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Simulation of noise exposure level of fire-fighters in emergency response services in Malaysia

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A R T I C L E I N F O

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A B S T R A C T

Excessive exposure to noise may lead to noise-induced hearing loss (NIHL). NIHL has emerged as the biggest cause of world occupational disease in recent years. Occupational hearing loss is among the common work related diseases in Malaysia. It has been proven that occupational NIHL shows the highest number of cases compared to other occupational diseases. Many occupational noise exposure studies have been conducted in various occupational sectors. However, no studies have been done on noise exposure of fire-fighters in Malaysia. This study aims to determine noise intensity and noise dose exposed to the fire-fighters during emergency response activity, to develop fire-fighter noise exposure indicator profile, and to propose solutions in order to reduce potential hearing loss among fire-fighters. Noise measurement from sirens emitted from truck and sirens at the station was carried out at Taman Universiti Fire Station using Sound Level Meter (SLM). Measurement was conducted on all pieces of equipment on truck including power saw, circular saw, hydraulic power unit, generator set, air compressor, and high and low pump. In order to assess the noise dose, a list of noise-producing equipment and the estimated total time of exposure is provided. Once the data had been analysed, an indicator system was constructed. As anticipated, all types of sirens and equipment produced noise greater than 85db except for noise emitted from AlarmCAD lite, emergency siren and generator set. Useful exposure indicator profile and solutions were proposed to reduce fire-fighters potential hearing loss.

1. Introduction

Different countries refer to different regulations regarding noise emission (Mulholland and Attenborough, 1981). Certain countries allow certain noise emission level during specific period of time, task and characteristic of noise. Malaysia practices noise regulations from Factory and Machinery Regulation (FMR), Occupational Safety and Health Act (OSHA), Health and Safety Executive (HSE), Department of Environment (DOE) and a few other approaches for recommendation and reference issue on noise to human and environment. The noise regulation in Malaysia came into force in 1st February 1989 which is Factory and Machinery (Noise Exposure) Regulation (1989). The regulation requires compliance from all factories in any occupations involving exposure to excessive noise level in workplace. However, whenever it is not feasible to comply with this regulation, the occupier must provide or supplement controls with approved hearing protection devices.

The Occupational Safety and Health Act came into force on 25th February 1994 (OSHA, 1994). This act is to make further provision for security, health and welfare of a person at work. The OSHA regulations provide a permissible exposure level (PEL) for workers. OSHA's Occupational Noise Exposure rule (29CFR 1910.95) requires for employers to carry out noise exposure assessments and all the employees must be protected against the effects of noise exposure above an 8-h time-weighted average (TWA) of 85 dB (dB) with an exchange rate of 5. The World Health Organization (WHO) has developed recommended guidelines for noise exposure for the general population to include leisure-based activities. WHO recommended guidelines for noise exposure suggest up to 70 dB over a 24-h period can be considered safe to human hearing at which the risk for hearing impairment is negligible. To avoid hearing impairment, the peak sound pressure level (SPL) of impulse noise for adults and children shall not exceed 140 dB and 120 dB respectively (Berglund et al., 1999).

Firefighting is a dangerous occupation and associated with a variety of hazards, including rigorous physical training activities, exercise and emergency situations involving high temperatures, smoke and other air contaminants, ergonomic issues, and others (Poplin et al., 2011). According to Paterson et al. (2016), responding to an emergency alarm could lead to a significant risk on the fire-fighters' health and safety. As a result, roughly 1.1 million fire-fighters in U.S National Fire Protection

