examination of burnout among Malaysian junior doctors revealed a prevalence of 26.5%, while the prevalence of burnout among academics at a public university stood at 10.7% (Zuraida and Zainal, 2015; Henny et al., 2014). Banfield et al. (2022) investigated the awareness and perceived helpfulness of mental health peer workers in Australia and revealed limited awareness across the general community and positive perceptions of peer workers. Mohamed et al. (2022) explored the mental health of Malaysian police officers and reported that large proportions of officers experienced moderate depression (41.1%), anxiety (45%), and stress (31.8%). Their findings underscored the prevalence of moderate-to-severe mental health challenges among police officers, and identified stressors that could inform best practices. Shkembi et al. (2023) scrutinised the association between effort, reward, overcommitment, and poorer mental health among waste workers in the US, emphasising the importance of assessing workers' perceptions of overcommitment for targeted improvements. An analysis by Feldman et al. (2023) suggested that pregnant essential workers face a heightened risk of worsened mental health. However, the efficacy of mindfulness techniques in addressing the mental health conditions of workers remains unclear. Durand-Moreau et al. (2023) conducted a systematic review and found no conclusive evidence supporting durable and substantial improvement in mental health outcomes through mindfulness-based practices. Miranti and Li (2020) explored the link between mismatches in working hours, job strain, and mental health in Australia, emphasising significant associations and recommending flexible working environments to improve the mental health of mature workers. In Japan, Kitano et al. (2020) investigated the relationship between 24-h movement behaviours and mental health among workers, advocating proper time management focused on encouraging sleep in order to minimise psychological distress and optimise work engagement. Considering the prevalence of mental health problems among workers, it is imperative to extend these studies to service workers.

## 3.0 METHOD

To meet the set objectives, the therapy will be implemented in four steps involving a combination of quantitative and qualitative approaches.

Survey Methodology
Step 1: Identification of the target group of respondents and distribution of questionnaires using the e-MAST web-based platform

Experimental Methodology
Step 2: Selection of respondents with the highest e-MAST results

Step 3: Therapy sessions with the HSNZ team for the selected respondents

Statistical Analysis
Step 4: Analysis of the EEG and HRV data

Step 1: Identification of the target group of respondents

Each respondent will receive a set of questionnaires and will be required to answer based on their mental health status using the e-MAST software. The questionnaire consists of two parts: Part A focuses on the demographics of the respondents, and Part B is a test related to mental health screening using Depression Anxiety and Stress Scale (DASS) 21. We have distributed letters requesting 152 companies around Kuala Terengganu to participate in a mental health project. This project will include staff from service sectors in Kuala Terengganu and Kuala Nerus. Once a respondent clicks the submit button, the e-MAST will automatically compute the results. The scores, along with a detailed analysis of mental health status and personalised

recommendations, will be presented on the subsequent page. All result details will be recorded, allowing respondents to track both their current and past records. Individuals with high scores in e-MAST may be directed to receive therapy sessions.


**Figure 1: e-MAST**

Step 2 : Selection of respondents with the highest e-MAST results

When a respondent clicks the submit button, e-MAST will automatically generate results. The scores, along with a thorough analysis of mental health status and personalised recommendations for each respondent, will be presented on the following page. All aspects of the results will be documented, enabling respondents to monitor both their present and historical records.

Potential respondents who obtain high scores in e-MAST will proceed to receive therapy sessions. When a respondent attends the therapy session, the therapist will explain the therapy process and procedure, provide the 'Research Information Sheet & Consent Form,' and inquire whether the individual has diabetes or epilepsy.

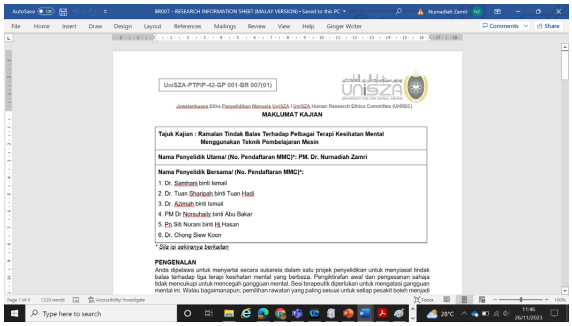



**Figure 2: Consent Form**

Step 3 : Therapy sessions with the HSNZ team for the selected respondents

Therapy Step 1: All participating respondents will be instructed to diligently and comprehensively fill out both the Beck Anxiety Inventory (BAI) and Beck Depression Inventory (BDI) as integral components of the assessment process. This will offer valuable insights into their levels of anxiety and depression, contributing to a thorough evaluation of their mental well-being.

The BDI serves as a widely employed tool for depression screening, evaluating the behavioural expressions and intensity of depressive symptoms. This tool comprises 21 self-reported items, and responses are provided using a multiple-choice format.

The BAI comprises 12 self-reported items, evaluated on a four-point scale, and it is employed to gauge the severity of physical and cognitive anxiety symptoms experienced within the preceding week.

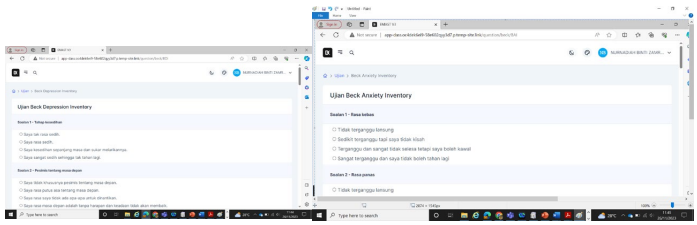



**Figure 3: Beck Anxiety Inventory and Beck Depression Inventory**

Therapy Step 2: The EEG and HRV monitoring equipment will be attached securely to the participating respondents, ensuring precise and stable placement to enable accurate and comprehensive data acquisition throughout the duration of the monitoring session.


**Figure 4: Electroencephalography and heart rate variability monitoring**

Subsequently, EEG and HRV monitoring will be incorporated into the therapy sessions. EEG offers insights into brain activity, enabling the detection of emotional states in each respondent. Frontal EEG activity patterns, particularly asymmetric patterns, differentiate between positive and negative valences, and overall frontal EEG activity distinguishes between high and low arousal levels. Determining arousal levels using EEG signals involves calculating the ratio of beta (12-28 Hz) to alpha (8-12 Hz) brainwaves in the prefrontal cortex. Valence values can be established by comparing the alpha power activation levels in the left and right cortical hemispheres (Ramirez et al., 2018). The primary objective of each therapy session will be to observe the emotional impact over time.

HRV refers to the physiological variation in heartbeats. Cardiac autonomic activity can be assessed using spectral analysis of HRV as a non-invasive and easily implementable tool. Two pivotal frequency domain parameters extracted from spectral analysis are commonly applied: low-frequency (LF) power (0.04-0.15 Hz), reflecting both sympathetic and vagal influences, and high-frequency (HF) power (0.15-0.40 Hz), indicating vagal tone modulation. Additionally, the LF/HF ratio offers insights into the balance between the sympathetic and vagal tones (Li et al., 2019). Our aim is to characterise the respondents' autonomic dysfunction, monitor the natural fluctuations in autonomic function, evaluate autonomic changes post-therapy, and predict prognosis after therapy sessions.

Therapy Step 3: The recording process for EEG and HRV will be initiated, the equipment will be set up meticulously to capture physiological data, and subsequently clear instructions will be provided to the respondent, directing them to rest for a period of 5 min to facilitate optimal data collection and analysis.

Therapy Step 4: Therapy sessions, each lasting 15 min, will be conducted. In the aromatherapy group, tailored interventions and methodologies will be applied to address the specific therapeutic objectives and modalities associated with each group's respective treatment approach.

Aromatherapy is a holistic healing practice that harnesses the aromatic essence of plant extracts, referred to as essential oils, to enhance physical, mental, and emotional well-being. It is a versatile and readily accessible wellness practice that individuals frequently integrate into their daily routines for relaxation, mood improvement, and comprehensive health benefits. In this therapeutic approach, Gelam oil extracted from the leaves of the Melaleuca cajuputi tree by steam distillation, will be introduced as a key element. This incorporation will capitalise on its distinctive fresh and medicinal aroma coupled with its potential antibacterial, antifungal, and decongestant properties to amplify the overall therapeutic experience and to target specific wellness concerns.

Gelam oil is often associated with the essential oil extracted from the Melaleuca cajuputi tree, commonly known as the "Cajuput" tree or "Gelam" tree. This tree is native to Southeast Asia, and its essential oil has traditionally been used in aromatherapy and traditional medicine. Aromatherapy with Gelam oil is an example of how essential oils derived from plants can be integrated into holistic wellness practices. It is essential to approach aromatherapy with an understanding of individual preferences and potential sensitivities, and, if necessary, consultation with healthcare professionals. Essential oils should always be used with care, and attention should be paid to safety guidelines.

Therapy Step 5: Following the completion of the designated activity or assessment, the respondent will be requested to take rest for a period of 5 min, allowing for a brief recovery and relaxation period, after which the EEG and HRV will be recorded to ensure a comprehensive and accurate representation of physiological data during the specified rest interval.

