Noise Monitoring Inside Malaysian Army 3-Tonne Truck Cabin Using Statistical Analysis

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ABSTRACT

Prolonged and excessive exposure to noise inside the truck cabin results in long term harm and adverse effect to the driver. Safety and health of drivers hearing are among ergonomic aspects that are very important in vehicle driving. The objective of this study was to monitor noise exposure at driver's ear level while driving Malaysian Army (MA) 3-tonne truck using statistical analysis method called Integrated Kurtosis-based Algorithm for Z-notch filter (I-kaz). Noise exposure is measured using a sound level meter which is capable to record raw sound pressure in Pascal (Pa) unit. The recorded raw data were analyzed by using this statistical analysis and provides I-kaz coefficient, Z^{∞} and 3D graphical representation of I-kaz display in order to measure the degree of data scattering. The results show that the Z^{∞} increases when noise exposure and vehicle speed are increased. This comparative study can be made by observing the difference of Z^{∞} and also the degree of scattering of I-kaz display for difference sound pressure level and truck speed. It shows that the I-kaz coefficient is very effective in noise monitoring even that the sound pressure level changes are very small.

INTRODUCTION

Noise-induced hearing loss is one of the most common occupational disabilities due to extremely loud noises or prolonged exposure to noise. Exposure to loud noise, even for a few minutes, can cause a temporary hearing loss. If exposure is repeated over time, however, recovery decreases and eventually the temporary degradations become permanent. Individual susceptibility to noise-induced hearing loss varies widely (Department of Defence US, 1993). Many studies have demonstrated the impact of decreased communication on vehicle operations (Weatherless *et al.* 2012). Some of these health effects include increased risk for cardiovascular disease, negative effects on sleep, communication, performance and behaviour, reading and memory acquisition, and mental health (Aziz *et al.* 2012)

Vehicle interior noise in the driver compartment is a combination of engine, road, intake and exhaust, aerodynamics, components and ancillaries, brake and noise from squeaks, rattles and tizzes. Noise and vibration also originates from outside the vehicle, interacting with the vehicle structure and then producing radiated sound

inside the driver compartment (Harrison, 2004). Vehicle noise has the potential to cause hearing loss and cause discomfort and annoyance to personnel performance whereas noise-induced hearing loss, which is mainly caused by exposure to high levels of noise (Aziz *et al.* 2012). Previous studies on several numbers of Malaysian Armed Forces (MAF) vehicles also indicate noise level inside the driver compartment increase with increasing truck speed (Aziz *et al.* 2014b; Aziz *et al.* 2012).

MIL-STD-1474 (Noise Limits for Military Materiel) was drafted as the standard to provide noise limits for preventing hearing loss and on communication requirements for military personnel (Department of Defence US, 1993).The basic steady state noise criterion for conservation of hearing is that unprotected personnel not be exposed to noise levels that are higher than 85 dB(A) for a duration of 8 hours of period (Department of Defence US, 1993; MIL-STD-1474C, 1991; U.S. Department of Health and Human Services, 1998). Prolonged exposure to noise levels above 85 dB(A) can damage inner ear cells and lead to hearing loss. Research has shown that noise is one of the leading causes of hearing loss for millions of people with impaired hearing in the United States (Fooladi, 2012). Noise can change a man's physiological state by speeding up pulse and respiratory rates. According to medical studies, there is an increased risk to the cardiovascular system from a sound pressure level of above 65 dB (A) (Fooladi, 2012).

Hearing loss is a widespread, severe, and costly problem to many military veterans returning from service (Humes, Joellenbeck, & Durch, 2006), the precise mechanisms and the full impact of hearing loss on dismounted operations remains uncertain operations (Weatherless et al. 2012). The Malaysian Armed Forces (MAF) Medical Board reported that an increasing number of MAF personnel and veterans are suffering from hearing problems, with 22 % of them found to be suffering from the problem between 2000 and 2008 (Bernama, 2011). Most importantly, hearing loss degrades the soldier's ability to understand direct commands and radio messages, making it more difficult for the soldier to operate as a member of a squad and increasing the soldier's vulnerability. In addition, reduced hearing ability creates situation awareness problems for soldiers operating on the battlefield (Humes *et al.* 2006). Radio communications further increase the noise exposure at the ear because operators tend to increase the volume to hear the speaker over the background noise (Pääkkönen & Lehtomäki, 2005). The high levels of noise exposure in the vehicles can compromise hearing and communication during the mission (Nakashima, Borland, & Abel, 2007).

