EFFECTIVE ENGINEERING NOISE CONTROL APPROACHES USING STOCHASTIC NOISE MAPPING SIMULATION TECHNIQUE: A CASE STUDY IN PALM OIL MILL

(Date received: 02.08.2023/Date accepted: 12.10.2023)

Tan Lee Hang[1], Lim Ming Han[2*], Lee Yee Ling[3], Tan Ooi Kuan[4]

[1,2,3,4] Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Cheras 43000, Kajang, Selangor, Malaysia

[*] Corresponding author: limmh@utar.edu.my

ABSTRACT

Excessive sound levels pose a substantial risk to the hearing health of industrial workers. This study is to employ the RW-eNMS stochastic simulation method for occupational noise monitoring and mitigation planning at a palm oil mill. A case study was conducted at a Malaysian palm oil mill to predict noise mapping, evaluate personal noise exposure, and recommend an effective noise control strategy using the RW-eNMS method. Results showed that 29.6% of the area fell within the high-risk zone, with 28.1% in the extremely high-risk zone. Personal noise monitoring revealed that many workers were exposed to excessive noise, with a maximum time-weighted average sound level of 99.2 dBA among the worker groups. Despite the provision of protective equipment by management, regular usage of hearing protectors during work shifts was lacking. To reduce noise levels, two engineering control methods were proposed: erecting noise barriers around high noise emission sources and limiting the maximum sound power to 110 dBA for dynamic noise sources. Implementing these controls resulted in a 10.9% decrease in the extremely high-risk zone and a 17.8% decrease in the high-risk zone. These findings hold significance as they can guide the implementation of noise monitoring practices and engineering noise control in the industry.

Keywords: Noise Control, Noise Risk Zone, Occupational Noise Exposure, Stochastic Simulation, Strategic Noise Map

1.0 INTRODUCTION

Occupational noise exposure problems remain a significant disease in global industries. Previous studies had found that severe occupational noise exposure problems occurred in current industries (Hasson *et al.,* 2011; Hanidza *et al.,* 2013; Ali *et al.,* 2012). A noise exposure survey revealed that the noise levels from the industries still exceeded the permissible limits (Kock *et al.,* 2012). Many workers have suffered from hearing problems because they had been overexposed to noise in their workplace (Antônio, 2006; Rachiotis *et al.,* 2006; Azman *et al.,* 2022). During the years 2019 to 2022 in Italy, hearing loss accounted for 15% of all reported occupational diseases (De Sio *et al.,* 2023). In Japan, a study estimated that millions of workers were exposed to high noise levels in their workplaces with more than 40 dB hearing loss at 4 kHz (Miyakita and Ueda, 1997). Prolonged noise exposure has been associated with a range of adverse auditory and non-auditory effects, including noise-induced hearing loss, tinnitus, disorders of the endocrine systems and the nervous, mental distress, sleep disturbance, stress, annoyance, cognitive deficits, low performance, high blood pressure, and speech interruption (Thurston, 2012; Said *et al.,* 2014; Milerová *et al.,* 2013; Zeydabadi *et al.,* 2019; Hosseinabadi *et al.,* 2019; Alnabih *et al.,* 2021). Exposure to high noise levels may additionally increase the number of work-related accidents experienced by workers (Choi *et al.,* 2005). The workers would have a high occupational injury risk if the noise levels were greater than 85 dBA (Amjad-Sardrudi *et al.,* 2012). Furthermore, it was discovered that substantial noise exposure was closely linked to both workplace accidents and commuting accidents (Monteiro Ferreira *et al.,* 2020). Consequently, industries must take steps to ensure noise levels are adequately addressed to mitigate the ongoing negative impacts of noise exposure in the workplace.

According to Ganday (Ganday, 1982), good noise monitoring practice should include a noise map and personal noise exposure measurement. Recognising the rising concern of the European Union over the current noise issue, Directive 2002/49/EC was enforced to mandate the utilisation of strategic noise maps in evaluating the noise exposure problem (Directive 2002/49/EC, 2002). A strategic noise map provided information such as the location of noise sources, the pattern of noise distribution, and the noise circumstances (Bite *et al.,* 2005; Zannin *et al.,* 2013) , which could be utilised to examine permissible limits, decide on noise abatement strategies and design the optimal placement for new machines (Lee *et al.,* 2008; Tsai *et al.,* 2009). In addition, the strategic noise maps could indicate high noise exposure areas, thereby allowing noise practitioners to utilise the noise map as a reference to decide on areas for conducting personal noise exposure measurements (Han *et al.,* 2015). In Malaysia, compliance with the Factory and Machinery Act (Noise Exposure) Regulations is required for all industries as a guide to monitor noise levels in their workplaces (Factories and Machineries Act, 2019). Workers should not be exposed to a noise exceeding the equivalent sound level (L_{Aeq}) of 85 dBA. Moreover, the Occupational Safety and Health Administration mandates that hearing protectors such as earmuffs and earplugs must be provided in environments with an 8-hour-time weighted average (TWA) of 85 dBA or a 100% noise dose (Occupational Noise Exposure, 1983), to ensure the safety and health of workers. Despite this protective measure, numerous workers have been found to suffer from hearing problems and not regularly utilise hearing protection devices (Bedi, 2006; Bockstael *et al.,* 2012; Kim, 2010). Ali *et al*. reported that merely 24.5% of noise-exposed workers in the cement industry habitually used hearing protection devices. This may be attributable to unsatisfactory noise management and a lack of awareness amongst the workers concerning the potential risks related to noise.