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Association (NFPA) in 2015 were known to be subjected to elevated risk of a number of occupational injuries and illness (Poplin et al., 2011). One potentially damaging illness is noise-induced hearing lost (NIHL) from constant excessive noise. Reports by Reischl et al. (1979), (1981) and Tubbs (1995) confirmed that NIHL was the reason for multiple hearing lost among fire-fighters that experience excessive high intensity noise exposure while working. Much worse is the hearing losses occurred early in their careers statistically (Ide, 2011). Organizations are required to measure noise levels and provide protective measures if warranted. Unfortunately, according to Schwennker (2011) noise control in the fire-fighting industry is difficult because loud noise is used as a control to warn people of impending danger. The relatively loud sirens and horns of fire trucks serve an alert system to the public to avoid the perimeter of emergency vehicles. In addition, research has shown that fire-fighters are exposed to relatively loud noise from the rescue equipment such as chainsaws (113 dBA), jaws of life (94 dBA), and chisels (106 dBA) (Diel, 2001). Neitzel et al. (2012) found that sawing metal, concrete, wood, and dry wall during ventilation activities produced some of the highest task-based noise levels (between 105 and 109 dBA) measured in the study. Nevertheless, despite of all the loud noise experienced by fire-fighters, there is also suggestion to come out with a more proper means of quantifying such exposure to noise in different work environments to aid in the diagnosis of hearing loss (Taxini and Guida, 2013). All of these reports clearly show that a proper monitoring and prevention measures should be made available immediately.

Average sound levels for the fire engine air horn and electric sirens were measured to be about 98 dBA inside the engine's crew cab and about 115 dBA outside the cab. Fig. 1 shows the noise monitoring on emergency equipment whereas Figs. 2 and 3 illustrates various types of fire-fighter saws and electrical sirens on fire truck, respectively as claimed by Moss (2015). Additionally, a study conducted by Schwennker (2011) stated that the equipment used at the fire stations showed noise level measurements ranging from 81 dBA to 108 dBA whereby 13 of the 15 pieces of equipment had measured noise levels greater than 85 dBA. Therefore, it is highly recommended by that study for fire-fighters to wear hearing protection devices while using these pieces of equipment to lower their risk of NIHL. According to a study conducted by Ide (2007), more than 90% of approximately 230 fire-fighters agreed that good hearing is essential for the majority of fire ground tasks. Other studies have documented low use of hearing protection devices among fire-fighters (Hong et al., 2011), despite acknowledgement by many surveyed fire-fighters of the potential for NIHL. Previous study also claimed that while fire-fighters acknowledged the importance of hearing on the job, few were willing to use hearing protection devices during firefighting activities (Hong and Samo, 2007). Previous research has suggested that fire-fighters' hearing threshold levels (HTLs) decline faster than expected during their careers compared with age-matched members of the general population (Kang et al., 2015). Kales et al. (2001) found that fire-fighters experience an average accelerated hearing loss of 6 dB at the 90th percentile when compared with population databases from the International Standards Organization (ISO). These researchers also claimed that hearing loss associated with firefighting is strongly associated with age and the duration of service as a fire-fighter, and that hearing loss is associated with the relative higher frequencies of sound perception.

In a second study, Hong et al. (2008) stated that hearing conservation programs and diligent use of hearing protection devices could significantly reduce the risk and prevalence of NIHL in the firefighting population. Their study showed that hearing loss interventions could be successful if followed appropriately. Some previous studies have stated that individual perception as well as contextual factors are important predictors of safety behaviour, including the use of hearing protection devices (HPD) (Arezes and Miguel, 2005). Researchers also recommended that effective interventions are needed to educate fire-fighters about the hazardous effects of noise and the importance of hearing protection devices. The aim of this study was to assess occupational noise exposure among fire-fighters and the compliance of permissible noise exposure limit to the fire-fighters emergency service activity. Fire-fighter noise exposure indicator profile was developed and solutions were proposed in order to reduce potential hearing loss among fire-fighters.