Therapy Step 6: All participating respondents will be kindly and explicitly requested to diligently and comprehensively revisit and complete the BAI and BDI once more as part of the assessment protocol to provide additional or updated insights into their anxiety and depression levels, thereby contributing to a more thorough and nuanced understanding of their mental health status.

Step 4: Analysis of the EEG and HRV data

The analysis of the EEG and HRV data will involve a comprehensive examination of the recorded information to derive meaningful insights into the brain's electrical activity and variability in the time intervals between consecutive heartbeats. In this study, we will extract key features from the EEG and HRV signals, such as frequency bands in EEG and time- and frequency-domain features in HRV. Subsequently, metrics that quantify the variability in both the EEG and HRV data will be calculated. In addition, EEG rhythms including alpha, beta, theta, and delta waves will be used to understand different states of consciousness. We will also explore patterns in HRV data to assess autonomic nervous system activity and stress levels and will examine correlations between EEG features and HRV metrics to identify potential relationships. Finally, we will relate the findings to the goals of the study or clinical context, considering the impact on mental state, cognitive processes, and overall well-being.

## 4.0 RESULTS

We distributed information regarding this project to 157 organisations around Kuala Terengganu and Kuala Nerus. Consequently, 30 organisations agreed to participate in the program. Across the 30 participating organisations, approximately 294 respondents completed the DASS questionnaire on the e-MAST website. The results for all the respondents are available to be retrieved from the E-MAST website.

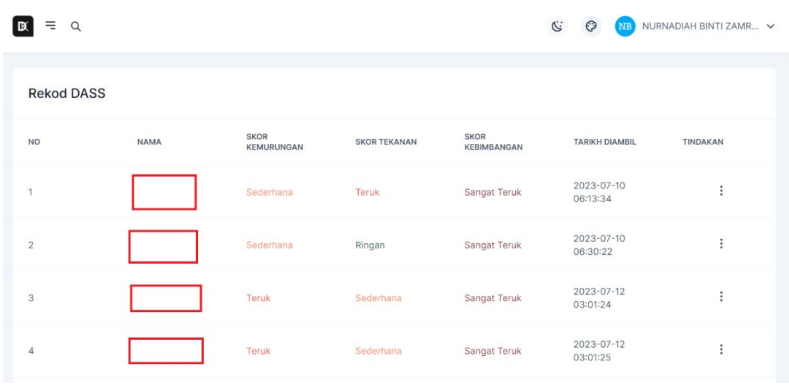



**Figure 5: Depression Anxiety and Stress Scale Results**

Some of the DASS results are listed in Table 1.

**Table 1 Depression Anxiety and Stress Scale Results**

| Respondent | Depression | Stress | Depression |
|---|---|---|---|
| 1 | Mild | Normal | Moderate |
| 2 | Mild | Normal | Moderate |
| 3 | Severe | Moderate | Moderate |
| 4 | Moderate | Moderate | Severe |
| 5 | Severe | Moderate | Very Severe |
| 6 | Moderate | Low | Normal |
| 7 | Very Severe | Low | Low |
| 8 | Very Severe | Severe | Severe |
| 9 | Low | Normal | Moderate |

Around 72 respondents have been identified as having either moderate or higher levels of depression, anxiety, or stress. All these 72 respondents have been invited to join the therapy sessions.

Once the respondents agree to participate in the therapy, we will explain all the details of the therapy process and procedure. We will provide them with the 'Research Information Sheet & Consent Form' retrieved from UniSZA's Ethics Committee, which outlines all the pros and cons that could arise before, during, and after the therapy sessions. Respondents with diabetes, epilepsy, or those currently on medication will be excluded.

Prior to commencing therapy sessions, all participants will be required to fill out the BDI. It is important to note that the BDI is already integrated into the E-MAST software.

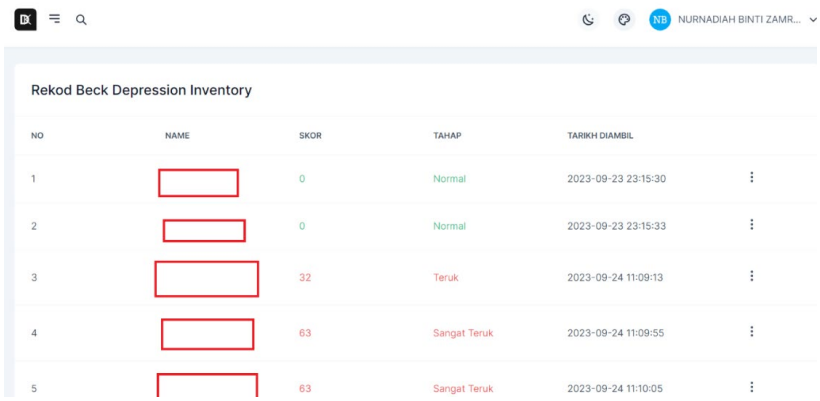



**Figure 6: Beck Depression Inventory Results**

Apart from the BDI, participants must also fulfil the requirement of completing the BAI.

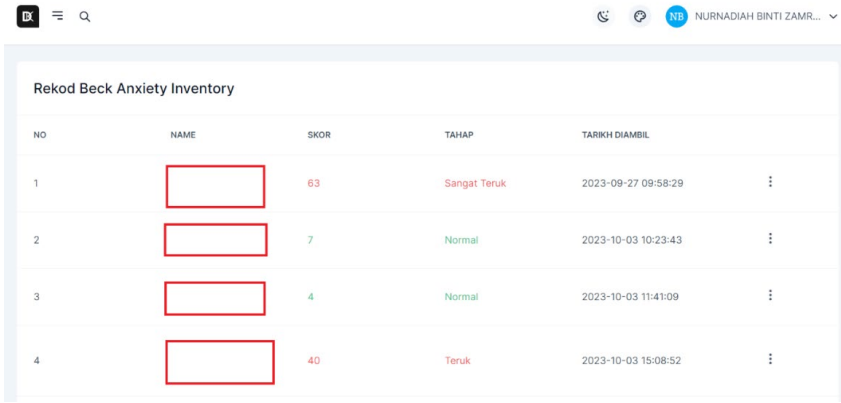



**Figure 7: Beck Anxiety Inventory Results**

Seventy-one respondents attended the therapy. These respondents were randomly assigned using the Randomiser software (https://www.sealedenvelope.com/simple-randomiser/v1/lists). Based on the randomisation of this software, 17 respondents attended the aroma therapy session.

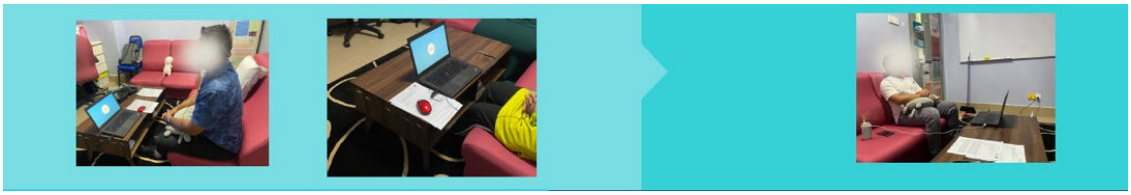
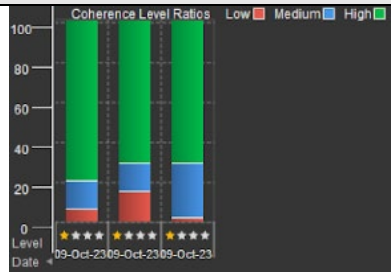
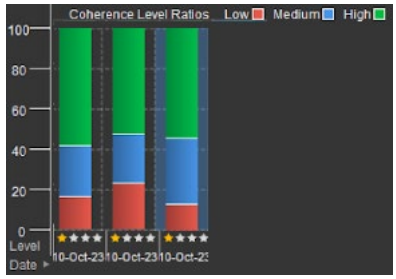
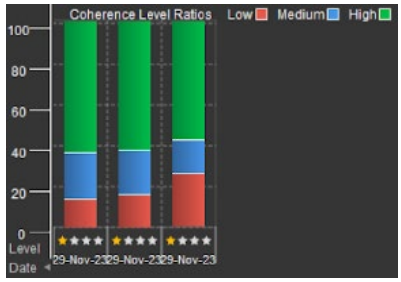


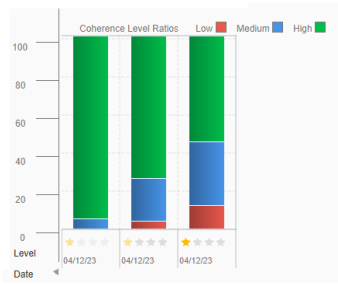
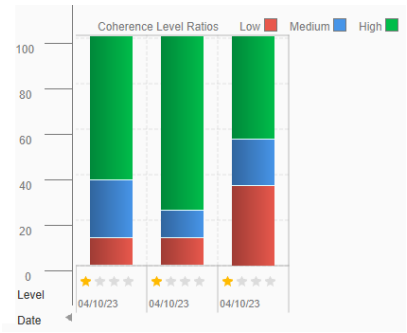
**Figure 8: Aroma Therapy Sessions**

## 5.0 DISCUSSION

To understand the multifaceted effects of therapeutic interventions on psychological well-being, the comprehensive analysis presented in Table 2 comprises a vast array of data, delineating the outcomes derived from the assessments of DASS, BDI, BAI, and HRV results. This extensive summation provides nuanced insights into the effectiveness of applied therapies in addressing and mitigating psychological distress among participants. Through an extensive examination of the collected data, this study seeks to unravel the intricate tapestry of therapeutic influence on mental health, paving the way for a deeper comprehension of the interconnected dynamics between emotional well-being and therapeutic interventions.