Malaysia is the world's second-largest producer and exporter of palm oil products, comprising nearly half of the world's palm oil production share with an export value of over 44%. The expansion of the palm oil industry has been remarkable, with the total planted area reaching 4.85 hectares in 2010. Consequently, many workers were recruited to operate the palm oil mills, exposing them to occupational noise. Studies have been conducted regarding noise exposure and its influence on workers during oil production activities. Ohimain *et al*. (2013) found that activities during the digesting and oil extraction process involved high noise emission machinery. Naeini and Tamrin conducted a study on environmental noise monitoring and noise exposure on workers of two palm oil mills. They had concluded that the main working areas such as the engine room, nut plant, boiler house, thresher, pressing and digestion, clarification station, and sterilising areas were noisy and the workers might incur hearing problems as a result of prolonged exposure to noise in these areas (Naeini and Tamrin, 2014a; Naeini and Tamrin, 2014b; Naeini *et al.,* 2014). Furthermore, it was also found that about 66.7% of workers did not wear hearing protection devices in the investigation of five mills (Naeini *et al.,* 2014). A recent study revealed noise exposure as the main hazard in palm oil mills (Ruslan *et al.,* 2017; Azodo and Onyekwere, 2023). It is crucial to conduct further research on the noise exposure problem and noise control strategies in this industry. Current noise mapping practice still relies on unstandardised approaches for the development of noise maps for this industry (Han *et al.,* 2015). The latest noise mapping prediction technique (Han *et al.,* 2015) has confidentially demonstrated its high accuracy and reliability through its proposed stochastic simulation method. However, there is a lack of scientific rationale for incorporating this method into current noise control strategies. Therefore, the main objective of this study is to employ the RW-eNMS stochastic simulation technique to monitor occupational noise and recommend mitigation strategies at a palm oil mill. A case study was conducted on the selected palm oil mill and the activities included the sound power measurement, predictions of strategic noise map and noise risk zone, personal noise measurement, and engineering noise control simulation. The result from the study was used to conclude the effectiveness of the noise control strategy with the proposed method and the current noise circumstances in the palm oil industry. The following sections discuss the research methodology, results, engineering noise control, and discussion.

2.0 METHODOLOGY

A case study was conducted on a palm oil mill, which was located in the southern region of Peninsular Malaysia. The working period was divided into two shifts, namely the morning shift (8 am to 4 pm) and the evening shift (4 pm to 12 am). This study was conducted during the morning shift only with the presence of a total of 48 general workers and 7 management staffs. All workers were provided with hearing protectors to protect them from high noise exposure in this palm oil mill. The types of measurement equipment used were a sound level meter (3M SoundPro SE/DL Type 2) to measure the noise level and a dosimeter (3M the Edge) to measure the personal noise exposure level and a distometer to measure the distance from the source to the receiver. The sound level meter and dosimeter conformed to the requirements of the International Electrotechnical Commission (IEC), such as IEC 61672-1 (Sound Level Meters – Part 1, 2002). Both devices were calibrated at the start and end of measurements to ensure the accuracy of measurement results in the current environment and that the microphone was in good condition. Sequential activities of noise monitoring are shown in Figure 1. The first activity was a visit to the palm oil mill to observe the noise circumstances and noise sources in this workplace. The sound power measurement was conducted on the operating machinery. The measurement methods complied with the British Standards BS EN ISO 3744:2010 and BS ISO 6393:2008. Both methods were used to determine the sound power levels for static and dynamic machines, respectively. The duty cycles of machinery such as on, off, and idling modes were also recorded as the inputs were to be used in predicting a noise map for this workplace.