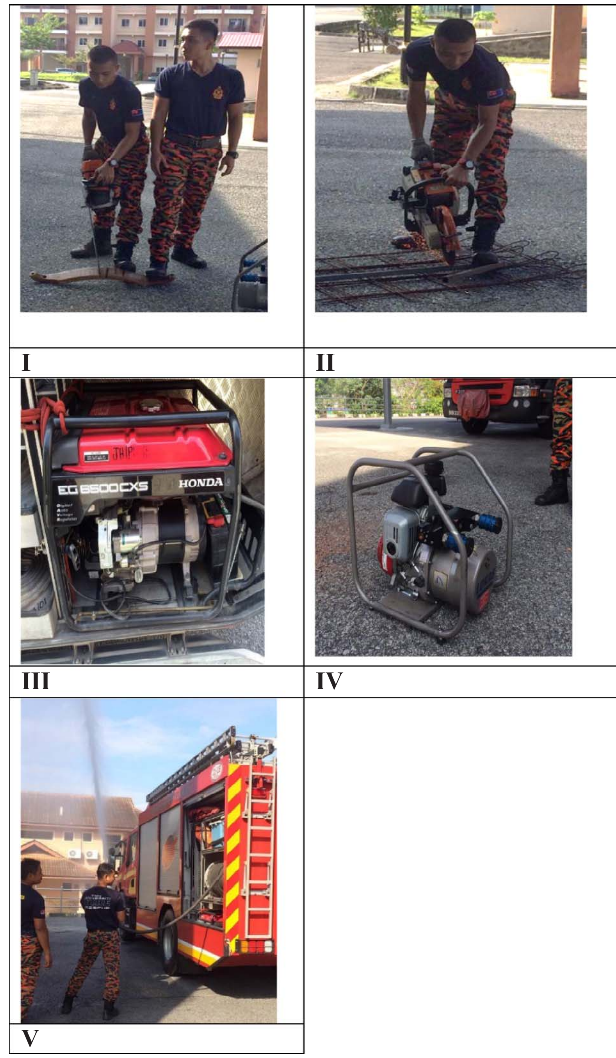

Fig. 1. Noise monitoring on emergency equipment. (I) Noise measuring while cutting log with chain saw. (II) Noise measuring while cutting metals with circular saw. (III) Generator set. (IV) Hydraulic power unit. (V) Noise measuring while running high pump and low pump.

Fig. 2. Fire-fighters various types of saws, roof chainsaw, K-12/Partner (rotary) saw, standard chainsaw, and/or a reciprocating saw.

Fig. 3. Siren on a fire truck.

2. Methods

2.1. Data collection

Noise sampling was conducted at Taman Universiti Fire Station, Skudai, Johor, Malaysia. The fire station has a total of 45 firefighters whereby there are 3 groups which consist of 13–14 fire-fighters each. This station was chosen as the site for testing to demonstrate the worst case scenario as it is considered as the busiest fire station in Johor. According to the Station Leader there are of three to four cases per shift on average and the noise exposure is not identical as the exposure depends on the type of cases. Noise exposure is likely to be the highest in cases where there are fallen trees and branches, whereby chainsaw is used for long duration. Accident cases in which circular saw and generator set are used could also contribute to the high noise level to the fire-fighters. In this study, the data collection was divided into two main parts: noise monitoring and noise dose estimation.

2.2. Noise monitoring

Noise sampling was conducted using a Larson Davis Sound Level Meter 824 (SLM)/octave band analyser (Larson Davis, Provo, Utah). The SLM was both pre- and post-calibrated for accuracy within acceptable limits for calibration (94 dB and 114 dB). For conducting the noise sampling, the OSHA Technical Manual (1999) Section 3 Chapter 5 was used for guidance. The microphone was always held at ear height and approximately one meter from the researcher.

2.2.1. Siren noise monitoring

Noise measurements of truck siren and air-horn were taken from the trucks that were randomly selected at the fire station. Measurements were taken at the front, passenger's side, rear, and driver's side of each truck to simulate where a fire-fighter would be standing during an actual firefighting activity. Not only from the truck, this study also measured another two types of sirens which are AlarmCAD lite and emergency warning alarm at the station.

2.2.2. Equipment noise monitoring

Noise monitoring was also conducted on all pieces of equipment on truck that will likely emit loud noise. The equipment includes all emergency equipment such as chain saw, circular saw, generator set, hydraulic power unit and pump as illustrated in Fig. 1. Measurements were taken on those truck pumps while operating at high and low settings. Again these samples were taken at the front, passenger's side, rear, and driver's side.

2.3. Noise exposure estimation

Fire-fighters at the Taman Universiti Fire Station work a 12-h shift rather than a typical 8-h shift and may be exposed to noise sources from tasks at the fire station and during an emergency response. A list of noise-producing equipment and their attendant noise levels was provided to the Fire-fighter Team Leaders who estimated the time of exposure for each equipment activity and the average number of fire calls during a 12-h shift. The percentage of dose was calculated the following Eq. (1) as described by Berger et al. (2003):

$$\text{Dose} = 100[C(1)/T(1) + C(2)/T(2) + \ldots + C(n)/T(n)] \quad (1)$$

where

C = Total time of exposure at a specified noise level;
T = total time of exposure permitted at that level.