INTEGRATED KURTOSIS-BASED ALGORITHM FOR Z-NOTCH FILTER (I-KAZ)

Statistical analysis method is a mathematical science pertaining to the collection, analysis, explanation, and determine the distribution of data and classify random signals. In this study, statistical analysis for noise exposure is performed using the Integrated Kurtosis-Based Algorithm for Z-notch Filter (I-kaz) method. The I-kaz method was developed based on its capability to detect changes in the measured mechanical signal. Unlike existing statistical analyses, such as standard deviation, variance, and kurtosis, the I-kaz method can indicate both amplitude and frequency differences by simultaneously obtaining the I-kaz three-dimensional (3D) display and the I-kaz coefficient, Z^{∞} (Nuawi *et al.* 2008). The I-kaz technique, which is a newly developed analysis method, is chosen to assess its capability to evaluate noise exposure more than its known capability to create 3D diagrams.

The I-kaz method was developed on the concept of frequency distribution about its centroid. This method provides a three dimensional graphic representation of the frequency distribution (Nuawi *et al.* 2008). The Z^{∞} as shown in the Equation (1) was generated which measures the space of scattering of the I-kaz display.

$$Z^{\infty} = \sqrt{\frac{\sum_{i=1}^{N}(x_i^L-\mu_L)^4}{N^2} + \frac{\sum_{i=1}^{N}(x_i^H-\mu_H)^4}{N^2} + \frac{\sum_{i=1}^{N}(x_i^V-\mu_V)^4}{N^2}} \quad (1)$$

where x_i^L, x_i^H, x_i^V are the values of discrete data in the LF, HF and VF range respectively at the *i*-sample of time, μ_L, μ_H and μ_V are the means of each frequency band and *N* is the number of data.

The I-kaz method is capable of detecting small changes in the measured noise exposure. This method is used for extracting the raw data features of the sound pressure that was measured from the sound level meter during noise monitoring based on kurtosis, variances, and standard deviation. The recorded data is transferred to a computer and analysed by using MATLAB to calculate Z^{∞} and produce the I-kaz display in real time (Aziz *et al.* 2014a).

METHODOLOGY

This study was conducted in Malaysia highway with tarmac road surface. A DuO smart noise monitor that utilizes an A-weighted scale was used in measurements of sound pressure (Pa) and sound pressure levels dB(A)) and its calibration was performed by using Bruel & Kjaer 4231 calibrator. In this study, sound pressure and sound pressure levels during variable truck speeds occurring in truck driver compartment were measured. Measurements were done at same level as the ear position of the drivers as stated in ISO Standard 5128. The measurement for each truck speed was repeated to ensure that the data is accurate and reliable for further analysis. All measured raw data was converted to sound pressure level (SPL) in dB and the arithmetic mean value for each trial was determined. Sound pressure level *SPL* and sound pressure *p* are related by the following equation:

$$SPL = 20 \log_{10} \frac{p}{p_{ref}} \quad dB(A) \quad (2)$$

where p_{ref} is the reference sound pressure value and equals 20 x10^{-6} Pa. The measurements were considered as valid if the range of the measurements for every speed made immediately one after the other was not greater than 2 dB. The highest SPL value given by these measurements constituted the result (Federal Subsidiary Legistlation, 1987), and was used as raw data for the I-kaz statistical analysis.

RESULTS AND DISCUSSION

Table 1 and Figure 1 shows the changes value of sound pressure levels and Z^{∞} with varying speed of the truck. The truck at idle position shows the lowest sound pressure level (67.7 dB(A)) and Z^{∞} (3.39 x 10^{-8}). When the truck's speed increased from idle to 100 km/h, sound pressure level and Z^{∞} also increase proportionately with the highest sound pressure level (82.4 dB(A)) and Z^{∞} (1.04 x 10^{-6}). Figure 1 shows

the I-kaz display towards changing of 3-tonne truck speed. From the data dispersion, it can be concluded that the lower value of $\not{Z}^{\infty}$ at 0 km/h represents small space scattering, while its higher value at 100 km/h represents larger space scattering. It was found that sound pressure level is proportional to the $\not{Z}^{\infty}$. This situation indicates that increase of sound pressure level will result in increasing the data scattering of I-kaz display and value of the $\not{Z}^{\infty}$.

Table 1: Sound pressure, $\not{Z}^{\infty}$ and sound pressure level for the various speeds of the truck

No. of tests	Truck Speed (km/h)	$\not{Z}^{\infty}$	Sound Pressure (Pa)	L_{Aeq} (dB(A))	$L_{Aeq(avg)}$ (dB(A))
1	0	2.85×10^{-7}	0.0570	69.1	68.1
2		7.17×10^{-8}	0.0480	67.6	
3		3.39×10^{-8}	0.0485	67.7	
4	20	6.93×10^{-7}	0.1026	74.2	73.7
5		8.62×10^{-7}	0.0925	73.3	
6		5.08×10^{-7}	0.0968	73.7	
7	80	1.15×10^{-6}	0.1722	78.7	79.1
8		5.46×10^{-7}	0.1762	78.9	
9		8.75×10^{-7}	0.1954	79.8	
10	100	1.17×10^{-6}	0.2489	81.9	82.2
11		1.04×10^{-6}	0.2637	82.4	