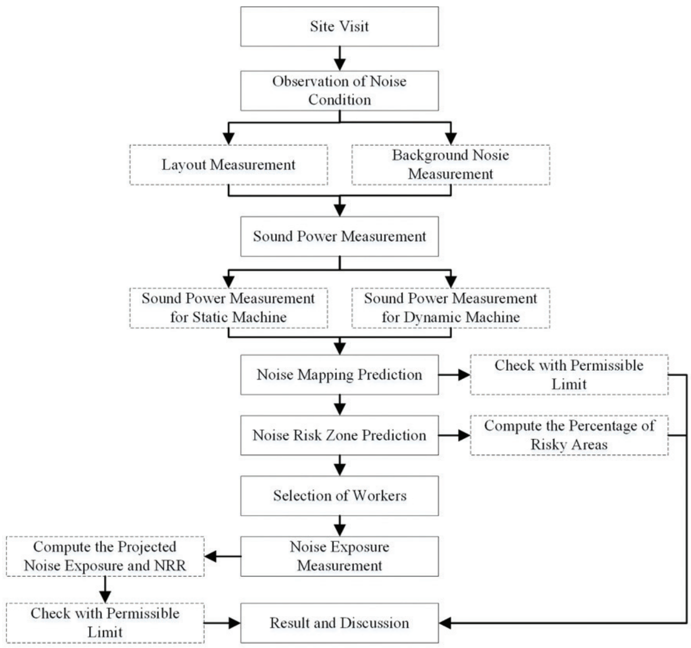

Figure 1: Framework of Noise Monitoring

This study utlised a stochastic simulation method, namely RW-eNMS, to predict a strategic noise map through the simulation of random movement and random noise emission from the machinery. This article explained the core concept and the development of the prediction method in detail (Han *et al.,* 2015). This method was established based on the theorem of stochastic modelling in a simulation process. It could effectively predict the noise levels by considering the dynamic noise circumstances from concurrent and non-concurrent activities. Han *et al*. proved that the accuracy of prediction results was mostly in the range of measurement, where most of the absolute difference from the prediction results was less than 2 dBA. Several inputs were required to be defined in this method, such as the site layout, background noise, locations of machinery, noise barriers, sound power levels, and duty cycles. This method also considered the barrier's effects, such as noise attenuation and noise reflection, and the computation method was referred to the British standard BS 5228:2009-1. The simulation process for this study was stopped at 1,500 steps since the prediction data had reached a steady absolute difference value, as mentioned in the previous study (Han *et al.,* 2015). All noise levels were predicted by assuming an equal height of 1.5 meters. After simulating 1,500 steps, the strategic noise map and the noise risk zone were generated from this method. A strategic noise map was used to study the noise circumstances by checking the permissible noise limit from Factory and Machinery Act and determining the percentage of noise that exceeded this limit. A noise risk zone was plotted by referring to the noise risk evaluation criteria (Han *et al.,* 2015). This evaluation was also implemented by previous studies to identify the sensitive spots of noise risk in the workplace (Al-Ghonamy, 2010; Armah, 2010).

Furthermore, the information obtained from the prediction significantly revealed the noise polluted areas and was used in the selection of noise-exposed workers for the personal noise exposure measurement. The selection was also based on the areas with critical noise risk and active working activities. Workers who were selected from the hazardous area were asked to wear the dosimeter and the duration of each measurement was 30 minutes. After that, the exposure result was normalised to 8 hours of full-shift noise exposure with the assumption that the workers were working in the same areas with constant noise exposure conditions. The projected noise dose and time-weighted average sound level were obtained through Eqn. 1 and Eqn. 2 (Occupational Noise Exposure, 1983). Likewise, the required noise reduction ratings (NRR) were also calculated to estimate the sufficient noise attenuation of hearing protectors protecting workers from hearing loss. The NRR calculation (Eqn. 3) followed the recommendation of the Occupational Safety and Health Administration (Occupational Noise Exposure, 1983).

Projected Dose =
Measured Dose x [(Shift Length/Sample Time)] (1)

where,
Projected Dose and Measured Dose are in units of percentage
Shift Length and Sample Time are in units of hours

$$TWA = 16.61\log_{10}\frac{D}{100} + 90dBA \qquad (2)$$

where,
TWA is time-weighted average sound level for 8 hours, dBA
D is the percentage of noise dosage for the whole shift, %

Estimated exposure = TWA - [(NRR - 7) x 50%] (3)

where,
NRR is noise reduction rating, dBA

After analysing the results, this study proposed engineering control methods, such as utilisation of quieter machinery and the erection of noise barriers, to minimise noise exposure levels at this workplace. The decision of noise control was made after identifying the high noise exposure areas and the locations of high noise emission machines. As reported by Mok *et al*. (2019), the use of quieter machinery is an effective approach to further reduce noise at its source and achieve a quieter living environment. For proposing the noise barrier erection as control strategy, the RW-eNMS was developed in accordance with the noise attenuation and reflection approximation method, as specified in BS 5228-1:2009, as outlined in Table 1. This method serves as an initial approach for estimating the attenuation and reflection effects of noise barriers on ambient noise levels in the vicinity. Afterwards, once the approximation levels from this method have been validated and have successfully met the required noise level under the permissible limit, further engineering and comprehensive noise barrier design process will be required. This design process entails meticulous determination of dimensions, functionalities, and materials. Additionally, any specific design will depend on the condition of the noise source, taking into account factors such as ventilation, heat dissipation, and other relevant machinery-related considerations. However, it is important to note that this study is focused solely on the prediction process and does not encompass the detailed design stage. This study will employ the RW-eNMS to recommend noise barrier placement and evaluate their efficacy in attaining compliance with the permissible noise level limit.