2.4. Statistical analysis

The noise data from the SLM were analyzed upon completion of data collection. Data analysis included descriptive statistics of the equivalent continuous sound pressure level (Leq) using the A-weighted scale and analysis of peak exposures. Noise source with the probability value (*p*-value) of less than 0.05 was considered to be significant statistically. The data was analyzed using SPSS software and graphed with Microsoft Excel 2016.

2.5. Constructing an indicator system

2.5.1. Step 1: Defining noise indicator and establishment of Maximum and target value

In this step, noise indicator was identified based on the measured equipment. Maximum and minimum target values were identified based on the range given by legislation, Occupational Safety and Health Act (Noise Regulation), and previous studies by Akosile et al. (2007) and National Institute of Deafness and Other Communication Disorder (2015). Target value was the lowest value of the range while maximum value was the highest value as appeared in Table 1. These two values were used in the Proximity-to-Target (PTT) calculation.

2.5.2. Proximity-to-target scoring

PTT was used to calculate the distance of the actual data from the target data in percentage. The range of each indicator stated in Table 1 was used as the target for PTT calculation of Noise Indicator Tool. Percentage of PTT was calculated based on Eq. (2):

$$\text{PTT}(\%) = \frac{(\text{Raw Data}-\text{Target})-(\text{Maximum}-\text{Target}) \times 100}{(\text{Maximum}-\text{Target})} \quad (2)$$

2.5.3. Step 2: Establishing index profiling using web based system development

In establishing an index profile, several aspects were taken into account. The data were presented using graphical method, specifically using Radar Chart whereby high values were interpreted as a bad performance. Radar chart of proximity-to-target for each component was developed using Microsoft Office Excel 2016.

Table 1
Maximum and target value.

A1	AlarmCADlite	85	70	dB	1. OSHA (1994).
A7	Hydraulic Power Unit	85	70	dB	2. Akosile et al. (2007).
					3. National Institute of Deafness and Other Communication Disorder (2015)

Table 2
Mean and 95% confidence intervals of noise from truck siren.

Location	Mean	95% Confidence Intervals (dB)
Driver's side	103.3	103.5, 103.1
Pasenger's side	103.3	103.5, 103.1
Front	104.6	105.2, 104.0
Rear	97.5	97.8, 97.2

3. Results

3.1. Siren noise monitoring

Mean siren noise monitoring results and 95% confidence limits calculated from noise measurements taken around the trucks are presented in Table 2. The mean noise levels were significantly different, with the highest mean noise level in front of the truck at 104.6 dB and the lowest at the rear of the truck at 97.46 dB. The passenger's and driver's sides showed similar results with 95% confidence where the noise levels were between 103.13 and 103.47 dB. These results are above the OSHA action level of 85 dB. The mean noise monitoring for truck air horn and the 95% confidence limits calculated from noise measurements taken around the trucks are shown in Table 3. The mean noise levels for truck air horn were significantly different, with the highest mean noise level at passenger's side with 89.63 dB followed by in front of the truck at slightly lower which was 89.57 dB and the lowest noise measurement was at the rear of the truck at 87.97 dB with a confidence level between 87.06 dB and 88.88 dB. These results are above the OSHA action level of 85 dB.

For AlarmCAD lite the noise was measured at 2 locations; operation room and also at operator's ear. Both locations showed noise values below than 85 dB. The mean noise measured at operator's ear was 72.3 dB while mean noise measured at operation room was 68.2 dB. Both values are below OSHA action level of 85 dB. Table 4 shows mean and 95% confidence of noise from AlarmCAD lite. Noise emitted from emergency siren (Table 5) was also measured at 2 locations; rest room and engine bay. Both locations showed noise measurement lower than 85 dB. Rest room showed noise mean value of 83.3 dB while engine bay showed 83.4 dB mean noise value. Both noise values are below OSHA action level.