**Table 2 Summarisation of DASS, BDI, BAI and HRV Results**

| Respondent | DASS | BDI | HRV | BAI |
|---|---|---|---|---|
| 1 | Depression- Very Severe<br>Stress- Severe<br>Anxiety- Severe | Before-Moderate<br>After-Normal |  | Before- Mild<br>After-Normal |
| 2 | Depression- Severe<br>Stress-Mild<br>Anxiety- Mild | Before-Normal<br>After-Normal |  | Before-Normal<br>After-Normal |
| 3 | Depression- Moderate<br>Stress- Moderate<br>Anxiety - Mild | Before-Normal<br>After-Normal |  | Before-Normal<br>After-Normal |
| 4 | Depression- Severe | Before-Normal<br>After- Normal | | Before- Normal<br>After- Normal |

| | | | | |
|---|---|---|---|---|
| | Stress-Moderate<br><br>Anxiety - Moderate | |  | |
| 5 | Depression-Mild<br><br>Stress-Normal<br><br>Anxiety-Moderate | Before- Mild<br><br>After-Normal |  | Before-Mild<br><br>After-Normal |

The outcomes summarised in Table 2 underscore the effectiveness of the therapies in ameliorating psychological distress in the participants. Exemplified by the case of Respondent 1, who initially presented with very severe depression, severe stress levels, and severe anxiety, the therapeutic interventions resulted in a notable positive impact. Prior to therapy, the BDI and BAI results indicated moderate and mild states, respectively. After the therapy, a significant improvement was observed, with the BDI and BAI results shifting to normal. In conjunction with psychological assessments, HRV analysis provided additional insights into the respondents' well-being. Pre-therapy HRV assessment indicated a 70% green graph, symbolising a certain level of equilibrium. As the therapy progressed, there was a discernible positive trend, with the green graph increasing to 80% at the end of the post-therapy period. These results collectively suggest that the implemented therapies not only contributed to the alleviation of depressive symptoms, but also positively influenced the autonomic nervous system, as reflected in the improved HRV metrics.

To explore the effects of aroma therapy, Figs. 9 and 10 present insights into the outcomes related to the frequency band powers. These figures provide a simple yet comprehensive view of how aromatic interventions influence specific frequency bands, thereby shedding light on the therapeutic effects of aromatherapy. Through this study, we aim to understand the straightforward yet impactful connections between aromatics and neural responses, contributing to a broader understanding of the therapeutic benefits of aromatic practices.

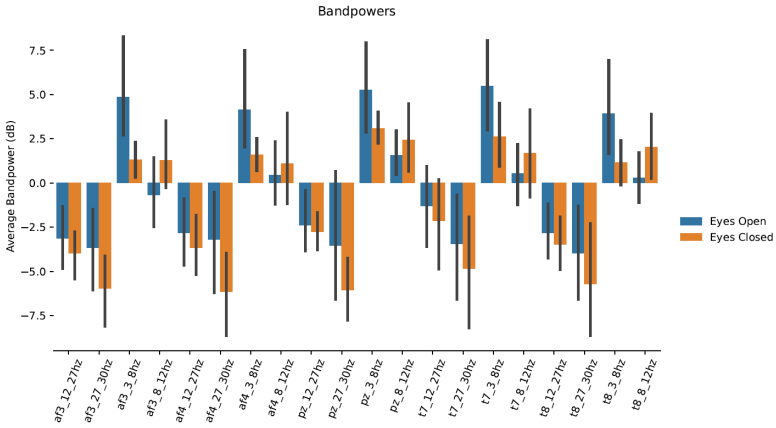



**Figure 9: Pre-Aroma Therapy Results**

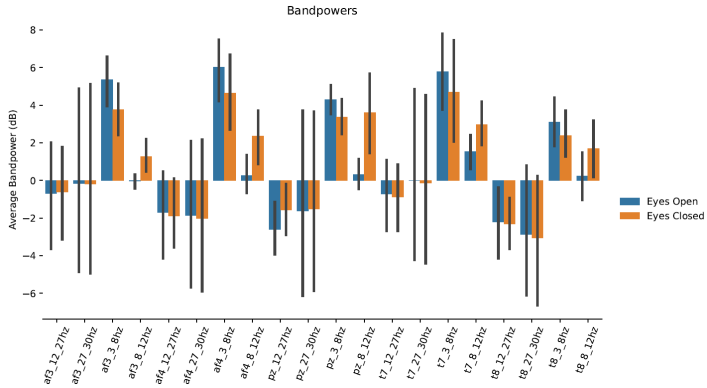



**Figure 10: Aroma Therapy Results**

The results show that aroma therapy based on Gelam oil exerts a potential influence on brainwave patterns, manifesting in an increase in high theta waves (3-8 Hz) and high alpha waves (8-12 Hz) during EEG recordings; this indicates a synergistic effect on inducing a deeply relaxed and meditative mental state, which may contribute to stress reduction, heightened relaxation, and an overall enhancement of mindfulness and tranquillity, thereby suggesting that aromatherapy could play a valuable role in modulating brainwave activity for therapeutic purposes and in promoting a holistic sense of well-being. The modulation and interaction of theta and alpha waves in the brain, representing distinct but interconnected neural oscillatory patterns, play a pivotal role in shaping cognitive processes, including attention, memory consolidation, and overall mental states. Variations in the amplitude, frequency, and synchronisation of these waves potentially serve as crucial indicators of neural network functioning and offer valuable insights into the intricate dynamics of brain activity during diverse cognitive tasks and states of consciousness.

## 6.0 CONCLUSION

This study aims to address the current mental health challenge by exploring how patients respond to therapy through a comprehensive analysis of EEG and HRV signals. This study will introduce a therapeutic approach utilising sensational oil derived from the Gelam tree by conducting therapy sessions and consultations tailored to workers in the Kuala Terengganu region. The integration of EEG and HRV signals facilitates the detection of alpha and beta waves, offering a nuanced understanding of physical signs and symptoms related to stress and anxiety. This mind-body technique interprets visual and auditory cues and provides a holistic approach to therapy. The analysis of the questionnaire responses and EEG and HRV data using statistical methods aims to achieve three primary objectives. The study seeks to predict responses to therapy, offering insights into the efficacy of the therapeutic approach. Based on the results, it aims to show that aroma therapy based on Gelam oil exerts a potential influence on brainwave patterns, manifesting in an increase in high theta waves (3-8 Hz) and high alpha waves (8-12 Hz) during EEG recordings, indicating a synergistic effect on inducing a deeply relaxed and meditative mental state, which may contribute to stress reduction, heightened relaxation, and an overall enhancement of mindfulness and tranquillity; this suggests that aromatherapy could play a valuable role in modulating brainwave activity for therapeutic purposes and in promoting a holistic sense of well-being. In essence, this research aspires to make significant strides in the field of mental health not only by improving early detection and intervention but also by advancing the precision and effectiveness of therapeutic sessions. Ultimately, the overarching goal is to contribute to the promotion of mental health within the community by cultivating a generation that is not only physically healthy but also mentally resilient.