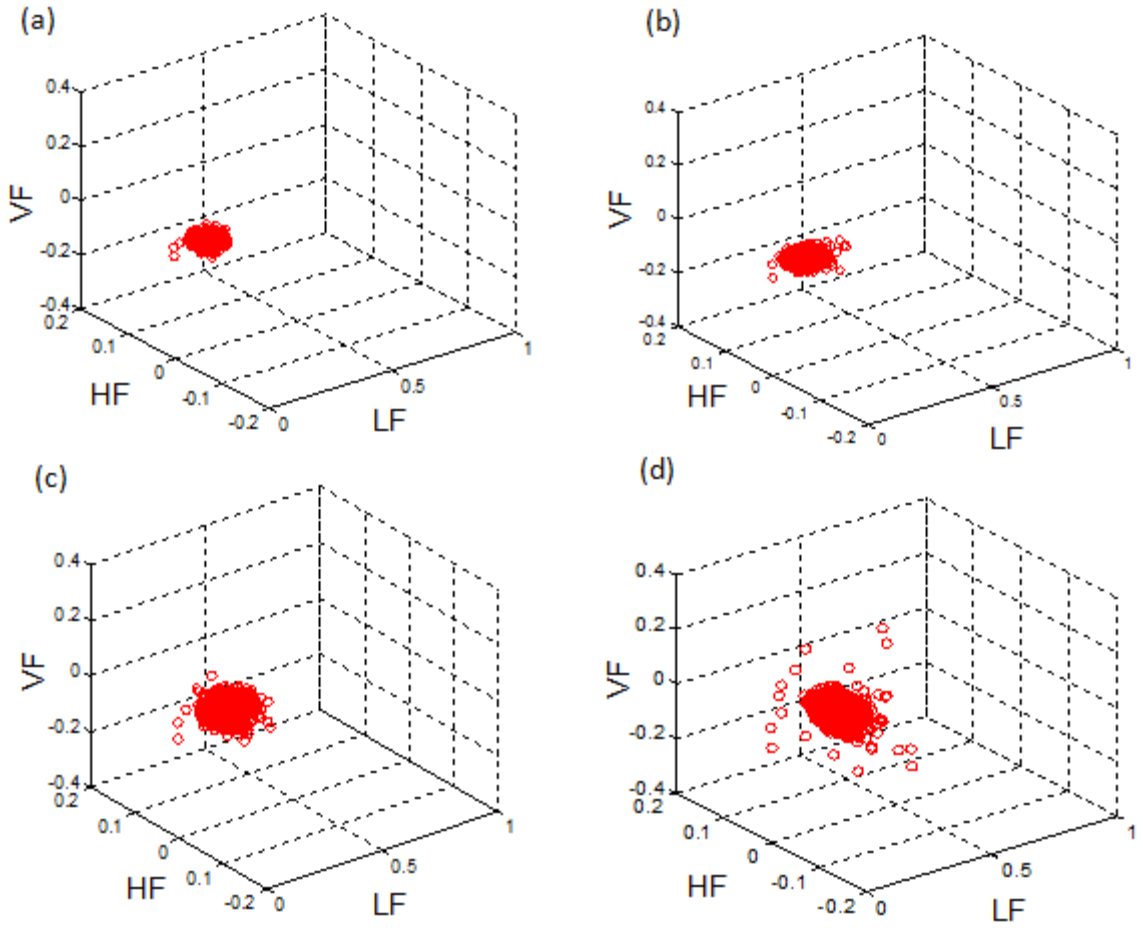

Figure 1: 3D graphical representations that show the scattering of Z^{∞} values in the I-kaz display at speeds of: (a) 0 km/h, Z^{∞} = 2.85 x 10^{-7} (b) 40 km/h, Z^{∞} = 6.93 x 10^{-7} (c) 80 km/h, Z^{∞} = 8.75 x 10^{-7} (d) 100 km/h, Z^{∞} = 1.04 x 10^{-6}

CONCLUSIONS

Noise in the driver compartment can cause hearing loss, annoyance, discomfort and interference with personal performance if it exceeds the permissible limit or exposed in long time period. Long-term exposure and exceeding the noise acceptable value can cause discomfort and negative effect to MA driver's hearing. A reduction of the sound pressure level of noise sources can be obtained by regular maintenance, early repairs, and replacement of defective items of the vehicles. In this paper, noise exposure for Malaysian Army 3-tonne truck drivers was analysed using the I-kaz statistical analysis method. The study shows that the Z^{∞} increase proportionately with increasing the SPL. From the I-kaz display, there was an increasing size of data scattering for increasing the sound pressure level and speed of the truck. Furthermore, I-kaz display are capable of providing a noise exposure observation, because it can detect small changes of noise exposure. This comparison is expected because such behaviour can be predicted based on the I-kaz value trend. Thus, a warning system of excessive noise exposure, particularly for comfort and healthy purposes to MA 3-tonne truck drivers is needed for future research. In addition, the system will help to determine if the noise value is exceeded the permissible limit.

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