3.2. Equipment noise monitoring

Samples were taken on the equipment found on the emergency response trucks and the mean noise levels are shown in Fig. 4. The equipment ranged in mean noise values from 83.1 dB to 99.7 dB with confidence interval from 82 to 100 dB. Three measurements were taken on each equipment, and the mean values were used. Chain saw showed the highest mean noise level which was 99.7 dB while generator set showed the lowest mean value of noise level (83.1 dB). All equipment except the generator set was over the OSHA action limit of 85 dB. Five of the six pieces (83.3%) of equipment had manifested noise levels greater than 85 dB.

Table 3
Mean and 95% confidence intervals of noise from truck air-hon.

Location	Mean	95% Confidence Intervals (dB)
Driver's side	89.2	89.5, 89.0
Passenger's side	89.6	90.0, 89.2
Front	89.6	90.1, 89.0
Rear	88.0	87.1, 88.9

Table 4
Mean and 95% confidence intervals of noise from AlarmCADlite.

Location	Mean	95% Confidence Intervals (dB)
Operation room	68.2	68.0, 68.4
Operator ear	72.3	72.0, 72.6

Table 5
Mean and 95% confidence intervals of noise from emergency siren.

Location	Mean	95% Confidence Intervals (dB)
Rest room	83.3	83.0, 83.6
Engine Bay	83.4	82.7, 84.1

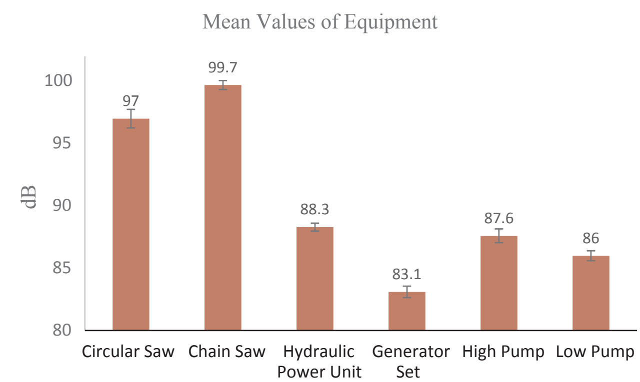

Fig. 4. The mean value for equipment used by the fire-fighters.

3.3. Noise dose estimation

The estimated noise dose was based on a typical 12 h shift in the Taman Universiti Fire Station. The estimated times of exposure for each task were provided by the fire-fighter Team Leader. An average noise dose of 1.5% was calculated for the 12-h shift, which may vary depending on the activities the fire-fighters experience during the shift. Dose was calculated using the OSHA criterion level of 85 dBA and an exchange rate of 5 dB.

3.4. Index profiling using radar chart

Fig. 5 illustrates the comparison of raw data and the target value, 70 dB. The target value was set as 70 dB in accord to Akosile et al. (2007); and National Institute of Deafness and Other Communication

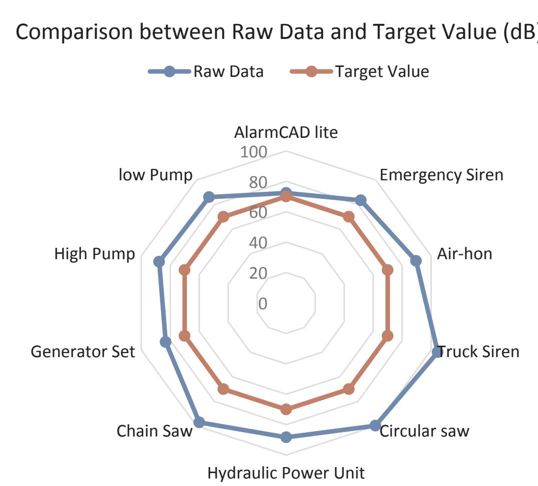

Fig. 5. Comparison between raw data and target value (dB).

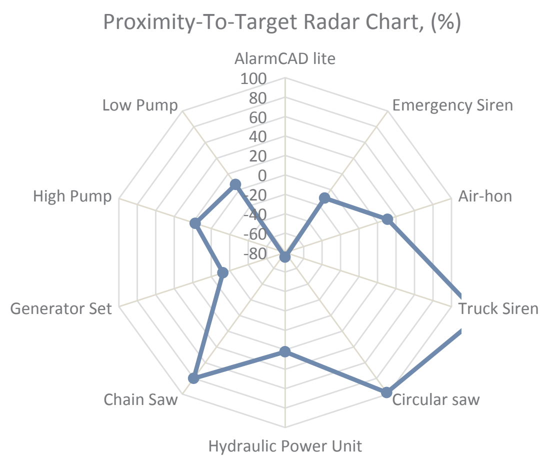

Fig. 6. Proximity-to-target Radar Chart.