## ACKNOWLEDGEMENT

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Original Article

# Construction Personnel's Perception of Gamified Safety Training

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**ABSTRACT:** *Construction workers consistently face various occupational hazards of varying complexity across different projects. Consequently, there is a pressing demand for training modules that equip them with knowledge and skills to ensure occupational and environmental safety on construction sites. However, existing safety training methods predominantly rely on theoretical content and lack practical, hands-on approaches. This limitation stems from the inherent challenges of applying hands-on techniques in specific hazardous scenarios within the construction industry. Integrating technology into training has proven to be a potent tool for enhancing learning, catering to both children and adults. One promising avenue is the adoption of gamified approaches, which have gained traction in educational contexts and across diverse sectors such as the military, mining, transportation, oil and gas, and the construction industry. Therefore, this study assesses construction workers' perceptions of using gaming as a training tool. To this end, a customised questionnaire was designed and descriptive statistics were employed to analyse the questionnaire responses. The findings underscored construction workers' strong interest in leveraging gaming to provide hands-on training in a safer environment. The participants also expressed confidence in the potential of game-based training modules to create cost-effective, interactive, and engaging training experiences for the industry. This research contributes to better understanding the safety training requirements within the construction sector, advocating for an approach that is both safer and more engaging while being cost-effective.*

**Keywords:** *Gamification, Safety Training.*

## 1.0 INTRODUCTION

The construction industry is known as the 4D industry: dirty, dangerous, dark, and deathly (Misnan et al., 2014). According to the Department of Occupational Safety and Health Malaysia (DOSH), Malaysia's construction industry recorded the third highest accident rate after manufacturing and agriculture. Owing to this concern, through government initiatives, the Construction Industrial Development Board (CIDB), National Institute of Occupational Safety and Health (NIOSH), and other related agencies have started to provide training to increase awareness and enhance knowledge of safety among key players in the construction industry. Various types of training have been conducted, including induction, on-the-job training, competency training, seminars, and forums (Mansur & Peng, 2009; Jason et al., 2020). However, the approach to delivering these training sessions has remained the same for years, that is, in the form of lectures, video demonstrations, and hands-on applications. Apart from competency training, other training types pay less attention to hands-on approaches. However, safety training requires hands-on and practical approaches. However, the nature of the hazards restricts the implementation of practical approaches in real-life situations. According to Goetsch (1993), one of the fundamental principles for learning is 'learning by doing' thus, emphasising adequate hands-on learning opportunities for learners (Al-Sahar, 2021). Consequently, researchers have explored other methods to improve safety training delivery, particularly the usefulness of technology in creating safety training modules (Assfalg et al., 2002; Mohd et al., 2019). By using technology, training has become more flexible in terms of time, cost, and experience (Mohd et al., 2019; Mohd, Liyana, et al., 2020).

## 2.0 GAMES AS TRAINING TOOLS

Many authors have interpreted the definition of games differently. Felix and Johnson (1993) described games by listing their structural components, such as dynamic visuals, interaction, rules, and goals (Moya et al., 2016), whereas Gredler (1996) described games according to their essentials, such as the stated task, player roles, multiple tasks to the goal, and degree of player control (Utoyo, 2021). Meanwhile, Hays (2005) defined games as *"an artificially constructed, competitive activity with a specific goal, a set of rules and constraints that is located in a specific contact"* (p. 15).

Electronic games can create a more exciting and interactive approach for delivering complex or tedious learning content (Prensky, 2014; Supriana, 2017). As Whitton and Moseley (2012) noted, games can also enhance the learning process in terms of playfulness, practice, and engagement. This statement was supported by Gee (2005), who believes that games should be designed in a way that triggers deep motivation for learning. Most electronic games provide a highly structured environment, with tutorials for new players. Such games often break down complex tasks into smaller, more manageable ones, catering to each player's pace and providing immediate and continuous feedback (Gee, 2005; Hilliard & Kargbo, 2017). Moreover, electronic games often require players to formulate content, evaluate hypotheses, and experiment with the outcome–a cycle of activities closely related to the learning process, defined as 'experiential learning' (Kolb, Boyatzis, & Mainemelis, 2001; Lehane, 2020).

### 2.1 Game vs. Hazard Identification Training

Hazard identification training is part of the *Hazard Identification Risk Assessment and Risk Control* (HIRARC) training module of the NIOSH (NIOSH, 2017). This training proceeds as follows: 1) train construction workers to identify unsafe acts and conditions in the working environment, 2) train their actions toward hazards, and 3) train decision-making skills in handling hazards wisely. This training should be performed visually and hands-on, so that the consequences of the decisions can be seen and remain accessible. These consequences make trainees more cautious when performing tasks. However, hazard can occur. Therefore, applying a hands-on approach in training is sometimes almost impossible in real life because it exposes trainees, trainers, and the environment to risks. Therefore, the gaming approach is a practical solution.

Games that offer visual training in an objective-based scenario allow construction workers to train and apply their knowledge without causing unnecessary harm. Because of the nature of the construction industry, simulated training with real people and hazards for training purposes is unlikely. This is where games can become the missing link between knowledge and hands-on training. Games enable users to practice their skills using a "*trial and error*" approach based on their existing knowledge and experience (Hess & Gunter, 2013; Kasemsap, 2017). By using games, users can observe the consequences of their actions and decisions without causing harm or injury (Backlund & Engstrom, 2007; Engelbrecht et al., 2019). The game environment is also safe for training workers who can practice their skills in a realistic environment and minimise the human errors that construction workers make in the real world (K.-Y. Lin, Son, & Rojas, 2011; Feng et al., 2022).

Pedagogical elements make learning more effective in training decision-making and problem-solving skills allow to handle hazards. These elements will also be used as guidelines in designing games to appeal to users and trigger their minds by following the user's nature of learning (Harteveld & Guimarães, 2007; Hauge et al., 2022). In this case, the game module applies experiential learning theory. Hazard training has become more flexible in terms of time, cost, and health, using a serious game approach. Table 1 shows the compatibility between games and hazard training.

**Table 1: Compatibility between the natures of hazard identification training vs. games**

| Criteria of Game \ Nature of hazard training | Harmful | Need to experience | Hands-on training | Problems solving | Decision making |
|---|---|---|---|---|---|
| Visual (Abt, 1968; Mohd, Ariffin, et al., 2020) | X | X | X | | |
| Immersive (Susi, Johannesson, & Backlund, 2007; Ren et al., 2022) | | X | X | | |
| Scenario-based (K.-Y. Lin, Son, & Rojas, 2011) | | X | X | X | X |
| Safe environment (K.-Y. Lin, Son, & Rojas, 2011) | X | X | X | | |
| Re-usable/Re-play (Backlund & Engstrom, 2007; Ren et al., 2022) | | X | X | | |
| Pedagogy (Harteveld & Guimarães, 2007; Ren et al., 2022) | | | | X | X |
| Decision making (Hulst & Ruijsendaal, 2012) | | | | X | X |

## 3.0 METHODOLOGY

This pilot study aimed to evaluate the perspectives of individuals within the construction industry at various hierarchical levels. The data collection method employed was a survey complemented by a specific questionnaire. The questionnaire was structured into three distinct sections: 1) user characteristics, 2) user needs analysis, and 3) user perspectives on training utilising serious games, which form the focus of this study. Specifically, special attention was paid to the third section, which comprises two components: 1) the familiarity of users with games and 2) respondents' perspectives on using games as a training tool. Thirteen items adapted from previous studies investigating students' perceptions of the advantages of incorporating games into the learning process (Bourgonjon et al., 2010), were employed to measure respondents' perceptions. The data collection process involved the distribution of identical questionnaires among the participants to an occupational safety and hazard (OSH) training course, conducted both in-person and online. Although a minimum sample size of 30 respondents was sufficient for a pilot study (Bujang et al., 2024), we successfully gathered responses from 50 participants. Descriptive statistics were used to analyse the gathered data.

## 4.0 RESULTS AND DISCUSSION

Among the complete cohort of 50 respondents, an equitable distribution was maintained, with precisely half of the participants emanating from the occupational safety and hazard (OSH) training course and the remainder participating in an online survey. This ensured a balanced representation of perspectives from the in-person OSH training setting and virtual environment, enhancing the comprehensiveness and diversity of the data collected.

4.1 Exploration of Respondents' Acquaintance with the Gaming Approach

Most participants were 21–30 years old, constituting 64% of the sample (32 respondents). Subsequently, respondents aged 41 years and above comprised 22% of the cohort (11 respondents), and those aged 30-40 constituted 12% (6 respondents). Individuals aged 20 years accounted for 2% (1 respondent). Regarding professional experience, nearly half of the participants reported having one to three years of work experience (48%, 24 participants). This was followed by respondents with more than 10 years of industry experience (20%, 10 respondents), those with 5–10 years of experience (14%, 7 respondents), and individuals with 3–5 years of experience (12%, 6 respondents). A minority, constituting 6% (3 respondents), reported having less than one year of working experience.

Notably, all respondents were actively engaged in the construction industry during the pilot study. More than half (74%, 37 respondents) were already acquainted with gaming approaches. The results in Fig.1, which depicts the first part of the questionnaire's third section, illustrate users' familiarity with games categorised by age group. Notably, the 21–30 years old group exhibited the highest number of respondents who played video games, with 46% of participants (23 respondents), followed unexpectedly by the group aged 41 years and above, constituting 16% (8 respondents). This intriguing finding underscores that age did not emerge as a significant determinant of the engagement in gaming activities.