Table 1: Noise Attenuation and Reflection Due to Barriers From BS 5228-1:2009 (B.S., 2009)

Condition	Approximation
Source is visible to the receiver	Attenuation -5 dB
Source is hidden from the receiver	Attenuation -10 dB
1 m from the façade of a building	Reflection +3 dB

3.0 RESULTS

3.1 Current Noise Management Practices and Machinery

Figure 2a shows the site layout of the palm oil mill with the dimension of the mapping area of 130 m x 78 m. A total of 12 machines were operating and emitting high noise to the surrounding environment during the measurement. About 8 static machines (S1 to S8) and 4 dynamic machines (D1 to D4) were labelled on the site layout (Figure 2a) to indicate the location of the machinery. The dotted sub-areas indicate the working areas for the dynamic machines. In sub-area 1, the working activity included a bulldozer (D1) which was dragging the ramping loader into the sterilizer for the cooking of palm oil brunches with live steam. Three dynamic machines (D2, D3, and D4) were working on the activities of palm oil waste clearance and excavation in sub-area 2. During the site visit, it was observed that many general workers were working in the ramp, workshop, kernel plant, engine room, and boiler room. The background noise was recorded as 51.9 dBA to represent the ambient noise level before the working activities start. Most of the workers were provided with an earmuff, but none of them used it regularly when working in this palm oil mill during the time of this sound measurement. For existing noise preventive action, the management posted a simple noise map (Figure 2b) at the entrance of the workplace to provide noise information for their workers. The map was plotted by using the current industrial noise mapping practice. Also, the engine room was the only area labelled with a warning sign to indicate high noise exposure and the required wearing of a hearing protector in this area.

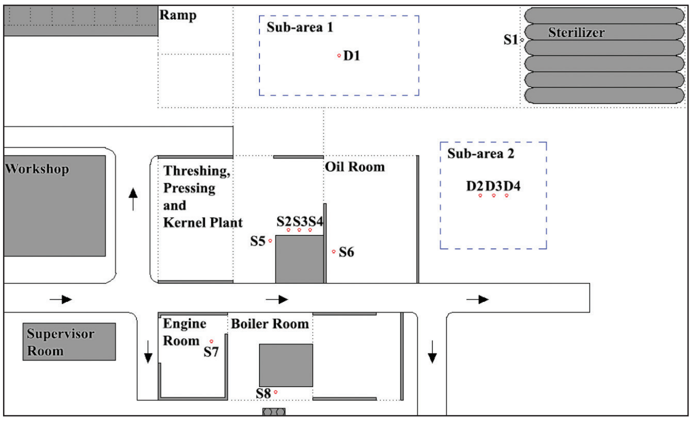

Figure 2(a): Site Layout of Palm Oil Mill

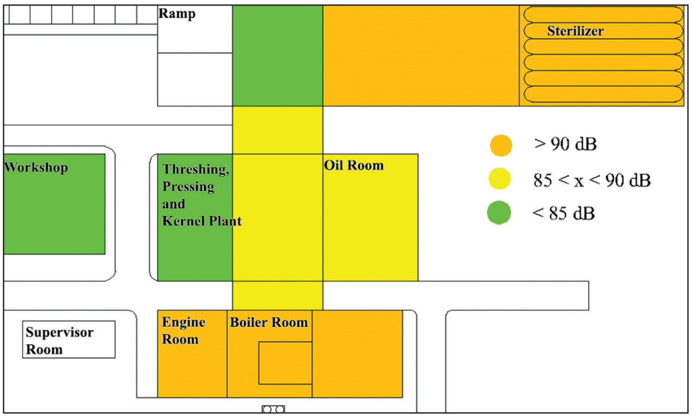

Figure 2(b): Existing Noise Map of Palm Oil Mill

Table 2 shows the properties of machinery including sound power level, dimension, and duty cycles. The dimension of machinery was important to be used in consideration of measurement as stated in BS standards and the percentage of duty cycles reflect the operating mode of machinery when the measurement was carried out. The turbine (S7) in the engine room was recorded as having the highest sound power level of 119.9 dBA and emitted a steady-continuous noise level to the environment; this machine was almost fully operating with a recorded 90% on mode during the measurement. This was followed by the bulldozer (D3) as the second-highest noise source, emitting fluctuating noise to the environment at 119.1 dBA. However, this dynamic machine was not fully operating at that time, and its duty cycles were recorded as 50% on and 50% idling modes, respectively.

3.2 Strategic Noise Mapping and Noise Risk Zone

A strategic noise map of this palm oil mill was predicted by simulating 1,500 steps from RW-eNMS as shown in Figure 3a. This map was plotted with different colours from blue to red, to represent the variation in noise levels in this workplace. The grey colour represents the existing buildings, walls, and structures which could bring the barrier effects on the attenuation and reflection of noise. According to the prediction results from the simulation software, it was estimated that about 28.1% of the mapping area exceeded the permissible limit of 85 dBA. Severe noise polluted areas were found in the engine room, kernel plant, boiler room, and sub-area 2. The workers might have a high risk of hearing loss and work-related accidents when working a full shift in these areas. Meanwhile, the working activities in sub-area 2 were temporarily in operation, and the noise levels were always changing, but still, the operators must always wear hearing protectors while working in this area. Moreover, a noise risk zone was plotted by using the noise mapping data to determine the category of risk zone from the noise risk evaluation criteria. Figure 3b shows a noise risk zone for this study and each risk zone was filled with colour to imply the risk