Disorder (2015) reported that noise below than 75 dB will not cause hearing problem even after a long exposure. PTT percentage for each item was also calculated to get the distance of the actual data from the target data as shown in Fig. 6. Raw data, maximum and target values for each item were used in calculating PTT percentage.

Based on the calculation, truck siren shows the highest PTT percentage, 104.6%, which is the highest distance of the actual data from the target value. This is because the noise emitted from the truck siren was 34.6 dB above the target value. PTT value of the circular saw was slightly lower than the truck siren, 98%. The noise emitted from the circular saw was 29.7 dB more than the target value. The lowest PTT percentage was from AlarmCAD lite. This is because the noise emitted from AlarmCAD lite was just 2 dB above the target value.

4. Discussions

Similar with the previous finding by Root et al. (2013) who studied fire-fighter truck, the highest measured Leq was 79 dB at the front of the engine, and the lowest was 68 dB at the rear of the engine. Schwennker (2011) also stated that when examining the noise levels emitted from the four positions around the trucks, the highest noise levels were associated with the front of the truck and the quietest, (76 dB and 75 dB), areas were the backs of the trucks. This might be due to the engine noise and the air movement into the radiator and fans within the engine compartment at the front of the truck. These results suggest that a simple control can be implemented to reduce noise exposure from the siren during operations which is to stay away as far as possible and avoid from walking by the front of the truck while the truck siren is on.

This study also reflects the finding by Root et al. (2013) who reported that majority of equipment used by the fire-fighters, both station and fire engine, produced noise levels equal to or exceeding 85 dB. Schwennker (2011) also found that thirteen of the fifteen pieces of equipment have measured noise levels greater than 85 dB. These results are also consistent with the noise measurements conducted by Blehm (1989) for the similar pieces of equipment. Therefore, it is highly recommended for fire-fighters to minimise the duration of use of equipment especially when using circular saw. In order to minimise the use of equipment, the rotation to use the equipment between the teammates is needed. Other than minimising the use of equipment, Hearing Protection Devices (HPD) should be worn while using these pieces of equipment to lower their risk of NIHL. Hearing protection should be provided when using these pieces of equipment. Emergency equipment used in instances such as car accidents for example circular saw is powered by a generator and fire-fighters may not be able to distance themselves from the generator depending on the length of the electrical cable for the piece of equipment. Equipment such as circular saw, power saw and hydraulic power unit need to be carried by the fire-fighters whereby these situations also pose difficulty in the fire-fighters to distance themselves from the noise. Therefore, hearing protection device such as ear plug or ear muff is a must-wear equipment while operating this equipment.

Based on the estimated time-of-use for the equipment measured in this study during a 12-h shift, a dose of 1.5% was calculated based on the OSHA criterion level of 85 dB with an exchange rate of 5 dB. Although an overexposure to noise was not predicted in this study based on the measured equipment noise levels and time of use, it is acknowledged that all fire-fighter noise sources were not taken into account such as noise encountered during firefighting activities within a burning structure. However, it can be assumed that the noise dose to fire-fighters from the measured equipment may contribute to NIHL since the study by Schwennker (2011) has shown that fire-fighters have elevated NIHL as compared to the general population.

4.1. Proposed solutions

Strategies to lower the noise exposure to fire-fighters encompassing the trucks, the station itself and equipment on the trucks should be implemented. Even though the exposure may be reduced since the shifts are 12 h in duration instead of 24 h, there are still items that should be addressed to lower the immediate exposure while conducting certain tasks. Kales et al. (2001) found that hearing loss associated with firefighting was strongly associated with age and the duration of service as a fire-fighter. This finding is also consistent with another previous finding by Reischl et al. (1981) which reported that the increased hearing loss with age for fire-fighters is due to the overexposure to noise during working time. These reports show that there is an association between fire-fighters' hearing loss and their age. Therefore, government should consider feasible risk control to reduce hazardous noise exposures to as lower as 70 db and provide appropriate hearing protection devices (HPDs) for all fire-fighters as required by OSHA regulations. According to Akosile et al. (2007) and National Institute of Deafness and Other Communication Disorder (2015), noise below than 75 dB will not cause hearing problem even after a long exposure. If the noise exposure can be reduced down to a minimum limit of 70–75 dB, fire-fighters who work 48 h per week would not be subjected to NIHL risk. Hearing Protection Programme also should be implemented at least once in a year followed by an auditory health surveillance programme to determine the efficacy of the hearing protection programme. Table 6 shows the proposed solutions in order to reduce NIHL among fire-fighters.