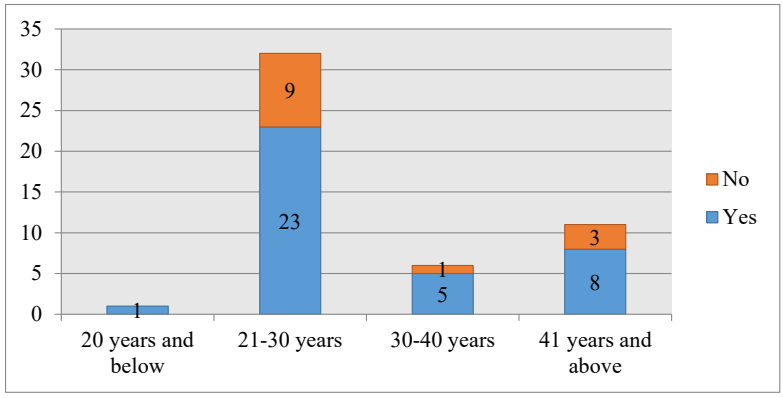
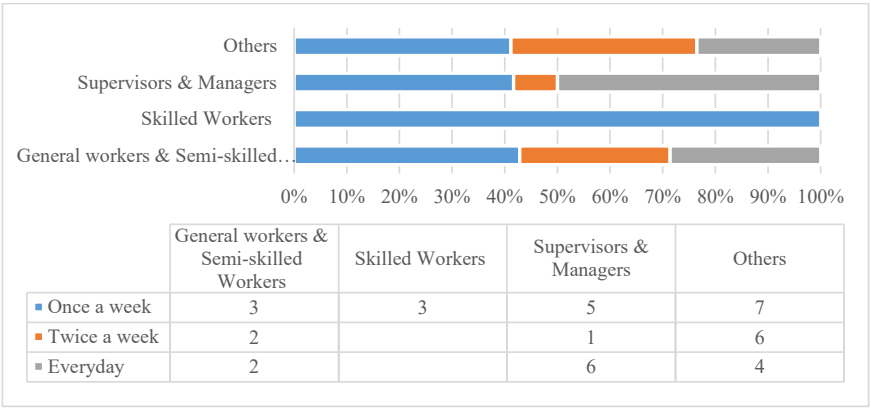



**Figure 1: Numbers of respondents who played games according by age group**

Fig. 2 provides a detailed breakdown of the descriptive statistics of respondents' familiarity with the game approach. The data outlined in this table reveal that the highest frequency of weekly playtime occurred once a week, constituting 36% of the respondents (18 individuals). This was closely followed by those who engaged in daily gaming activities (24%, 12 respondents) twice a week (18%, 9 respondents). Examining workers' weekly playtime ascertained the frequency with which they could allocate time for playing games. Notably, the findings indicated that respondents within the construction workforce could dedicate time to training at least once per week.




| | General workers & Semi-skilled Workers | Skilled Workers | Supervisors & Managers | Others |
|---|---|---|---|---|
| Once a week | 3 | 3 | 5 | 7 |
| Twice a week | 2 | | 1 | 6 |
| Everyday | 2 | | 6 | 4 |

**Figure 2: Respondents' weekly game playtime**

Beyond merely assessing the hours spent playing a game, the survey delved into workers' preferred game genres (Fig. 3). It is essential to note that only workers who actively engaged in gaming activities responded to this particular item. The respondents preferred puzzles (18%) and action games (16%). Other genres, such as arcades, sports, and role-playing games, garnered 10% of the responses. In comparison, simulation games received 6% and strategy games 2%. The nuanced distinction between puzzle and action games was imperative for gaining insights into the types of video games that respondents typically played during their leisure time.

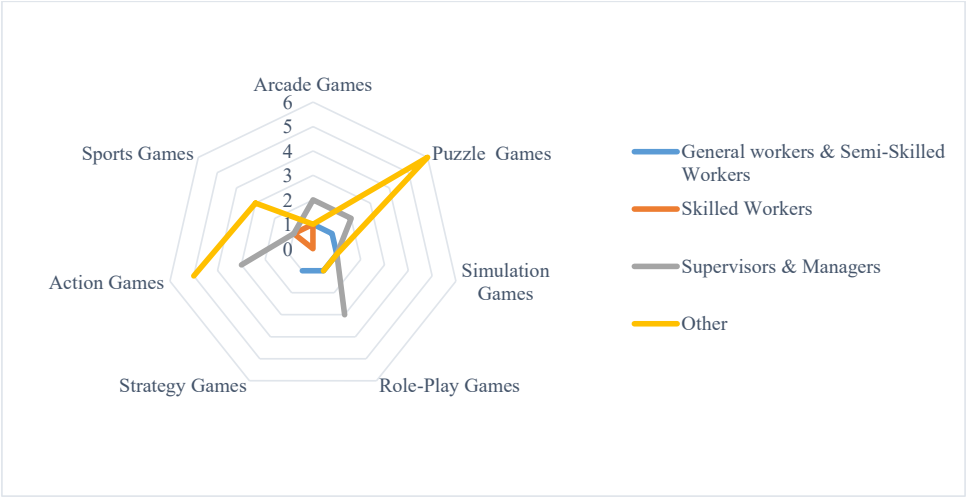



**Figure 3: Respondent's preferred game genre**

4.2 Respondents' Attitudes Regarding the Utilisation of Games as Training Tools

Table 2 and Fig. 4 show respondents' perspectives regarding the incorporation of the game approach into training, as elucidated by Girard et al. (2013). This perspective signifies one of the advantages offered by the game approach for individuals employed in the construction sector. The results revealed that three out of five distinct groups (other supervisors, managers, and skilled workers) displayed heightened expectations concerning the efficacy of the game approach in augmenting their knowledge and skills in alignment with prevailing market requirements. Notably, the mean scores for these groups were 3.74, 3.67, and 3.60, respectively, which were the highest scores among all categories. These findings suggest a pronounced willingness among construction workers' respondents to embrace the game approach as part of their occupational safety and hazard (OSH) training for continuous learning.

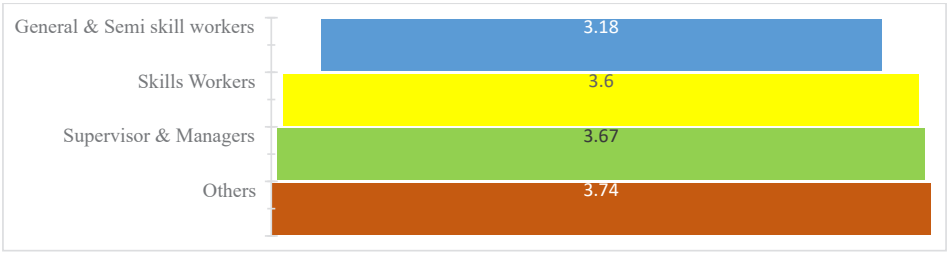



**Figure 4: Construction workers' attitudes toward games as training tools**

Moreover, unanimous agreement was observed among all respondents regarding the perceived benefits of employing the game approach in training. Specifically, they concurred that practising with a game approach could yield time and cost savings in addition to offering a safer methodology for training, mainly when dealing with on-site hazards. The gaming training paradigm is also known to provide a flexible schedule. This flexibility enables construction workers to conveniently engage in training sessions without compromising their daily routines.

The positive attitude and perceptions of construction workers toward games as training tools signify a paradigm shift in learning methodologies within the construction industry. Traditionally, training has been conducted using conventional methods in this field. However, the emergence of games as a tool for skill development has garnered enthusiasm among construction workers. This positive response is rooted in the recognition that game-based training provides a dynamic and engaging learning environment. Construction workers appreciate the interactive nature of games, which allows them to simulate real-world scenarios and apply their theoretical knowledge to practical situations. A gamified approach fosters a sense of immersion, making the learning process enjoyable and impactful.

Further, the adaptability and flexibility of game-based training resonate well with the demands of the construction workforce. Specifically, workers appreciated the convenience of accessing training materials at their own pace and schedule, which enhanced the overall effectiveness of the learning process. Construction workers perceived games as practical tools for honing their decision-making skills, hazard identification, and overall job preparedness. The gamification of training enhances their understanding of theoretical concepts and provides a safe space for hands-on practice. Construction workers' positive attitudes and perceptions of games as training tools underscore the industry's openness to innovative approaches, ultimately contributing to a more dynamic, engaging, and effective learning environment.