Table 2: The Properties of Machinery

Machine	Label	Sound Power level, dBA	Dimension	On, %	Off, %	Idle, %
Sterilizer	S1	109.3	1.0m x 1.0m	90	0	10
Crusher Silo 1	S2	117.2	3.0m x 2.0m	50	0	50
Crusher Silo 2	S3	117.2	3.0m x 2.0m	50	0	50
Crusher Silo 3	S4	117.2	3.0m x 2.0m	50	0	50
Siever	S5	111.3	8.5m x 1.5m	50	0	50
Oil Purifier	S6	103.2	0.8m x 0.8m	90	0	10
Turbine	S7	119.9	4.0m x 2.3m	90	0	10
Fan	S8	110.9	1.5m x 1.0m	90	0	10
Bulldozer 1	D1	106.5	4.8m x 2.5m	90	0	10
Bulldozer 2	D2	112.7	5.0m x 2.5m	50	0	50
Bulldozer 3	D3	119.1	6.0m x 2.5m	50	0	50
Excavator	D4	112.1	6.0m x 2.5m	50	0	50

circumstances in this workplace. For example, the red colour represents an extremely high-risk zone, where the noise levels in this area were above 85 dBA. Four risk zones were found at this workplace, such as extremely high-risk, high-risk, moderate risk, and low-risk zones. Based on the results, it had shown that more than half of the mapping area was categorized as a high-risk zone (29.6%) and an extremely high-risk zone (28.1%). About 29.2% and 13.1% of mapping areas were under the moderate and low noise risk zone.

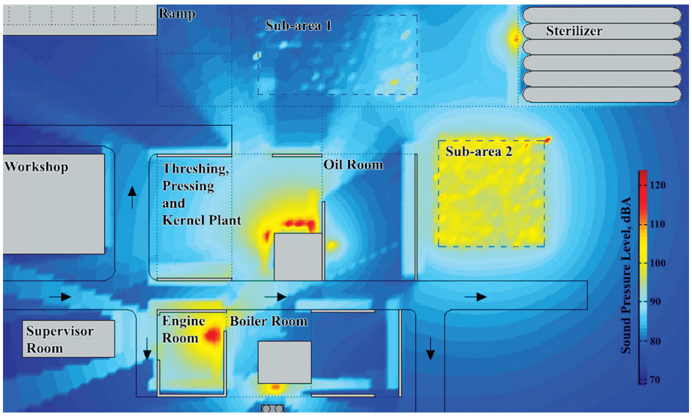

Figure 3(a): Strategic Noise Map

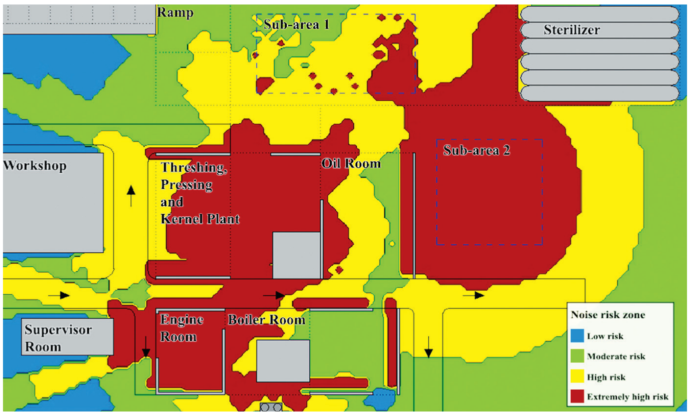

Figure 3(b): Noise Risk Zone

3.3 Personal Noise Exposure

In this study, a strategic noise map and a noise risk zone were used to determine the areas for personal noise exposure measurement. Three areas, such as the engine room, kernel room, and boiler room, were identified as having particularly high noise exposure and risk of noise-related problems and were consequently selected for the measurement. The sub-area 2 was not selected in this measurement because its activities were involved complex, dynamic, and not always in operation. Two workers from each of these selected areas were chosen to carry out personal noise exposure measurements. In total, six workers were involved as representatives of their respective areas to study the noise exposure problem. The measurement data were analyzed to produce noise dose projections over 8 hours, and the results were recorded in Table 3. All measurement results exceeded the TWA permissible exposure limit of 90 dBA as stated in OSHA regulation (Occupational Noise Exposure, 1983). The highest TWA was Worker 2 in the engine room, who had a 99.2 dBA exposure level. In the kernel plant, the TWA sound levels were 97.8 and 98.1 dBA, implying that the information from the strategic noise map and noise risk zone have accurately revealed high noise exposure and high risk in this area. Table 2 also shows the NRR of hearing protectors estimated to reduce the noise exposure level to 85 dBA. The proposed NRRs for the engine room, kernel plant, and boiler room areas are 35 dBA, 33 dBA, and 27 dBA, respectively. For adequate noise reduction in all independent working environments, it is recommended that workers wear hearing protectors with the proposed NRRs.