5. Conclusion

Taman Universiti Fire-fighters in this study were found to be potentially exposed to relatively high levels of equipment noise depending on the tasks. The equipment noise exposure was estimated to contribute a noise dose of 1.5%. However, since there are numerous tasks that have to be considered into the calculation of fire-fighter noise dose during a 12-shift, there remains significant variability in the daily noise exposure. Index profiling has been constructed showing that truck siren emits the highest PTT percentage, 104.6% which is the furthest of the actual data from the target value. Solutions and strategies to lower the noise exposure for fire-fighters encompassing the trucks, the station itself and equipment on the trucks were proposed and should be implemented.

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Table 6
Proposed solutions and corrective measures.

Siren/equipment	Control measure	
	Category	Justification
AlarmCADLite/Emergency Alarm	Elimination	– Nil – Not able to eliminate because alarmCADlite and emergency alarm are used to warn firefighters
	Substitution	– Nil – Not able to substitute because alarmCADlite and emergency alarm are used to warn firefighters
	Engineering	– Nil – Engineering control to lower the noise is not needed to make sure the purpose of the alarms is met
	Administrative	– New rule is needed to not to stand near alarmCADlite and Emergency alarm
	PPE	– Nil – Not able so that all firefighters are alert if there is any emergency
Truck/Air hon Siren	Elimination	– Nil – Not able to eliminate because siren is needed on emergency vehicles
	Substitution	– Nil
	Engineering	Design modification – Adding mufflers or silencers to intakes and exhausts – Providing damping to reduce vibration – Isolating vibration to reduce excitation of other structures – Providing acoustical shielding from the source
	Administrative	– Stay away from the front of the truck as far as possible and try to work toward the rear
Chain/Circular Saw	Elimination	– Nil – Not able to eliminate as chain and circular saw are needed for cutting wood/steel
	Substitution	(1) Substitution of equipment: – Rotating shears rather than square shears; (2) Substitution of parts of equipment: – Replace straight edged cutters with spiral cutters (e.g. wood working)
	Engineering	(1) Reduction of mechanical shock between parts by: – Modifying parts to prevent rattle and ringing. (2) Reduction of noise resulting from friction between metal parts by: – Lubrication – Use saw blade with the greatest number of teeth and of the smallest width (3) Maintenance: – Replacement or adjustment of worn or loose parts – Use of properly shaped and sharpened cutting tools.
	Administrative	Maintenance: – The saw blade must be changed regularly to avoid an annoying high pitched "whining" noise from developing. – Maintaining equipment in good condition to reduce noise, including the addition of noise mufflers, vibration isolators, or duct silencers. – Proper training on how to use the equipment
	PPE	Head, Hearing, Face Protection – A hardhat, combined with a mesh visor or shield and earmuffs (earmuffs are preferable to earplugs because they also provide some protection to the outer ear).
Generator Set/Hydraulic power unit	Elimination	– Nil – Not able to eliminate as generator set and hydraulic power unit are needed for power supply
	Engineering	(1) Reduction of noise resulting from out-of-balance by: – Balancing moving parts; – Use of vibration absorbers and dampers tuned to equipment resonances. (2) Reduction of mechanical shock between parts by: – Modifying parts to prevent rattle and ringing
	Administrative	– Lubrication of moving parts; – Replacement or adjustment of worn or loose parts
High/Low Pump	Engineering	Design Modification – Adding mufflers or silencers to intakes and exhausts – Providing damping to reduce vibration – Isolating vibration to reduce excitation of other structures – Providing acoustical shielding from the source
	Administrative	– Proper training on how to handle/control the pump
	PPE	– Ear plug must be worn for those controlling the pump

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