**Table 2: Mean scores of respondents' perceptions of different types of workers**

| Items | Mean Analysis | | | |
|---|---|---|---|---|
| | General and semi-skilled workers | Skills Workers | Supervisor & Managers | Others |
| Keenness to experiment with the most recent computer applications. | 3.00 | 2.60 | 3.79 | 3.50 |
| Quick learner | 3.43 | 3.00 | 3.71 | 3.63 |
| I was assured of the simulation application's proficiency, which can facilitate training in decision-making processes. | 3.43 | 3.60 | 3.64 | 3.79 |
| Comfortable with the digital-based training environment | 3.29 | 3.20 | 3.57 | 3.71 |
| A digital learning environment enables me to conduct training anywhere and anytime. | 3.29 | 4.00 | 3.86 | 3.88 |
| Training-based skills will be more effective with the help of games. | 2.86 | 3.40 | 3.64 | 3.63 |
| Incorporating games will be appealing and contribute to a pleasurable training atmosphere. | 3.29 | 4.20 | 3.93 | 3.83 |
| Integrating gaming into training can offer an alternative method of delivering training. | 3.43 | 4.00 | 3.71 | 3.88 |
| Utilising game applications makes it easier to conduct experiential training for hazard identification. | 3.14 | 3.80 | 3.64 | 3.83 |
| I am enthusiastic about participating in training sessions that involve game-based methods. | 3.00 | 4.20 | 3.86 | 3.75 |
| I am confident that the assistance of games will enhance my comprehension of theories and knowledge. | 3.14 | 4.00 | 3.36 | 3.75 |
| Playing a game allows me to practice and develop my decision-making skills. | 2.50 | 3.40 | 3.43 | 3.63 |
| Utilising simulations is anticipated to enhance my readiness for the work environment on construction sites. | 3.50 | 3.40 | 3.57 | 3.79 |
| **Means:** | 3.18 | 3.60 | 3.67 | 3.74 |

## 5.0 CONCLUSIONS

This study evaluates construction workers' perspectives on the use of games as a training tool, focusing on the safety training domain. The findings revealed a noteworthy degree of openness and a positive reception among diverse groups of construction workers. The anticipated significance lies in the potential integration of a blended training module that combines traditional methods with game-based approaches. This is particularly important for addressing the safety concerns prevalent in the construction industry, including occupational hazards. The incorporation of games as a training tool presents a novel and effective avenue for construction workers to enhance their decision-making skills in hazard management. The virtual environments simulated in these games closely mirror real workplace scenarios, providing workers with practical experience and insights. This enhances their ability to navigate and respond to potential hazards, and contributes to a more profound understanding of safety protocols and procedures.

Adopting games as training tools has several advantages. In addition to their demonstrable safety and cost-effectiveness, these tools offer high interactivity and entertainment value. This aspect is crucial for engaging construction workers, making learning more enjoyable and conducive to knowledge retention. Furthermore, the flexibility in accessing these training modules at any time and location aligns with the dynamic and often unpredictable schedules of construction workers, ensuring that training is accessible and adaptable to their individual needs. In conclusion, the positive outlook of construction workers toward game-based training tools signals a potential transformative shift in safety training methodologies within the construction industry, aligning with the evolving needs and preferences of the workforce.

## ACKNOWLEDGEMENT

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Original Article

# Development and Evaluation of Safety Culture Assessment Tool for the Construction Industry in Malaysia

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**ABSTRACT:** *The lack of a safety culture in the construction sector contributes to accidents in the industry due to the employer's failure to identify the level and the elements of the safety culture that need to be adopted in the work practice. This study aims to assess the safety culture in Malaysia's construction industry using a structured questionnaire adapted based on the Integrated Safety Culture Model as a comprehensive safety culture tool. A total of 119 construction companies and 329 respondents participated in this study. A focus group discussion was organized to review existing tools and applications to make them more reliable and valid for data collection and analysis in the construction industry. The developed questionnaire was then evaluated using the Delphi technique by 30 experts from various backgrounds, especially occupational safety and health in the construction industry. A qualitative and quantitative content validity test was conducted to check the validity of the developed instrument. The results indicated that the designed questions are valid for tackling the safety culture problem at construction sites. The findings also showed that the type of company, grade of the contractor, and size of the company have significant associations with the total safety culture score. The findings also indicated that each safety culture element is important to tackle safety culture issues and need to be applied together in the safety cultural assessment. This study will help the relevant stakeholders understand the level of safety practice in the industry so that they can introduce a suitable safety program to meet their objectives.*

**Keywords:** *Construction Safety Culture, Construction Safety, Safety Culture Evaluation Tool, Safety Culture Index, Safety Culture Tool*

## 1.0 INTRODUCTION

Increasing statistics on fatalities and injuries related to the construction industry have become a significant issue in Malaysia. According to the Department of Statistics Malaysia (DOSM, 2022), there were a total of 34,216 occupational accidents recorded in 2022, with 317 resulting in fatalities. The service sector had the highest number of accidents (10,403), followed by the manufacturing (9,906) and construction (4, 324) sectors. Although the construction sector ranked third in terms of the number of injuries, it had the highest rate of occupational fatalities compared with other industries, making it the most dangerous sector. The lack of a safety culture in this sector contributes to the high number of accidents (Misnan et al., 2007). This is because employers fail to identify the level of safety culture in their workplace and what elements of safety culture need to be adopted. Consequently, initiatives and programmes to improve safety culture are inaccurate and ineffective. Accordingly, an appropriate indicator is needed to measure safety culture in the construction industry to reduce accidents and fatalities from construction activities. This study thus examined the correlation between the type of contractor company and the size of the industry using the safety culture score. It also examined the correlation between the elements of safety culture and the correlation between competencies and scores for each safety culture element.

This study provides an overview of the industry safety practices, which will help stakeholders understand the level of safety practices in Malaysian construction companies so that they can introduce suitable safety programmes to meet their objectives.

### 1. 1 Definition of Safety Culture

Safety culture was introduced when The International Atomic Energy Agencies produced their initial report following the Chernobyl disaster in 1984, when the term ‘safety culture’ first appeared (Cooper, 2000). After the Bhopal disaster in 1984, the International Atomic Energy Agency further elaborated on the safety culture construct when defining it as the assembly of characteristics and attitudes of organizations and individuals (Cooper, 2018). According to the Health and Safety Executive (HSE), a recognised and respected definition or framework of safety culture remains undefined despite many reports, articles, and information dedicated to the subject (HSE, 2005).

Zhang et al. (2002) illustrated the significant disagreement among researchers regarding the definition of safety culture and whether safety culture is inherently different from the concept of safety climate. Zhang et al. (2002) suggested that common terminology and definitions may facilitate improved information sharing and strategies for enhancing safety culture. The evolution of the definition of safety culture began with Wert (2003), who defined it as ‘a work environment where a safety ethic permeates the organization’, a sentiment that can be simplified to equate it to a safety ethic. According to Glendon et al. (2000), safety culture refers to safety attitudes, values, beliefs, regulations, and practices. Tear et al. (2020) explained that individual factors, such as the individual’s role within the organisation, shape the perception and understanding of safety culture. According to Bisbey et al. (2021), safety culture reflects stable norms, values, and practices that influence safety.

Van Nunen et al. (2022) defined safety culture as the safety culture of an organisation that reflects the broad spectrum of established safety-related human, organizational, contextual, and technological aspects that prevail in the entire organisation. It entails observable, tangible factors, such as the safety management of an organisation, the physical working environment, and how individuals behave in relation to safety. Moreover, Mrugalska and Dovramadjiev (2022) concluded that the behaviours and awareness of humans and a positive safety culture directly influence good safety practices, hazard control, incident reporting, and, finally, the number and scope of accidents at work.

### 1. 2 Safety Culture Model

Although there has been much research regarding safety culture, a tool for quantitatively measuring safety culture has rarely been used in the literature (Wang & Sun, 2012, 2014). A relevant measurement tool that can be applied to this research is the safety culture measurement toolkit and its evaluation index system developed by Wang and Sun (2012, 2014) in their project

named HILAS (Human Integration Into Lifecycle of Aviation Systems, AIP4-CT-2005-516181). In the HILAS project, they proposed an integrated safety culture model (ISCM), which was used as the basis for this research.

## 2.0 METHOD

### 2.1 Research Design

A set of questions comprising the main elements of safety culture was based on the ISCM introduced by Wang and Sun (2012, 2014), as shown in Fig. 1.

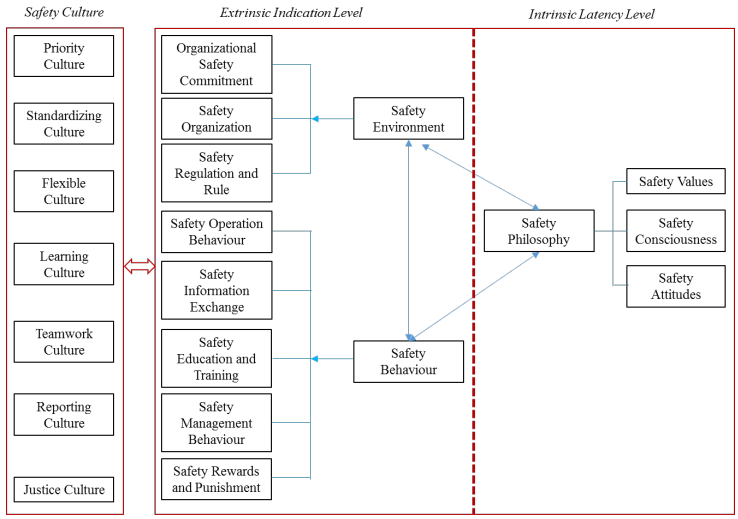


**Figure 1: Integrated Safety Culture Model**

Further, and a complete analysis of the structure and components of safety culture was conducted. Safety culture has been examined from a different angle, that is, from the perspective of subcultures. The tool for this research paper consists of questions on understanding of 'priority culture', 'standardising culture', 'flexible culture', 'learning culture', 'teamwork culture', 'reporting culture', and 'justice culture'.