Table 3: Personal Noise Exposure

Worker	Dose$_{30mins}$, %	Dose$_{8hours}$, %	TWA, dBA	NRR, dBA	Location
1	19.9	318.4	98.4	34	Engine Room
2	22.3	357.0	99.2	35	Engine Room
3	18.4	294.7	97.8	33	Kernel Plant
4	19.2	307.4	98.1	33	Kernel Plant
5	12.8	204.3	95.2	27	Boiler Room
6	12.1	194.2	94.8	27	Boiler Room

3.4 Proposed Engineering Noise Control Methods in Palm Oil Mill

This study proposed engineering control measures for reducing noise levels from noise sources, including machinery enclosure design and the implementation of low-noise emission machinery. Enclosures or covers could be erected to house the machinery located in engine rooms, boiler rooms, and kernel plants, utilising sound insulation materials such as fiber cement board, brickwork, chipboard, fiberboard, and plywood. The efficacy of noise control at noise sources and machinery enclosure design with respect to BS5228-1:2009 was further discussed. This study proposed the erection of covers in noisy areas to attenuate and reduce noise, as well as the implementation of low-noise emission machinery to minimise noise exposure in the workplace. To accurately determine the cover effects, a simple approximation method from BS5228-1:2009 was employed.

Furthermore, to mitigate the noise exposure of the sub-area 2, the study proposed the implementation of earth-moving machines with a maximum sound power of 110 dBA, as the three earth-moving machines D2, D3 and D4 in this area had sound power levels exceeding this proposed level. In the control simulation, these machines were replaced with sound power levels of 110 dBA. However, the replacement of static machines with low-noise emission machines was not recommended due to the large amount of cost associated with purchasing new machines and modifying the existing working layout for machine installation. The effectiveness of noise control was then determined by comparing simulation results before and after the incorporation of engineering control into RW-eNMS. After the incorporation of engineering control in the pertinent areas, the noise exposure levels within the new simulation results were observed to decrease. A new strategic noise map and noise risk zones were predicted by simulating 1,500 steps from RW-eNMS, as depicted in Figures 4a and 4b, with the covers represented in black. By exhibiting sound insulation characteristics, the covers successfully reduced the propagation of noise to the adjacent environment. The overall noise mapping result predicted that 7.1% of the mapping area exceeded the permissible limit, a decrease of approximately 21.0% from the previous findings.

Meanwhile, this study selected fifteen control points to compare the L_{Aeq} before and after the implementation of engineering noise control. The locations of control points were plotted in Figure 4a with red circles and labels from C1 to C15. Most of the control points were located in the engine room, kernel plant, and sub-area 2. Table 4 shows the results and differences of LAeq before and after the engineering noise control at the selected control points. In the engine room, the noise was reduced by at least 9 dBA by referring to the control points C1 to C3. It implies that the erection of covers at turbine machines could significantly decrease the noise levels in this area. Similar to the noise circumstances in the kernel plant area as the noise levels had reduced in the range of 7.6 dBA to 9.5 dBA. For the control points near sub-area 2, the noise levels were also reduced by at least 5 dBA through the replacement of earth-moving machines for D2, D3, and D4 with a sound power level of 110 dBA. Besides, the noise risk zone indicated a reduction in the percentage of risky areas in this workplace. Table 5 reveals the results of the noise risk zone before and after the inclusion of engineering noise control. For example, the extremely high-risk zone and high-risk zone had decreased to 10.9% and 17.8% respectively, but contrarily the percentage of the low-risk zone had increased from 21.1% to 34.1% in the whole mapping area. Thus, the implementation of the proposed engineering noise control was shown to effectively reduce noise exposure levels and the risk of noise problems in this palm oil mill.

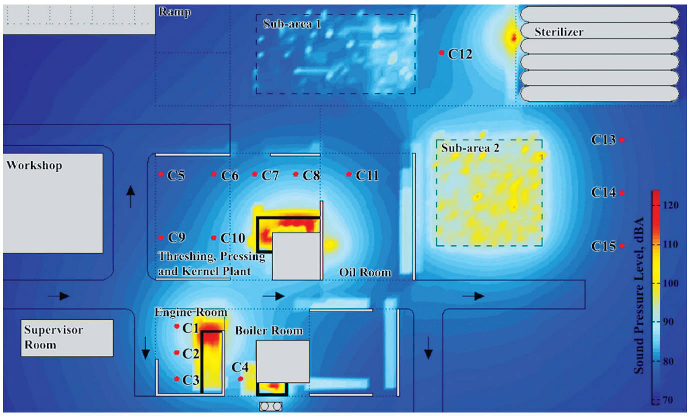

Figure 4(a): Strategic Noise Map and Noise Risk Zone

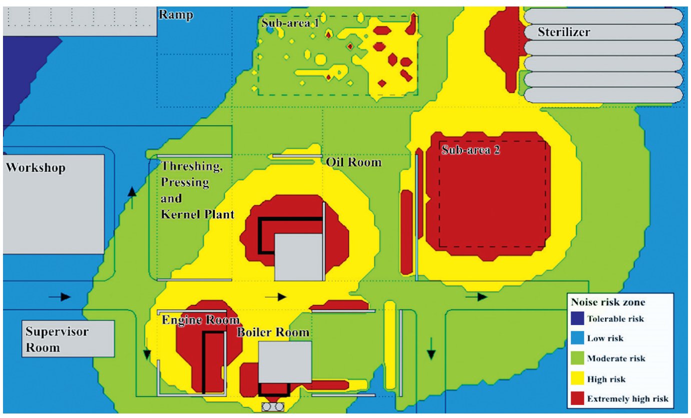

Figure 4(b): Strategic Noise Map After Engineering Noise Control

Table 4: Comparison of Equivalent Continuous Sound Pressure Level (L_{Aeq}) Before and After the Engineering Noise Control