### 2.2 Validity and Reliability

A focus group discussion on the development of a construction safety culture index was organised to review existing tools and applications and make them more reliable and valid for data collection and analysis in the construction industry. Content validity was assessed using a structured questionnaire. The constructed questionnaire was then evaluated using the Delphi technique, involving 30 experts from various backgrounds, particularly in the fields of occupational safety and health in the construction industry.

### 2.3 Target Population and Respondents

The study's target population and respondents are individuals who work in the construction industry and meet the inclusion and exclusion criteria in Table 1.

**Table 1: Criteria for Respondent Selection**

| Criteria | Details on the population and respondent selection criteria |
|---|---|
| Inclusion criteria | Top managerial positions include General Manager, Construction Manager, Project Manager, Operation Manager, Safety and Health Manager, Environmental Manager, or any equivalent top managerial level.<br><br>Middle managerial position such as Safety and Health Officer, Environmental Officer, Site Engineer, Quantity Surveyor or any equivalent middle managerial criteria<br><br>Low managerial positions such as Site Safety Supervisor, Site Supervisor, Safe Coordinator Site Foreman, or any other equivalent operative employees.<br><br>Workstation such as working on site or in site office and management office.<br><br>Company categories include project developer, project consultant, main contractor, sub-contractor, designer, or any company related to the construction project.<br><br>Classes of companies such as small, medium, and large companies. The company's classes were based on the definition of small medium enterprises (SME) by the Ministry of International Trade and Industry, Malaysia. The annual sales turnover or the number of full-time employees was the basis classification of the types of company in Malaysia, either small, medium, or large company, as follows:<br>- Small companies have sales turnover between RM 250,000 and less than RM 10 million or full-time employees between 5 and 50.<br>- Medium companies have sales turnover is between RM 10 million and RM 25 million or full-time employees between 51 and 150<br>- Large companies have sales turnover greater than RM 25 million or full-time employees of over 150.<br><br>The respondent's nationality is any Malaysian citizen working in top, middle, and low managerial positions. |
| Exclusion criterion | Non-Malaysian employees working in low managerial positions. |

2.4 Sample Design

The sample size was divided into two categories to suit the research design, which included a pilot study and descriptive cross-sectional study. A total of 69 construction workers participated in the pilot study. The sample size is the number of workers who work with the contractor.

Calculated sample size:

$$n = \frac{z^2 1 - \alpha/2 \, P(1-P)}{d^2}$$

$$n = \frac{1.96^2 \, x \, (0.50)(0.50)}{0.05^2}$$

Where:

P = estimated proportion

d = desired precision

Sample size = 384

Based on the calculated sample size, a minimum of 384 respondents are required. The 69 respondents involved in the pilot study did not participate again as respondents in the subsequent data collection, representing 384 respondents.

2.5 Research Instrument

The research instrument used in this study was a structured questionnaire designed based on a previous similar study. Personal interviews were conducted using a questionnaire to ensure that the respondents understood the message. It includes the following elements:

Section A: Socio-Demographic

Section B: Safety Sub-Culture (Standardising Culture, Justice Culture, Teamwork Culture, Reporting Culture, Priority Culture, Flexible Culture, and Learning Culture) with eight extrinsic elements (Organizational Safety Commitment, Safety Organization, Safety Regulation and Rule, Safety Operation Behaviour, Safety Information Exchange, Safety Education and Training, Safety Management Behaviour, Safety Rewards, and Punishment)

### 2.6 Pilot Study

A pilot project was conducted to determine the pretesting. The questionnaire was distributed on a small scale, and researchers noted any comments while the respondents filled out the questionnaire, such as the questionnaire format, time taken to complete the questionnaire, and their understanding of the language being used.

### 2.7 Data Analysis

All data were analysed using the SPSS for Windows version 17.0 software. Inferential analysis was used to reach conclusions that extended beyond the immediate data.

## 3.0 RESULTS

A total of 119 construction companies and 329 respondents participated in the study. A total of 69 respondents were involved in the pilot study, and 30 experts from various construction companies were involved in the focus group discussion.

### 3.1 Evaluation of Safety Culture Tool Content Validity Test

#### 3.1.1 Content Validity Test

A questionnaire consisting of 73 questions in nine sections was constructed based on the literature. The questionnaire was validated using both qualitative and quantitative approaches. The former involved the consideration of comments, opinions, and suggestions made by all panellists, either individually or through group decisions. The instrument was further validated using a quantitative content validity test. The results of the content validity index for both the itemised and scale levels are shown in Fig. 2; both levels are represented by blue and green bars, respectively.

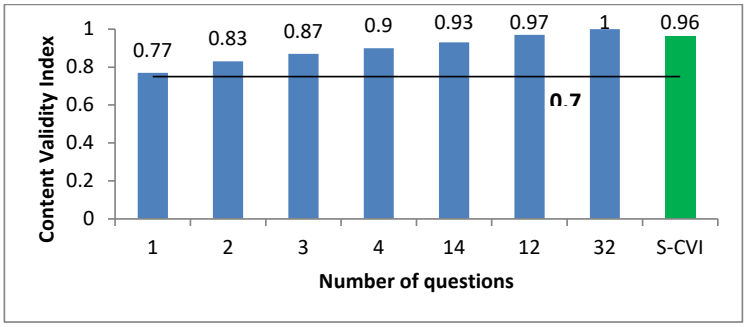


**Figure 2: The I-CVI and S-CVI for the Questionnaire Assessment**

3.1.2 Reliability Test

The reliability and internal consistency of the questions were tested, and the results are presented in Table 2.

**Table 2: Reliability Test of the Items in the Questionnaire**

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No. of Items |
|---|---|---|
| 0.978 | 0.981 | 57 |

3.2 Descriptive Analysis

3.2.1 Socio-demographic Information

Respondents' demographic information is shown in Fig. 3. Most respondents had education up to the diploma and degree levels (120 and 83 persons, respectively). Only one person received a doctorate, whereas 22 respondents had a master's degree. The remaining are at the certificate and lower levels. In addition, most respondents were married, for a total of 220 respondents. A total of 101 respondents were single, two divorced, five widowers, and one a widow. The graph shows that Malay comprised the highest number of respondents (277). This was followed by other nationalities, Chinese, and Bumiputera Sarawak with 16, 15, and 11 respondents, respectively. There were seven Indians among the respondents, and only three were from Bumiputera Sabah. Regarding gender, most participants were male (287 persons), and the rest female (42 respondents). Further, 125 respondents were within the age range of 30–39 years. This was followed by the 20–29 and 40–49 age groups, with 107 and 64 respondents, respectively. There were also 28 respondents were aged between 50 and 59 years, while the remaining five respondents were between 60 and 69 years old.

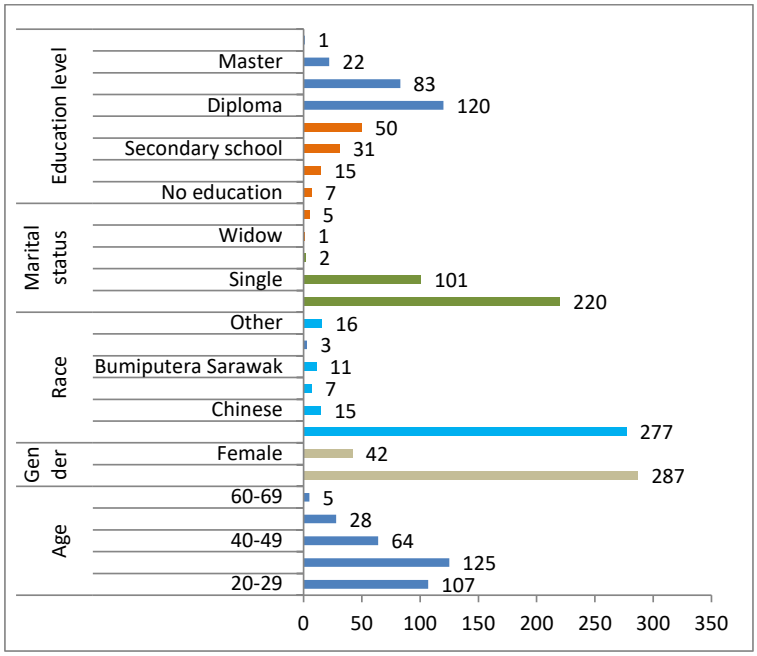

**Figure 3: Socio-Demographic Information of the Respondents**

An additional descriptive analysis of the total work experience and work experience in construction is shown in Fig. 4. Based on the observations, the highest proportion of respondents had total working experience between six and ten years, and the lowest had experience of more than 40 years. However, regarding working experience in the construction industry, most respondents worked for less than five years in the sector, while only one person worked for 31–40 years and 41–50 years.