Control Point	L_{Aeq} (Before), dBA	L_{Aeq} (After), dBA	Difference, dBA	Location
C1	95.0	85.4	9.6	Engine room
C2	94.7	85.0	9.7	Engine room
C3	91.5	82.1	9.4	Engine room
C4	87.9	83.3	4.6	Boiler room
C5	84.4	76.3	8.1	Kernel plant
C6	87.6	78.8	8.8	Kernel plant
C7	91.0	81.6	9.4	Kernel plant
C8	91.8	82.3	9.5	Kernel plant
C9	85.8	78.2	7.6	Kernel plant
C10	90.7	81.6	9.1	Kernel plant
C11	85.9	80.9	5.0	Oil room
C12	84.5	80.6	3.9	Near sterilizer
C13	82.3	77.3	5.0	Near sub-area 2
C14	82.8	77.4	5.4	Near sub-area 2
C15	82.1	76.8	5.3	Near sub-area 2

Table 5: Comparison of Noise Risk Zones Before and After the Engineering Noise Control

Category of Risk Zone	Percentage (Before), %	Percentage (After), %	Difference, %	Status
Safe	0.0	0.0	0.0	-
Tolerable	0.0	2.9	2.9	Increase
Low Risk	13.0	34.1	21.1	Increase
Moderate Risk	28.8	34.4	5.6	Increase
High Risk	30.6	17.8	-12.8	Decrease
Extremely High Risk	27.5	10.9	-16.6	Decrease

4.0 DISCUSSION

A strategic noise map was plotted using the RW-eNMS, a stochastic simulation method which can effectively predict the noise by taking into account the complexity and dynamism of operating activities (Han *et al.*, 2015). Comparison of the generated map with the existing noise map (Figure 2b) in the palm oil mill demonstrated the inadequacy of conventional methods in considering the random duty cycles of machines and dynamic noises from earth-moving machines. This finding is in agreement with earlier studies which highlighted the neglect of randomness, uncertainty, and dynamics of work activities (Zhang *et al.,* 2014). Random duty cycles and machine movement have been identified as the main factors contributing to the spatial variation of equivalent noise levels (Haron *et al.,* 2009; Haron and Yahya, 2009). Analysis of the strategic noise map revealed that several manufacturing processes emitted superfluous noise into their surrounding environment, including sterilizing, stripping, pressing, threshing, digesting, boiling, and generating processes. These noisy processes have in turn been linked to numerous adverse effects on the workers (Naeini and Tamrin, 2014a; Naeini and Tamrin 2014b).

For current noise prevention practices, the management implemented the provision of hearing protectors to workers and a noise map to reflect the ambient sound levels in the workplace. However, many workers do not wear hearing protectors regularly, and some do not use them at all. The protective efficacy of a hearing protector is diminished if it is not used consistently (Hong, 2005). This situation is likely to cause both noise-induced hearing losses and work-related accidents. Various reasons have been identified to explain the intermittent use of hearing protectors, including bad attitudes and behaviours of workers, discomfort, interruption of communication, and reduced motivation (Arezes and Miguel, 2012; Tak *et al.,* 2009; Saleha and Hassim, 2006). Poor risk recognition on the part of the worker is also known to contribute to the reduced utilisation rate of hearing protectors (Arezes and Miguel, 2006). Thus, improvement of the quality of current noise maps to enhance the awareness of workers regarding the noise problem in their daily working area can be an effective alternative for management to consider. Management could use the findings from this study to disseminate information to their workers, who could self-perceive noise levels and risks through noise map information and risk zone information (Han *et al.,* 2015). Increased risk perception and self-efficacy levels could motivate workers to take preventive action more frequently [47, 48]. In addition, only one warning sign was found located in the engine room, when this study detected high noise exposure in other working areas, such as the kernel plant, boiler room, oil room, and sterilizing area. Therefore, warning signs should also be provided in these areas, to serve as a reminder to workers to use hearing protective equipment (Wogalter *et al.,* 2002).

Occupational noise exposure can be significantly reduced through the effective implementation of a noise control strategy, which is typically divided into two approaches: administrative or engineering control. The management can execute administrative control through the division of work shifts in a day. This strategy can be effective through the reduction of noise exposure time within the working period of 8 hours in their respective shifts. Hearing protection devices should be supplied adequately to workers as a common occupational hearing safeguard. A study by Saleha and Hassim found that Malaysian industries preferred to provide hearing protectors to their workers rather than implement the noise control method because it is a cheaper option compared to noise control. Still, the implementation of engineering controls on noise sources is the most effective way to reduce noise exposure levels in the workplace. Few strategic actions could be implemented to optimize engineering controls (Tuli *et al.,* 2020), including the replacement of low-noise emission machinery and the erection of enclosures at the noise source, as suggested in this study. This study has proven the efficacy of engineering noise control methods with the assistance of RW-eNMS to address the noise abatement strategy in the palm oil mill examined. Consequently, the management should consider implementing the proposed engineering control methods for optimal noise abatement.

5.0 CONCLUSION

In conclusion, it was found that the prevalence of severe noise exposure issues in the current palm oil industry was high. This study predicted that nearly 28.1% of the mapping area exceeded the permissible noise limit, which included areas such as the engine room, boiler room, kernel plant, and sub-area 2. Consequently, workers were exposed to a high risk of hearing problems in these areas. A strategic noise map and noise risk zone provided insight into the noise circumstances in the palm oil mill. The management should disseminate the relevant information of the noise map and risk zone to the workers to raise their awareness of the issue in their workplace and to encourage them to take preventive measures regularly. The proposed engineering noise control methods could be utilised by the management in devising the optimal sound abatement strategies. All in all, the palm oil industry needs to manage noise levels effectively to ensure a safe working environment and protect workers from hearing problems. This study has demonstrated that the stochastic noise mapping simulation method is capable of accurately predicting noise exposure levels while being suitable for use in designing a noise control strategy. It is recommended that future work includes the implementation of the proposed noise control methods outlined in this study, such as installing noise barriers around high noise emission sources and imposing limits on maximum sound power at the palm oil mill. Furthermore, future noise measurements should be conducted to validate the actual reduction achieved compared to the prediction results obtained in this study.

6.0 ACKNOWLEDGMENTS

This research was supported by the Ministry of Higher Education (MoHE) through Fundamental Research Grant Scheme (FRGS/1/2021/TK02/UTAR/02/2). The authors would like to thank Dr Zaiton Haron and Dr Khairulzan Yahya for their assistance with this research study. ■

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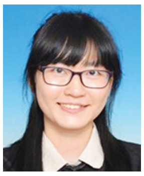
PROFILES

TAN LEE HANG is a dedicated Ph.D. student in the field of Civil Engineering at the esteemed University Tunku Abdul Rahman. Recently graduated with a bachelor's degree in civil engineering from the same university in the year 2021. Currently, he is actively engaged in research within the field of Civil Engineering, with a specific focus on noise-related studies. His research endeavors are driven by a passion for understanding and mitigating noise pollution, which is a critical concern in our modern urban environments.
Email address: leehangtan@1utar.my

DR LIM MING HAN is the assistant professor under the Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science from the Universiti Tunku Abdul Rahman in Malaysia. He was graduated the degrees of Ph.D. in civil engineering in the year 2017 from Universiti Teknologi Malaysia, master of business administration with the major in entrepreneurship in the year 2016 from Open Universiti Malaysia, and a bachelor of engineering in civil engineering in the year 2012 from Universiti Teknologi Malaysia. His areas of expertise are included noise monitoring, noise prediction, stochastic modelling, artificial intelligence, programming, business planning and management. He was awarded several research awards, including the gold medal awards from the 2016 international invention innovation competition in Canada, Malaysia technology expo 2015, international invention, innovation & technology exhibition 2016 and Malaysian research conference and innovation exhibition 2015. He is currently working on research in noise mapping prediction and artificial intelligence.
Email address: limmh@utar.edu.my



DR LEE YEE LING is the assistant professor under the Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science from the Universiti Tunku Abdul Rahman in Malaysia. She was graduated the degrees of Ph.D. in civil engineering in the year 2016 from Universiti Teknologi Malaysia and a bachelor of engineering in civil engineering in the year 2010 from Universiti Teknologi Malaysia. Her areas of expertise are included noise monitoring, cold-formed steel design, lightweight concrete, and lightweight composite structures. She was awarded several research awards, including the gold medal awards from 2016 international invention innovation competition in Canada, Malaysia technology expo 2015, international invention, innovation & technology exhibition 2016 and Malaysian research conference and innovation exhibition 2015. She is currently working on research in noise monitoring, acoustical concrete materials, and deep learning.
Email address: yllee@utar.edu.my

Ir. TS DR TAN OOI KUAN is the assistant professor under the Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science from the Universiti Tunku Abdul Rahman in Malaysia. He obtained a Doctorate in Business Administration specialising in engineering Management in the year 2015 from Universiti Utara Malaysia, Master of Technopreneur in the year 2005 from United Business Institute, Belgium and Bachelor of engineering in civil engineering (Hons) in the year 2002 from Universiti Putra Malaysia. He registered his professional development with The Board of Engineers Malaysia (P.Eng) and the Malaysia Board of Technologists (Ts). His areas of expertise are included environmental, safety and health management, engineering Management, Technopreneurship, entrepreneur behaviour. He is currently working on the research in engineering management focussing on smart construction digitalization, construction project management and safety, and human development in construction. Before joining as an academician, he has developed vast experience in the engineering design and construction industry as a practitioner engineer. Moreover, with his knowledge in business, he was promoted to the position of HR and Admin Manager.
Email address: oktan@utar.edu.my