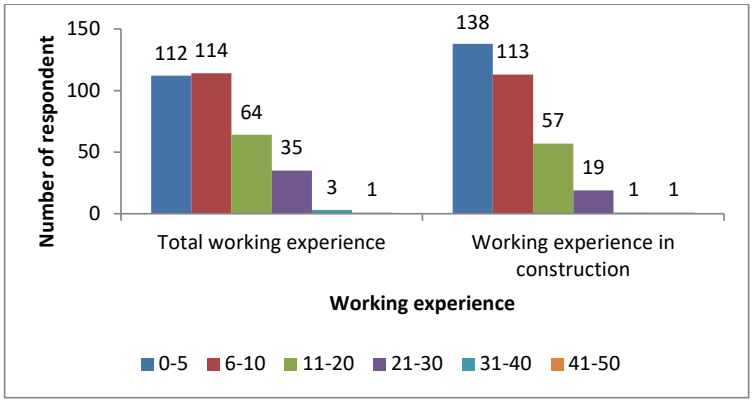


**Figure 4: Total Working Experience and Working Experience in Construction**

The results of the company distribution based on the five types of companies are shown in Fig. 5.

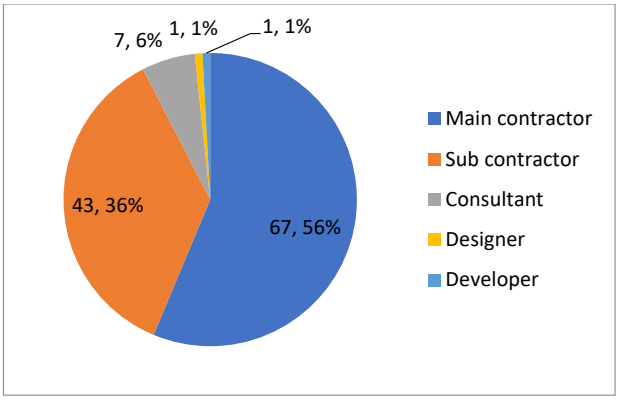


**Figure 5: Classification of Companies**

The contractor grade distribution is shown in Fig. 6. Most companies (90) were G7 contractors, while 16 companies were G1 contractors. Only four companies hold G2 and G6 licences, three were licenced as G3 contractors, and two were listed as G4 contractors. No company is a G5 contractor.

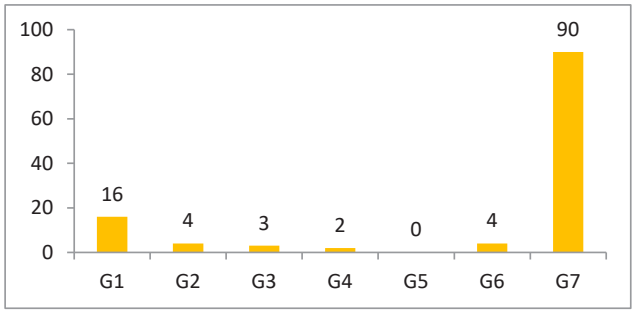


**Figure 6: Grade of Contractor License as Approved by the Construction Industry Development Board (CIDB), Malaysia**

3.2.2 Mean Score of Safety Culture Elements

Fig. 7 shows the mean scores obtained by the respondents for each section and the total scores they achieved. The maximum possible scores for each section are indicated by the blue lines. Based on the results, respondents' mean score for the Organizational Safety and Health Commitment section was 17.83(±4.31). The subsequent section B, which is Safety and Health Organization, together with section C (Safety and Health Regulation and Rule), showed mean scores of 10.26(±2.68) and 8.53(±2.11), respectively. The respondents' mean score for section D (Safety and Health Management Behaviour) was 11.46(±2.69). The mean scores obtained by the respondents on Safety Operation Behaviour and Safety Education and Training are 8.29(±2.06) and 11.61(±2.70), respectively. The mean scores for the last two sections are 9.67(±2.55) for Safety Information Exchange and 4.15(±1.21) for Safety Reward and Punishment. The mean total score of the respondents was 81.79(±18.84).

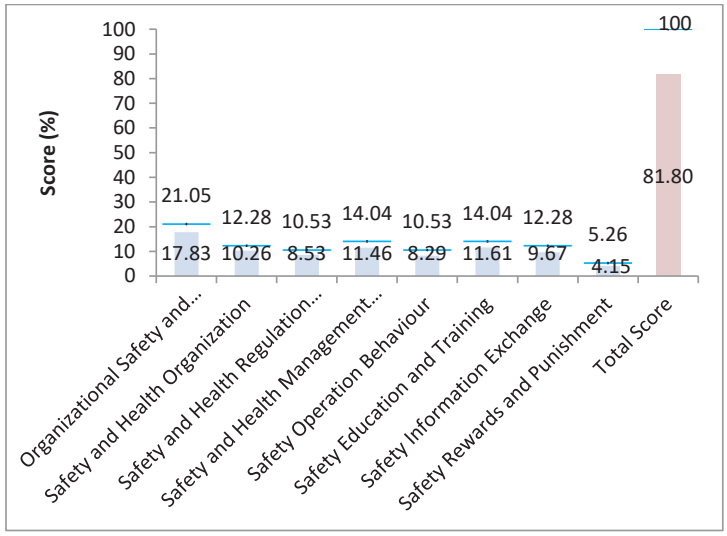


**Figure 7: Mean Scores of Each Section and the Total Scores Obtained by the Respondents**

3.3 Association and Correlation Test

3.3.1 Association between the independent variables with the safety culture score

Table 3 presents the results of the association test between three independent variables (type of company, grade of contractor, and size of company) and the total safety culture scores obtained by the respondents.

**Table 3: Chi-Square Tests**

| Variable | $X^2$ Value | df | Level of Significance |
|---|---|---|---|
| Type of company | 29.378 | 12 | 0.003* |
| Grade of contractor | 24.645 | 15 | 0.050* |
| Size of industry | 16.346 | 6 | 0.012* |

* significance at $p \leq 0.05$

3.3.2 Correlation between the elements of safety culture

Correlation tests were performed between the eight sections of the questionnaire to identify the associations between the sections, as shown in Table 5.

**Table 5: Pearson Correlation Test Between Eight Elements of Safety Culture**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Organizational Safety and Health Commitment | - | | | | | | | |
| **2** | Safety and Health Organization | **0.808**** | - | | | | | | |
| **3** | Safety And Health Regulation and Rule | **0.640**** | **0.742**** | - | | | | | |
| **4** | Safety and Health Management Behaviour | **0.734**** | **0.776**** | **0.771**** | - | | | | |
| **5** | Safety Operation Behaviour | **0.335**** | **0.393**** | **0.521**** | **0.444**** | - | | | |
| **6** | Safety Education and Training | **0.610**** | **0.695**** | **0.679**** | **0.749**** | **0.482**** | - | | |
| **7** | Safety Information Exchange | **0.573**** | **0.617**** | **0.670**** | **0.709**** | **0.497**** | **0.778**** | - | |
| **8** | Safety Rewards and Punishment | **0.610**** | **0.624**** | **0.499**** | **0.586**** | **0.305**** | **0.620**** | **0.592**** | - |

** significant at $p < 0.01$ (two-tailed)

## 4.0 DISCUSSION

### 4.1 Evaluation of Safety Culture Tool

Based on the Content Validity Test, all 57 questions showed I-CVI greater than the minimum value required, which is 0.75 (Yaghmale, 2003). Only one question showed an I-CVI of 0.77, whereas the highest I-CVI achieved was 1 for 32 questions. At the scale level, the results showed that the obtained S-CVI was very good, at 0.96. The results indicated that the designed questions were valid for addressing safety culture issues at construction sites. Cronbach's alpha, which measures the strength of consistency, was 0.978. Based on the rule of thumb for internal consistency, a score of 0.978 is considered excellent.

A descriptive analysis of the classification of companies showed that the largest proportion is 56% (67 companies), which are main contractors. Subcontractors followed the results for 43 companies (36%). There were seven consulting companies (6%); the remaining were designers and developers, and only one company represented the other categories. The analysis also showed the different grades of contractors involved at construction sites. Most companies (n = 90) were G7 contractors, while 16 were G1 contractors. Only four companies held G2 and G6 licences, three were licenced as G3 contractors, and two were listed as G4 contractors. No company was a G5 contractor in this study. This means that, at a construction site, various people and contractors of different grades are involved in the construction activity, which contributes to safety culture.

Based on the Chi-square tests, the independent variables (type of company, grade of contractor, and size of company) and the total safety culture score obtained by the respondents, type of company, grade of contractor and size of company showed a significant association with the total safety culture score obtained, with p-value less and equal to 0.05.

For the correlation between the eight elements of safety culture, there was a significant correlation between all the elements with a p-value below 0.01. These findings indicate that the elements considered in each section are essential for tackling safety culture issues and must be applied together in safety culture assessments.

## 5.0 CONCLUSION

The increasing number of deaths and injuries in Malaysia's construction sector is a significant concern, emphasising the urgent need for better safety measures. This includes using accurate tools to assess the safety culture of the construction industry and understanding how different factors such as the contractor's grade and the industry's size affect safety in the construction industry. The contractor grades significantly correlated with the total safety culture score. The findings also indicated that each safety culture element is essential for tackling safety culture issues and must be applied together in a safety culture assessment.

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